Abstract: Study by Fairview Lake Association; http://www.fairviewlakeasso.org/

Elevated levels of turbidity in shallow aquatic ecosystems affect the biological and chemical integrity of the aquatic environment. It is measured routinely in water quality surveys and is at the center of studies concerning the effects of human recreational activity. There is abundant evidence in the literature documenting the effects of turbidity and sediment resuspension on aquatic health. The following review includes studies written between 1978 and 2000. It focuses on documented evidence of impacts on water quality, fish, macroinvertebrate and macrophyte communities of shallow water lakes and draws conclusions for future study.

Fairview Lake

Located in Pike County, Pennsylvania, Fairview Lake is a 169-acre natural lake. The maximum depth of the lake is 48 feet. The Pennsylvania Fish and Boat Commission maintains a boat launch on the southwestern corner of the lake, open to the public. There is no available record of the number of boats per season using this launch.

In addition to recreational boating, Fairview residents and visitors value the area for sport fishing. The lake, like many Pocono area waters, is stocked with trout. There are typically fall, winter, late winter and spring stockings to maintain a population of catchable trout for sport fishing (PA FWS Internet 2000).

Methods of Measuring Turbidity

Measuring turbidity is a difficult process because of the variety of factors influencing sediment mixing. Many studies have investigated the individual effects of these factors. It has been recognized that motorboats and PWC have a direct impact on the biotic and abiotic parameters of lakes.

A variety of methods have been documented for measuring turbidity. Primary considerations are 1) to what depth does light penetrate, allowing plants to continue photosynthesis and 2) what is the concentration of sediment in the water column (Stern and Stickle 1978).

Sampling should include water clarity (secchi depth), orthophosphorus, total phosphorus, pH and dissolved oxygen. Turbidity can either be determined in the field using portable meters or in the lab where samples must be transported from the site. Secchi depth readings will help determine water clarity fairly simply and inexpensively. Field meters may include the Hach Portable turbidimeter or the pocket turbidimeter (Hach 1999). Laboratory measuring instruments can be very complex and expensive. They may include the AMINCO fluorocolorimeter, (Hilton and Philips 1982), the 2100AN or the 2100N turbidimeter (Hach 1999).

Causes of Turbidity

Human activity effects increased turbidity in lakes and rivers through a number of avenues. Erosion from nearby agricultural lands, runoff as a result of increased waterproofing of the land, industrial effluents, flooding, dredging, thermal stratification and water currents are causes of sedimentation (Kerr 1991, Liddle and Scorgie 1980). Human activity such as motorboat and personal watercraft use is the subject of increasing concern in lakes and rivers all over the United States and Europe. Physical forces associated with recreational activity on lakes include wash, turbulence, propeller action (cutting effects), direct contact with bottom sediment and disturbance by sight and sound (Liddle and Scorgie 1980).

Waves produced by watercraft erode the shoreline. The more energy the wave contains, in terms of velocity, the greater the amount of stress put on the shoreline upon contact. Furthermore, the greater the number of boats on the water, the greater the stress on the eroding shoreline. Wave heights are additive, thereby increasing damage with increasing number of boats acting simultaneously. Erosion of the shoreline and resuspension of bottom sediment will add to the sediment load in the water causing decreased water clarity, poor odor and taste, changes in chemistry and effects on the biology of the lake (Johnson 1994).

The complexities of an aquatic ecosystem and the impacts of outside activities may act synergistically making it difficult to quantify a particular effect. Studies have documented significant increases in turbidity levels from periods of no boat traffic, very early in the morning hours, to heavy boating traffic in the daytime hours (Johnson 1994).

2 vs. 4 stroke engines

Personal watercraft (PWC) are becoming increasingly popular and controversial in the recreational boating industry. They are powered by two stroke engines, which are one of the most highly polluting engines in use today. They spill up to one third of their fuel unused and emit an astonishing amount of hydrocarbons and nitrogen oxides (Martin 1999).

PWC's use an inboard, internal combustion engine which powers a water jet pump used for propulsion. The design of this watercraft allows for high speed and extreme mobility. Because PWC's are able to reach shallow areas, they often interfere with aquatic macrophytes, nesting waterfowl and shore animals in addition to disturbing the benthic (bottom) community (Martin 1999).

Motorboats are less able to maneuver close to the shoreline in most cases but still have an impact on the biology and chemistry of the lake. The four stroke engines used in motorboats are more fuel-efficient than PWC, getting up to twice the mileage of a two-stoke engine. They are cleaner still because there is no mixing of oil and gas. However, the weight, speed and high cost of four stroke engines contribute to the lower percentage of four them on the water (Water skiing and the Environment 9/11/00).

The unburned gasoline spilled from PWC's especially, contain benzene, toluene, and other aromatic compounds can be toxic to aquatic organisms. Burnt fuel creates compounds called polycyclic aromatic hydrocarbons, which are linked to cancer and genetic mutations (Water skiing and the Environment 9/11/00).

Chemical considerations

Fourteen years of chemical analysis of Fairview Lake (Urban 1999), shows significant trends in water quality. Secchi depth readings have decreased from 1986 to 1999, showing a decrease in the clarity of the water. Dissolved oxygen levels have almost doubled and phosphate levels have increased by three since 1986 (Urban 1999). Disturbance of bottom sediment by recreational watercraft and some natural mixing may be responsible for increased turbidity.

Lake sediments contain much higher concentrations of phosphorus than the water column. The effects of mixing sediment has been given attention because it is often regarded the most limiting nutrient for biological activity (Yousef et al 1978). Although phosphorus is not found in great quantity in most aquatic life, phytoplankton and zooplankton can absorb excess phosphorus for later use. Phytoplankton in particular can take up to more than ten times their normal content for storage (Yousef et al 1979). Large crops of phytoplankton can result from the release of nutrients, causing a severe increase in turbidity in a short time (Garrad 1987). The process of eutrophication caused by increased algae growth results in decreased water clarity, poor odor and taste and depletion of dissolved oxygen. About 90-95% of the phosphorus in a lake is accumulated in the top layer of bottom sediment where it is unavailable to algae. Mixing of this sediment allows nutrients to be utilized in the eutrophication process (Nedohin and Elefsiniotis 1997). Significant increases in phosphorus concentration in the water column have been detected after mixing of the sediment (Yousef et al 1978). There is evidence that sediment resuspension from motorboat activity is the catalyst for increased turbidity.

The concentration of dissolved oxygen increases as a result of a new abundance of phytoplankton. However, decreased water clarity and light penetration will inhibit macrophyte growth, reducing the available substrate for macroinvertebrate habitat. Less vegetation and disturbance of bottom sediment directly affects macroinvertebrate diversity and subsequentially the health of the aquatic ecosystem.

Effects on Macrophytes

Excessive increases in turbidity levels may create an environment beyond the acceptable level of tolerance for the living components of an aquatic ecosystem. Studies indicate that reduced light penetration due to increased turbidity may cause a decrease in macrophyte growth (Hilton and Phillips 1982). Submerged aquatic plants will not survive in the absence of light needed for photosynthesis. The spatial distribution and productivity of submerged aquatic macophytes is regulated in part by the availability of light. Suspended material in turbid waters interferes with the transmission of light through a liquid medium (Stern and Stickle 1978). Decreased water clarity due to turbidity causes mortality of macrophytes at varying rates depending on the species and their tolerance (Goldsborough and Kemp 1988).

Direct cutting and uprooting of macrophytes by motorboat and PWC activity causes a significant decline in productivity and biomass (Asplund 1997). Emergent aquatic plants have been disturbed by boat waves causing for less cover along the shoreline and greater erosion. Areas where boat traffic is the greatest and sediment resuspension is highest have been found to be areas with limited aquatic macrophyte growth (Johnson 1994).

Effects on Macroinvertebrates

Because of invertebrate diversity in a particular lake community and the complexity of biological and chemical parameters of the ecosystem, it is difficult to quantify the effects of increased turbidity on living freshwater organisms. However, there is significant evidence to indicate that the abundance and diversity of invertebrate populations are associated with increased turbidity and suspended solids in the water column. Diversity and taxa richness of species such as filter feeders have declined due to sedimentation (Kerr 1995).

Kirk and Gilbert (1990) studied the effects of suspended clay on populations of planktonic rotifers and cladocerans using long-term laboratory experiments. They showed that four cladoceran species were intolerant of coarse clay particles in suspension. Two of the four species included in Kirk and Gilbert's study are found in Fairview Lake: *Daphnia pulex* and *Bosmina longirostris* (Urban 2000). The later of the two species has shown a significant decrease from the summer of 1987 to Spring 1999: 26.2 per liter and 1 per liter, respectively.

Kirk and Gilbert showed that inhibited growth rates differed according to clay particle size. Cladocerans were not adversely affected by high concentrations of fine particles. The rotifer population did not experience decreased growth rates. It was concluded that in turbid environments rotifers are dominant over cladocera, influencing the structure of the zooplankton community. The presence of increased sediment reduces the amount of nutritious phytoplankton cells ingested by the cladocerans. Because cladocerans do not discriminate between particles sizes when feeding, the ingestion of suspended clay particles reduces phytoplankton ingestion. Decrease in light penetration may decrease phytoplankton biomass and productivity, further limiting zooplankton growth rates. Rotifer species do not ingest suspended clay particles and are not inhibited by turbidity (Kirk and Gilbert 1990). Although both organisms are filter feeders, rotifers have other means of foraging and are not as dependent on suspension feeding as cladocerans (Thorp and Covich 1991).

The most work has been done on marine and freshwater bivalves (oysters, clams, mussels). Bivalves are primarily filter feeders and play an important role in removing suspended sediment from the water column. However, certain high concentrations of sediment have caused mortality in filter feeding species (Stern and Stickle 1978).

Species of aquatic insects (Class Insecta) inhabit the bottom sediment in lakes and rivers and use the vegetation (macrophytes) for shelter and food. Some, such as the "phantom midge larvae" (Diptera: Chaoborus), travel the depths of the water column for foraging purposes (Thorp 1991). Significant changes to the clarity and diversity of the water will have numerous implications for these aquatic species.

Fish

High levels of turbidity in lakes and rivers effect fish populations directly and indirectly. Direct effects include factors influencing reproduction, survival, growth and development. Indirect effects constitute modifications to their habitat and the organisms they depend on for food. Studies have shown mortality in fish species due to clogging of the gills, suffocation and decreased levels of dissolved oxygen. Fish survival is universally dependent on a few significant parameters: dissolved oxygen, temperature and concentration of sediment in the water column (Stern and Stickle 1978).

There is significant evidence that resuspension of sediment has a direct impact on the health and survival of fish species in lakes. Stern and Stickle (1978) give a detailed discussion of the studies done on fish disturbance and sediment resuspension in the 1960's and 70's.

Elevated turbidity may cause fish to avoid certain waters, effecting migration movements. Studies have determined that fish will vacate turbid areas only to return once the water clarity has improved (Kerr 1995). Fish species may experience physiological and behavioral changes as a result of increased turbidity. Species such as bluegill, larval striped bass, species of salmon, cutthroat trout and larval herring have all displayed depressed rates of foraging even while prey was abundant. Furthermore, prolonged sedimentation causes a protective mucous coating to put the fish under stress. The coating continually removes suspended particles from entering the gills. However, it reduces the surface available for oxygen exchange and causes respiratory difficulties (Kerr 1995).

Sedimentation can reduce fish abundance and alter growth rates. In rivers with high silt concentrations, populations of brown, rainbow and brook trout have all been reduced. Studies have also determined reduced growth rates in arctic graylings, coho salmon, crappies, rainbow trout, brook trout and largemouth bass (Kerr 1995).

Fairview Lake is inhabited by species of nesting fish such as trout and bass. There is increasing concern within the Fairview Lake Association over the interference of motorboats and PWC use on the establishment of these nesting areas. This concern is not without precedence. Sedimentation of spawning grounds inhibits successful hatching and incubation. In order for fish eggs to hatch properly they require a clean surface where oxygen is available. Turbid conditions reduce water flow and oxygen availability to eggs, causing suffocation. Numerous studies have explored concern over spawning interference. White perch, striped bass, pike, yellow perch, pikeperch and whitefish, have exhibited reduced spawning and incubation success and increased mortality (Kerr 1995). Furthermore, high rainbow trout mortality has resulted from heavy siltation in rivers. Best survival rates occurred in waters with stable stream discharge and low concentrations of sediment (Kerr 1995).

Conclusion

The impact of recreational watercraft use on shallow water lakes and rivers is significant. Evidence for this conclusion exists in the numerous studies that have focused on the impacts to macrophytes, macroinvertebrates, fish, water chemistry and shoreline erosion and habitat. Fairview Lake is amongst many shallow water lakes facing the difficult challenge of managing motorboat and personal watercraft use in a safe and ecologically sound manner. Waterways are especially valuable in the sports fishing and boating industries, in addition to property owners and environmentalists. In order to ensure they remain available for recreational use this valuable resource must be protected.

Future analysis of the biological and chemical parameters of Fairview Lake is necessary to determine the extent of recreational boating impacts. Continued documentation of water quality trends should include turbidity measurements with either a field or lab meter. Sampling should take place three or more times per year, specifically in the early spring, prior to heavy motor boat use; in the fall, when recreational use lessens and the winter, when boat use has generally stopped. Additionally, sampling should be done over a twenty-four hour period to determine the changes in turbidity from the early morning hours through the day, when boat traffic will typically increase (Adams et al 1991). Information pertaining to the number of boats that access Fairview Lake per season and the number of people who violate wake markings would be valuable for future survey of the issue.

Reference list: Annotated

Adams, J.R. and M. ASCE and E. Delisio. Ambient Suspended Sediment Concentration and Turbidity Levels. National Conference on Hydraulic Engineering. Pp. 865-869.

Study tested ambient sediment concentration and turbidity in lakes over time. Overall there was little variability in concentration. Research was conducted on the Upper Mississippi River System.

Asplund, Tim. 1997. Investigations of Motor Boat Impacts on Wisconsin's Lakes. Technical Report PUB-SS-927 97, Wisconsin Department of Natural Resources.

Shows correlation between increased motorboat use on ten Wisconsin lakes and increased turbidity, water clarity and total Phosphorus. Results are not consistent and other factors complicate the relationship between recreational activity and water quality.

Asplund, Tim and C. Cook. 1999. Can no-wake zones effectively protect littoral zone habitat from boating disturbance? *Lakeline*, pages 16-18, 48-52.

No-wake zones can be effective in protecting aquatic macrophytes, if people adhere to wake restrictions. However, boat propellers in no wake zones can uproot plants even at no-wake speeds. The more conservative the wake zones, the greater protection of littoral zones. Study conducted on Wisconsin's Long Lake.

Bhowmik, N.G. and T.W. Soong. December 1992. Waves Generated by Recreational Traffic: Part 1, Controlled Movement. Illinois State Water Survey.

Controlled wave calculations of wave height, duration and number of waves created per controlled passing boat. Studies were done on the Illinois and Mississippi Rivers. Study determined a regression equation o be used for estimating maximum wave heights on the basis of speed, draft, length of the boat and distance from the measuring point.

Bloesch, Jurg. 1995. Mechanisms, measures and importance of sediment resuspension in lakes. Marine and Freshwater Research, 46(1): 295-304.

Discusses causes of sediment resuspension in detail, including thermal stratification and wind patterns. The ecological importance of resuspension and methods for measuring such activity are also discussed.

A Cascade study of the impacts of recreational v. natural disturbance and water quality on food chain processes in European deepwater lakes.
http://www.geog.gla.ac.uk/general/nerc.htm
accessed 9/11/00

A research project will be conducted on the ecosystem and disturbance of four lake communities, focusing on producer populations. The results will impact lake management strategies and policy.

Garrad and Hey. 1987. Boat traffic, sediment resuspension and turbidity in a broadland river. *Journal of Hydrology*, *95*: 289-297.

Boat traffic can cause increased turbidity in addition to algal growths. A probe was used to measure levels of suspended sediment as recreational boats passed, showing a cycle of resuspension. The effect varies for different types of boats, indicating that size or speed restrictions may be necessary.

Goldsborough, W.J. and W.M. Kemp. 1988. Light Responses of a submersed macrophyte: Implications for survival in turbid tidal waters. *Ecology 69*(6): 1775-1786.

Tested response of macrophytes to decreased levels of light, which is the result of increased turbidity in the water column. Decreased growth in the macrophyte population indicates that sediment resuspension is detrimental to growth.

Giuliano, Jackie Alan, Ph.D. "Healing Our World: Weekly Comment. Two Strokes, You're out."
http://ens.lycos.com/ens/dec99/1999L-12-06g.html
Accessed 12/7/99

Information on the impacts of two-stroke engines, which are extremely fuel inefficient. They emit 1.1 billion pounds of hydrocarbon emissions per year. Jet skies emits as much as car emits per a year in only one hour of use.

Hach Product Analysis. 1999. Hach Company, Loveland Colorado.

Hilton J. and G.L. Philips. 1982. The effect of boat activity on turbidity in a shallow broadland river. *The Journal of Applied Ecology*, *19*:143-150.

High turbidity causes decreased macrophyte growth. Measurements of turbidity and boat traffic were conducted on shallow rivers. A model was used to determine resuspension by boat traffic.

Irvine, K.N., I.G. Droppo, T.P. Murphy and A. Lawson. 1997. Sediment resuspension and Dissolved Oxygen Levels Associated with Ship Traffic: Implications for Habitat Remediation. *Water Quality Research Journal of Canada, 32*(2): 421-437.

Concern over the impact of large ship passage motivated water quality testing and column profiles on a weekly basis. Ship passage significantly increased turbidity above ambient levels and the recommended levels for fish habitat. In addition, dissolved oxygen levels decreased significantly. Four studies where condusted under this title, all focused on determining proper remediation techniques.

Jeffries, M. and D. Mills. 1990. Freshwater Ecology: Belhaven Press: London. PP 188-189.

Discusses chemical and physical damage caused by boat traffic in aquatic ecosystems. Includes overview and discussion of some major studies in the area.

Johnson, Scot. February 1994. Recreational Boating Impact Investigations Upper Mississippi River System, Pool 4, Red Wing, Minnesota. Minnesota Department of Natural Resources.

Shoreline erosion is the result of recreational boat activity. The relationship between wave size and erosion was examined: the larger the wave, the more energy contained in the wave and the greater the capacity to erode the shoreline. Boat traffic has an effect on physical and chemical parameters, including decreased macrophyte growth, shoreline vegetation, disturbance of benthic organisms, and loss of habitat for fish, birds and other wildlife.

Kerr, S. J. 1995. Silt, Turbidity and Suspended Sediments in the Aquatic Environment: An Annotated Bibliography and Literature Review. Southern Region Science and Technology Transfer Unit Technical Report TR-008: Ontario, Canada 277pp.

Review of the literature on effects of suspended sediments, including sources of sediment, physical and chemical processes, and impacts of siltation on fish, macroinvertebrates, macrophytes, water clarity and quality, and techniques used to reduce sedimentation.

Kirk, K.L. and J.J. Gilbert. 1990. Suspended Clay and the population dynamics of planktonic rotifers and cladocerans. *Ecology, 71(5)*: 1741-1755.

Lab experiments determined that rotifers most often dominate in a turbid environment. Cladocerans are not tolerant of high sediment concentrations. Large clay particles decrease the ability for cladocerans to digest phytoplankton. The direct effect of sediment suspension depends on the concentration and size of suspended particle.

Liddle, M.J. and H.R.A. Scorgie. 1980. The effects of recreation on Freshwater Plants and animals: A Review. *Biological Conservation, 17*:183-206.

Physical, biological and chemical disturbances are discussed in relation to boat activity. Boat use impacts the number and size of plants growing at a particular site, the abundance of shoreline dueling animals, change in the chemical components of the water column including pollution from engines, and the erosion of the shoreline. It is stated that very little is known on the effects of boating on aquatic animals.

Martin, Laurie C. 1999. “Caught in the Wake: The Environmental and Human Health Impacts of Personal Watercraft.” Izaak Walton League of America.
Accessed 9/11/00

Excellent discussion of the effects of personal watercraft on aquatic ecosystems. Includes water and air pollution from two-stroke engines, noise pollution, effects on wildlife, conflicting human interests, safety, federal and state regulation and the potential for better technology to decrease negative impacts of PWC use.

National Parks and Conservation Association. NPCA Guide to Personal Watercraft.
http://npca.org/whatwedo/pwc_wildlife.html
Accessed 9/11/00

Personal watercraft have a negative effect on wildlife. They can reach shallow water areas where large boats cannot go, thus disturbing nesting birds, fish habitat and zooplankton communities.

Nedohin, D.N. and P. Elefsiniotis. 1997. The effects of motorboats on water quality in shallow lakes. *Toxicology and environmental chemistry, 61*:127-133.

Man-made mixing of the bottom sediment releases high levels of phosphorus into the water column to be used by algae, causing eutrophication. Two lakes were studied. One has a high level of boat traffic and the other lake has no motor powered boats, Brereton and Lyons respectively. Samples were taken from both lakes in the spring and fall, 1995. Brereton Lake showed significant surface algae where Lyons Lake did not. Turbidity and Phosphorus levels were higher in Brereton Lake, in both the spring and fall. It was concluded that motorboat activity had significant impacts on Brereton Lake.

Nelsen, Chad. June/July 1998. "Jet Skis Suck." Surfrider Foundation.
http://surfrider.org/makingwaves3/jetski6.htm
Accessed 9/11/00

Commentary on the impacts of PWC on human and non-human life. The article discusses water and air pollution from two-stroke engines, noise pollution, interference in wildlife habitat including manatees and salmon, human safety and the need for strict regulation.

Personal Watercraft and the Environment.
http://www.pwia.org/Env_PWC.htm
http://www.pwia.org/Env_Engi.htm
Accessed 9/11/00

The Personal Watercraft Industry Association supports the view that PWC should not be permitted in all lakes. They ask that PWC are affected under the same laws as motorboats and not singled out as the sole problem. They argue that studies have shown PWC to be no more disturbing than other recreational watercraft and that the operators are not interested in exploring shallow water areas because grasses will clog their engines. Also, sound tests show that PWC are quieter than other boats. The EPA established new emissions standards for marine engines in 1996. They state that over the next six years, emissions of hydrocarbons and nitrogen oxides will be reduced by 75%.

Rodgers, Terry. July 20, 2000. Personal Watercraft restrictions considered.
Houston Chronicle Publishing Company.
Lexus Nexus Academic Universe

Stern, E. M. and W. B. Stickle. 1978. <u>Effects of turbidity and suspended materials in aquatic environments</u>. U.S. Army Chief of Engineers, Mississippi: Technical Report D-78-21.

Includes important information on measuring turbidity, origins of sediment and effects on water quality, aquatic invertebrates, plants and fish. Slightly dated but still relevant to current studies.

Stolpe, Nils E. July 29, 1992. "A survey of potential impacts of boating activity on estuarine productivity." U.S.E.P.A Office of Air and Radiation
http://www.fishingnj.org/artobm1.htm

Discussion of physical impacts of boating activity includes heat, turbidity, temperature and salinity stratification, engine emissions, etc. Other concerns include waste releases, leaching of toxins from paints, propeller scouring and fuel spills during maintenance operations. Overall boating use has increased dramatically since the 1970's, when concern over boating began.

Summary of research findings regarding the impact of water skiing on the environment.
http://www.iswp.com/ebmeeting98/EnvirReport.htm
accessed 9/11/00

Research paper discussing the impacts of water skiing on the environment. Includes discussion of fuel and oil emission and noise pollution as the major public concerns. Discusses efficiency of two and four stroke engines, wildlife and waterfowl disturbance, disturbance of aquatic biota, turbidity and new technologies for lessening impact. Case studies are used to exemplify the issue and positive impacts of water skiing are mentioned. Recommendations are made for future management of boating activities.

Thorp, James H. and Alan P. Covich. Ecology and Classification of North American Fresh Water Invertebrates. Academic Press Inc: San Diego.

A collection of essays and identification keys discussion invertebrate foraging, reproduction, behavioral and habitual characteristics.

Urban, Mark. A biological and chemical analysis of Fairview Lake, Pike County, PA over fourteen years: 1986-1999. Technical Report. Submitted to the Fairview Lake Association.

Urban, Mark. Plankton Analysis of Fairview Lake, Pike County, PA over Fourteen years: 1986-1999. Technical Report. Submitted to the Fairview Lake Association, April 2000.

Yousef, Y.A., W.M. McLellon and H.H. Zebuth. 1980. Changes in Phosphorus concentrations due to mixing by motorboats in shallow lakes. *Water Research, 14*: 841-852

Controlled motorboat activity was measured and analyzed in three Florida Lakes. Results showed increased levels of turbidity and phosphorus after mixing by motorboat activity. Also, two isolation chambers representing aquatic habitats were placed in each lake for a control.

Yousef, Y.A. et al. 1978. Mixing Effects due to Boating Activities in Shallow Lakes. Technical Report ESEI No. 78-10.

The report states that ecological differences in the study lakes and the variability in motorboat parameters make conclusions difficult. This is a detailed analysis of the chemical, physical and biological effects of resuspension via motorboats.

Zeroka, Daniel. A Physical, Chemical and Biological Overview of Fairview Lake, Pike County, Pennsylvania. Unpublished. Written for the Fairview Lake Association.