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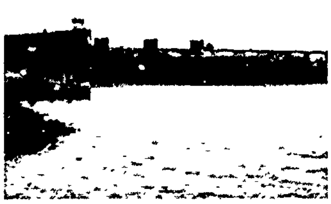

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TECHNICAL REPORT EL-90-13

TRAFFIC: AN INFORMATION RETRIEVAL SYSTEM TO EVALUATE THE ENVIRONMENTAL IMPACTS OF COMMERCIAL NAVIGATION TRAFFIC

by

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Environmental Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
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The software system, TRAFFIC, was developed to provide technical information and literature on the physical effects of navigation traffic, particularly on selected riverine organisms. The TRAFFIC software program has been designed to run on an IBM-PC or compatible microcomputer with a minimum of 256 K of computer memory and type of video card and monitor. TRAFFIC is easy to use and requires no knowledge of computers. Depending upon the program selections made by the user, either a bibliographic listing or a technical discussion of the effects of a physical navigation system on a selected riverine organism can be obtained. The results can be read directly from the computer monitor or output to an IBM or Epson compatible printer. A copy of TRAFFIC can be obtained by writing either Dr. Carl M. Way or Dr. Andrew C. Miller at the US Army Engineer Waterways Experiment Station or by calling (601) 634-3224 or (601) 634-2141. This programs considers the environmental impact of water waves, suspended sediments, turbulent flow and erosion of banks caused by the traffic.

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PREFACE

In October 1985, the US Army Engineer Waterways Experiment Station (WES) initiated a study on the environmental effects of commercial navigation traffic. This work is part of the Environmental Impact Research Program (EIRP) at WES and was conducted under Work Unit No. 32393. The purpose was to investigate reported biological and physical impacts of the movement of navigation vessels in large waterways. Field and laboratory studies were initiated to investigate effects of commercial traffic. As part of this project, considerable literature was obtained and reviewed.

In March 1986, a software system to retrieve published information on commercial navigation traffic effects was developed by George Williams, Louisiana State University. Subsequently the information retrieval system was modified and information was added by Drs. Carl M. Way and Andrew C. Miller of the WES Environmental Laboratory (EL).

Mr. Edwin Theriot was Chief, Aquatic Habitat Group, EL, Dr. Conrad J. Kirby was Chief, Environmental Resources Division, EL, Dr. John Harrison was Chief, EL, and Dr. Roger Saucier was Program Manager of the EIRP during the preparation of this report. The report was edited by Ms. Janean Shirley of the WES Information Technology Laboratory. The EIRP Technical Monitors for the study were Dr. John Bushman, CECW-PO, Mr. Dave Mathis, CECW-PO, and Mr. Dave Buelow, CECW-EH-W.

Commander and Director of WES was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	metres
horsepower (500 foot-pounds (force) per second)	745.6999	watts
inches	2.54	centimetres
miles per hour (US statute)	1.609344	kilometres per hour

TRAFFIC: AN INFORMATION RETRIEVAL SYSTEM TO EVALUATE THE ENVIRONMENTAL IMPACTS OF COMMERCIAL NAVIGATION TRAFFIC

PART I: INTRODUCTION

Background

1. Passage of a commercial vessel can cause brief periods of elevated suspended solids, turbidity, and turbulence, as well as transient changes in water velocity and movement. The physical effects of traffic are unique in that although they last only a few minutes, they are often repeated many times over a 24-hr period. Concern has been expressed that these physical disturbances could negatively affect the feeding, respiration, and recruitment of aquatic organisms such as fishes, mussels, crustaceans, and immature insects (Rasmussen 1983; Nielsen, Sheehan, and Orth 1986). In addition, tow passage can cause a brief period of drawdown and wave wash which can expose shoreline vegetation and resident biota and may contribute to bank erosion (Sparks 1975; Holland 1983; Holland and Sylvester 1983).

Purpose and Scope

2. The purpose of this document is to describe an information retrieval system that can be run on an IBM or compatible personal computer in order to evaluate the environmental impact of commercial navigation traffic. The information retrieval system is easy to use and requires no knowledge of computers. It provides pertinent literature and a discussion of biological and physical effects of commercial traffic.

3. There have been numerous attempts to investigate the physical and biological effects of commercial t. ic using biological and field methods. Much of this information has been reported in the g vernment or non-refereed literature; fewer papers have been published in the refereed literature. Most of the studies on navigation traffic effects have been directed by a need to develop an environmental impact statement or assessment. It is rare that navigation-related studies would be designed or initiated to obtain data on general principles and problems important to aquatic ecology. As a result, the literature on traffic effects is scattered and much of it is virtually unavailable to the general reader. Results have often been contradictory or poorly interpreted since the emphasis was to provide information on a navigation project for decision makers. This literature retrieval system was designed to assist the reader in searching through and evaluating studies that directly or indirectly relate to commercial traffic effects. Information contained in this report will assist the biologist or planner in evaluating the effects of commercial traffic and design studies to obtain information on this subject area.

PART II: DETAILS OF THE SOFTWARE SYSTEM

Description

4. TRAFFIC is a software program designed to be used as an information retrieval system for those requiring technical information and literature on the physical effects of navigation traffic and the effects of traffic on selected riverine organisms. This software program has been designed to run on an IBM-PC or compatible microcomputer with a minimum of 256 K of computer memory and any type of video card and monitor. The program can be executed from the supplied floppy diskette or loaded into a subdirectory on a hard disk drive. The program was written in Turbo Pascal and a compiled version is supplied with this document. TRAFFIC can be obtained by writing Dr. Carl M. Way or Dr. Andrew C. Miller at the US Army Engineer Waterways Experiment Station or by calling the authors at (601) 634-3224 or (601) 634-2141.

Operation

5. TRAFFIC is completely menu driven and has been designed for use by persons with little or no computer knowledge. The enclosed 5-1/4 in. floppy disk should be placed in drive A; after logging on to drive A, the user types **DISPLAY** and hits the **RETURN** key to start the program. The opening screen displays the title and authors of the program and informs the user to hit any key to start the information retrieval system or to hit the **ESCAPE** key to return to the DOS prompt (Figure 1). Striking any key but the **ESCAPE** key will bring the user to a selection screen that provides an opportunity to obtain on-line help for using the program. To see the **HELP** screens, the user types **Y**(es) and hits the **RETURN** key; the program will lead the user through the various **Help** screens. Typing **N**(o) or simply hitting **RETURN** will take the user to the next screen, which allows the user to generate hard-copy output for any results generated by the program. Typing **Y**(es) will send the program information to an attached printer; typing **N**(o) or **RETURN** will send the output of the program to the screen.

Navigation Traffic Effects

Information System

by

Carl M. Way and Andrew C. Miller

US Army Engineer Waterways Experiment Station

Vicksburg, Mississippi 39180-6199

[Hit any key to start program or Escape for DOS]

Figure 1. Opening screen for TRAFFIC program

6. The fourth screen of the TRAFFIC program determines the type of information to be retrieved from the program (Figure 2). The selection **LITERATURE** generates a listing of bibliographic information on the effects of commercial navigation traffic; the bibliographic data base in TRAFFIC is current through 1988. The **DISCUSSION** selection provides a technical summary of

Choose the TYPE of output to be generated.

- **Literature**
- **Discussion**

Figure 2. Information retrieval screen of the TRAFFIC program

the physical effects of navigation traffic on a selected riverine organism. The up and down arrow keys can be used to move between the selections. Hitting any key while the cursor is next to a selection will choose that selection.

7. The fifth and sixth screens define the search criteria for the information retrieval system. Depending upon the selections made, the user will be provided with either a bibliographic listing or technical discussion of the effects of a physical navigation effect on a selected riverine organism. The fifth screen, **PHYSICAL EFFECTS**, provides the user with a listing of the known physical effects of navigation traffic (Figure 3). The sixth screen, **BIOLOGICAL ORGANISMS**, provides a listing of riverine organisms potentially affected by navigation traffic (Figure 4). The arrow keys are used to move the cursor between selections on both screens; hitting any key while the cursor is next to a selection will choose that selection. After selecting a physical effect, the user must also select a riverine organism on the subsequent screen. When a **DISCUSSION** search has been selected, brief technical summaries of the physical effect and the riverine organism are presented

Choose the desired PHYSICAL effect

- **Drawdown**
- **Wave wash**
- **Turbulence**
- **Impingement**
- **Sediment Resuspension**
- **Sedimentation**
- **Winter Conditions**
- **Water Quality**
- **Auditory/Visual Disturbance**
- **General Impact Studies**

Figure 3. PHYSICAL EFFECTS screen of the TRAFFIC program

along with any known information on the effects of the physical factor on the selected organismic group. A complete listing of the physical and biological information included in TRAFFIC can be found in Appendices A and B. When a **LITERATURE** search has been selected, a listing of technical literature pertinent to the effects of the chosen physical factor on a biological group will be provided. A complete bibliographic listing of the literature included in TRAFFIC is given in Appendix C.

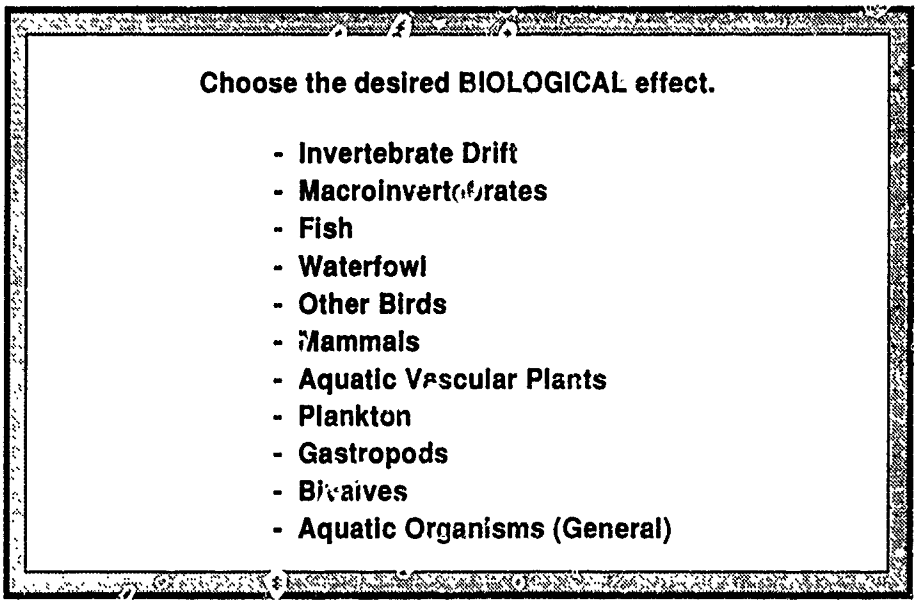

*Figure 4. **BIOLOGICAL ORGANISMS** screen of the TRAFFIC program*

REFERENCES

Academy of Natural Sciences of Philadelphia. 1980. Analysis of Effect of Tow Traffic on the Biological Components of the Ohio River, US Army Engineer District, Huntington, WV.

Alger, G. R. 1979. Ship-Induced Waves and Physical Measurements on the St. Mary's River, Environmental Evaluation Work Group, Winter Navigation Board, Detroit, MI.

Arruda, J. A., Marzolf, G. R., and Faulk, R. T. 1983. The Role of Suspended Sediments in the Nutrition of Zooplankton in Turbid Reservoirs, *Ecology*, Vol 64, pp 1225-1235.

Balanin, V. V., and Bykov, L. S. 1975. Selection of Leading Dimensions of Navigation and Channel Sections and Modern Methods of Bank Protection, *Proceedings, Twenty-first International Navigation Congress*, Stockholm, Sweden.

Barnes, R. D. 1987. *Invertebrate Zoology*, 5th ed., W. B. Saunders Company, Philadelphia, PA.

Beckett, D. C., Kasul, R. L., Winfield, L. E., and Bowles, G. E. 1985. Vertical, Horizontal, and Diel Distribution of Invertebrate Drift in the Lower Mississippi River, Technical Report E-87-5, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Bellrose, R. C., Paveglio, F. L., Jr., and Steffect, D. W. 1979. Waterfowl Populations and the Changing Environment Of The Illinois River Valley, Illinois Natural History Survey Bulletin, No. 32, pp 1-54.

Berger Associates, Ltd. 1980. Environmental and Physical Impact Studies for Gallipolis Locks and Dam, Ohio River; Phase 1 Replacement Study, Vol II, Navigation Impacts, Academy of Natural Sciences.

Bhowmik, N. G., Adams, J. R., Bonini, A. P., Guo, C-Y., Kisser, D., and Sexton, M. 1981a. Resuspension and Lateral Movement of Sediment by Tow Traffic on the Upper Mississippi and Illinois Rivers, Illinois State Water Survey Division, SWS Contract Report 269, for Environmental Work Team, Upper Mississippi River Basin Commission Master Plan Task Force, Minneapolis, MN.

Bhowmik, N. G., Demissie, M., and Osakada, S. 1981. Waves and Drawdown Generated by River Traffic on the Illinois and Mississippi Rivers, Illinois State Water Survey Division, SWS Contract Report No. 271 for Environmental Work Team, Upper Mississippi River Basin Commission Master Plan Task Force, Minneapolis, MN.

Bhowmik, N. G., Lee, M. T., Bogner, W. C., and Fitzpatrick, W. 1981b. The Effects of Illinois River Traffic on Water and Sediment Input to a Side Channel, Illinois State Water Survey Contract Report 270 for Environmental Work Team, Upper Mississippi River Basin Commission Master Plan, Minneapolis, MN.

Bjorklund, R. G. 1975. On the Death of a Midwestern Heronry, Wilson Bulletin No. 87, pp 284-287.

Buck, D. H. 1956. Effects of Turbidity on Fish and Fishing, *Transactions of the 21st North American Wildlife Conference*, pp 249-261.

Camfield, F. E., Ray, R. E. L., and Eckert, J. W. 1979. The Possible Impact of Vessel Wakes on Bank Erosion, prepared by USAE, Fort Belvoir, Virginia, for US Department of Transportation and US Coast Guard, Washington, DC, Report No. USCG-W-1-80, NTIS No. ADA-083-896.

Carlson, R. W. 1984. The Influence of pH, Dissolved Oxygen, Suspended Solids, or Dissolved Solids upon Ventilatory and Cough Frequencies in the Bluegill *Lepomis macrochirus* and Brook Trout *Salvelinus fontinalis*, *Environmental Pollution Act*, Vol 34, pp 149-169.

Chew, R. L. 1969. Investigations of Early Life History of Largemouth Bass in Florida, Project Report F-024-R-02, Florida Game and Freshwater Fish Commission, Tallahassee, FL.

Chutter, F. M. 1969. The Effects of Silt and Sand on the Invertebrate Fauna of Streams and Rivers, *Hydrobiologia*, Vol 34, pp 57-76.

Ciborowski, J. J. H., Pointing, P. J., and Corkum, L. D. 1977. The Effect of Current Velocity and Sediment on the Drift and Settlement of the Mayfly *Ephemerella subvaria* McDonnough, *Freshwater Biology*, Vol 7, pp 567-572.

Clark, W. R. 1981. Assessment of Navigation Effects on Muskrats in Pool 9 of the Upper Mississippi River, Final Report to the Upper Mississippi River Basin Commission, Minneapolis, MN.

Clark, W. R., and Clay, R. T. 1985. Standing Crop of *Sagittaria* in the Upper Mississippi River, *Canadian Journal of Botany*, Vol 63, pp 1453-1457.

Coker, R. E., Shira, A., Clark, H., and Howard, A. 1921. Natural History and Propagation of Freshwater Mussels, Bulletin of the US Bureau of Fisheries, Vol 37, pp 75-182.

Cordone, A. J., and Kelly, D. W. 1961. The Influence of Inorganic Sediment on Aquatic Life in Streams, *California Fish and Game Commission*, Report No. 47, pp 189-228.

Cross, F. B. 1967. *Handbook of Fishes of Kansas*, Miscellaneous Publication 45. Museum of Natural History of the University of Kansas, Lawrence, KS.

Das, M. M. 1969. Relative Effect of Waves Generated by Large Ships and Small Boats in Restricted Waterways Hydraulic Engineering Laboratory, University of California at Berkeley, CA.

Demissie, M., and Osakada, S. 1981. Waves and Drawdown Generated by River Traffic on the Illinois and Mississippi Rivers, Illinois Institute of Natural Resources, Grafton, IL.

Dorris, T. C., Copeland, B. J., and Lauer, K. J. 1963. Limnology of the Middle Mississippi River. IV. Physical and Chemical Limnology of River and Chute, *Limnology and Oceanography*, Vol 15, pp 879-888.

Eckblad, J. W. 1981. Baseline Studies and Impacts of Navigation on the Benthos and Drift (Work Task 6), on the Quantity of Flow to Side Channels (Work Task 14), and on the Suspended Matter Entering Side Channels (Work Task 16) of Pool 9 of the Upper Mississippi River, Report prepared for the Environmental Work Team, Upper Mississippi River Basin Commission, Minneapolis, MN.

Eckblad, J. W., Peterson, N. L., Ostlie, K., and Temte, A. 1977. The Morphometry, Benthos and Sedimentation Rates of a Floodplain Lake in Pool 9 of the Upper Mississippi River, *American Midland Naturalist*, Vol 97, pp 433-443.

Eckblad, J. W., Volden, C. S., and Weilgart, L. S. 1984. Allochthonous Drift from Backwater to the Main Channel of the Mississippi River, *American Midland Naturalist*, Vol 11, pp 16-22.

Ellis, M. M. 1931. Some Factors Affecting the Replacement of the Commercial Freshwater Mussels, *US Bureau of Fisheries*, Vol 1, pp 1-10.

________. 1936. Erosion Silt as a Factor in Aquatic Environments, *Ecology*, Vol 17, pp 29-42.

Ellison, L.N., and Cleary, L. 1978. Effects of Human Disturbance on Breeding of Double-Crested Cormorants, *Auk*, Vol 95, pp 510-517.

ERT/Ecology Consultants, Inc. 1979. Potential Environmental Impacts of Mississippi River Year-Round Navigation on Commercial Fishing, Report prepared for the US Army Engineer District, Rock Island, IL.

European Inland Fisheries Advisory Commission. 1964. Water Quality Criteria for European Freshwater Fish, Technical Paper No. 1, EIFAC Working Party on Water Quality Criteria for Freshwater Fish, Rome, Italy.

Fraser, J. D., Frenzel, L. D., and Mathisen, J. E. 1985. The Impact of Human Activities on Breeding Bald Eagles in North-Central Minnesota, *Journal of Wildlife Management*, Vol 49, pp 585-592.

Fudge, R. J. P., and Bodaly, R. A. 1984. Post-Impoundment Winter Sedimentation and Survival of Lake Whitefish (*Coregonus clupeaformis*) Eggs in Southern Indian Lake, Manitoba, *Canadian Journal of Fisheries and Aquatic Science*, Vol 41, pp 701-705.

Fuehrer, M., and Romisch, K. 1977. Effects of Modern Ship Traffic on Inland and Ocean-Waterways and Their Structures, *Proceedings of the 24th International Navigation Congress*, Leningrad, Russia.

Fuller, T. K., and Robinson, W. L. 1982. Some Effects of Winter Shipping on Movements of Mammals across River Ice, *Wildlife Society Bulletin*, Vol 10, pp 156-160.

Gammon, J. R. 1970. The Effect of Inorganic Sediment on Stream Biota, Water Pollution Control Research Series, Environmental Protection Agency, Cincinnati, OH.

Gates, E. T., and Herbich, J. B. 1977. The Squat Phenomenon and Related Effects of Channel Geometry, *Hydraulics in the Coastal Zone, 25th Annual Hydraulics Division Specialty Conference*, American Society of Civil Engineers, College Station, TX.

Gray, L. J., and Ward, J. V. 1982. Effects of Sediment Releases from a Reservoir on Stream Macroinvertebrates, *Hydrobiologia*, Vol 96, pp 177-184.

Gregg, R. E., and Bergersen, E. P. 1980. *Mysis relecta* Effects of Turbidity and Turbulence on Short-Term Survival *Transactions of the American Fisheries Society*, Vol 109, pp 207-212.

Grubb, T.G., Jr. 1977. Weather-Dependent Foraging in Ospreys, *Auk*, Vol 94, pp 146-149.

Hagerty, D. J., Spoor, M. F., and Ullrich, C. R. 1981. Bank Failure and Erosion on the Ohio River, *Engineering Geology*, Vol 17, pp 141-158.

Harrison, A. D., and Farina, T. D. W. 1965. A Naturally Turbid Water with Deleterious Effects on Egg Capsules of Planorbid Snails, *Annuals of Tropical Medicines and Parasitology*, Vol 59, pp 327-330.

Hawkinson, R., and Grunwald, G. 1979. Observations on the Wintertime Concentration of Catfish in the Mississippi River, Investigations Report No. 365 of the Minnesota Department of Natural Resources, Minneapolis, MN.

Hay, D. 1968. Ship Waves in Navigable Waterways, *Proceedings of the 11th Conference on Coastal Engineering*, London, UK.

Heimstra, N. D., Damkot, D. K., and Benson, N. G. 1969. Some Effects of Silt Turbidity on Behavior of Juvenile Largemouth Bass and Green Sunfish, Technical Paper 20, US Bureau of Sport Fisheries and Wildlife, Washington, DC.

Helwig, P. C. 1969. An Experimental Study of Ship-generated Water Waves, M.S. thesis, Queen's University, Kingston, Ontario.

Herricks, E. E., and Gantzer, C. J. 1980. Effects of Barge Passage on the Water Quality of the Kaskaskia River, Civil Engineering Studies, Environmental Engineering Series No. 60, University of Illinois, Urbana, IL.

Herricks, E. E., Osborne, L. L., Cairns, C., Gantzer, C., Himelick, D., and Schritt, L. 1982. Effects of Barge Passage on Physical, Chemical, and Biological Conditions in the Navigation Reach of the Kaskaskia River, Final Report, Upper Mississippi River Basin Commission, Urbana, IL.

Hildreth, D.I. 1976. The Influence of Water Flow Rate on Pumping Rate in *Mytilus edulis* using a Refined Direct Measurement Apparatus, *Journal of the Marine Biological Association of the United Kingdom*, Vol 56, pp 311-319.

Holland, L. E. 1983. Evaluation of Simulated Drawdown Due to Navigation Traffic on Eggs and Larva of Two Fish Species of the Upper Mississippi River, US Fish and Wildlife Service, National Fisheries Research Laboratory, LaCrosse, WI.

Holland, L. E., and Lester, M. L. 1984. Relationship of Young-Of-the-Year Northern Pike to Aquatic Vegetation Types in Backwaters of the Upper Mississippi River, *North American Journal of Fisheries Management*, Vol 4, pp 514-522.

Holland, L. E., and Sylvester, J. R. 1983. Distribution of Larval Fishes Related to Potential Navigation Impacts on the Upper Mississippi River, Pool 7, *Transactions of the American Fisheries Society*, Vol 112, pp 293-301.

Horkel, J. D., and Pearson, W. D. 1976. Effects of Turbidity on Ventilation Rates and Oxygen Consumption of Green Sunfish, *Lepomis cyanellus*, *Transactions of the American Fisheries Society*, Vol 1, pp 107-113.

Hubert, W. A. Undated a. Impacts of Navigation Traffic on Fish, Iowa Cooperative Fishery Research Unit, Iowa State University, Ames, IA.

________. Undated b. Assessment of Possible Navigation Impacts on Channel Fishes of Pool 9 Utilizing Data from 1980 Reconnaissance Study, Iowa Cooperative Fishery Research Unit, Iowa State University, Ames, IA.

Hubert, W. A., Darnell, G. E., and Dalk, D. E. 1983. Evaluation of Wintering Benthic Macroinvertebrates of Pool 13 of the Upper Mississippi River, Wyoming Cooperative Fish and Wildlife Research Unit, Laramie, WY.

Hurst, C. K., and Brebner, A. 1969. Shore Erosion and Protection of the St. Lawrence River, Canada, Permanent International Association of Navigation Congresses, XXIInd International Congress, Paris, Sec 1, pp 45-56.

Hynes, H.N.B. 1970. *The Ecology of Running Waters*, University of Toronto Press, Toronto, Canada.

Johnson, D. D., and Widish, D. J. 1982. Effect of Suspended Sediment on Feeding by Larval Herring (*Clupea harengus*), *Bulletin of Environmental Contaminants and Toxicology*, Vol 29, pp 261-267.

Johnson, F. H. 1961. Walleye Egg Survival During Incubation on Several Types of Bottoms in Lake Winnibigoshish, Minnesota, and Connecting Waters, *Transactions of the American Fisheries Society*, Vol 90, pp 312-322.

Johnson, J. H. 1976. Effects of Tow Traffic on Resuspension of Sediments and Dissolved Oxygen Concentration in the Illinois and Upper Mississippi River under Normal Flow Conditions, Technical Report Y-76-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Johnson, J. W. 1958. Ship Waves in Navigation Channels, *Proceedings of the 6th Conference on Coastal Engineering*, Berkeley, CA.

________. 1969. Sguo Waves in Shoaling Waters, *Proceedings of the Conference on Coastal Engineering*, American Society of Civil Engineering, Vol 2, pp 1488-1498.

Karaki, S., and Van Hoften, J. 1974. Resuspension of Bed Material and Wave Effects on the Illinois and Upper Mississippi Rivers Caused by Boat Traffic, Prepared for US Army Engineer District, St. Louis, under Contract No. LMSSD 75-881, Colorado State University, Fort Collins, CO.

Kat, P. W. 1982. Effects of Population Density and Substratum Type on Growth and Migration of *Elliptio complanata* (Bivalvia: Unionidae), *Malacological Review*, Vol 15, pp 119-127.

Killgore, K. J. 1979. The Ecological Relationships of *Hydrilla verticillata* Royle in Lake Conroe, Texas, MS thesis, Sam Houston State University, Huntsville, TX.

Kiorboe, T., Mohlenbwerg, F., and Nohr, G. 1981. Effect of Suspended Bottom Material on Growth and Energetics in *Mytilus edulis*, *Marine Biology*, Vol 61, pp 283-288.

Kirby-Smith, W.W. 1972. Growth of the Bay Scallop: the Influence of Experimental Water Currents, *Journal of Experimental Marine Biology and Ecology*, Vol 8, pp 7-18.

Knight, R. L., and Knight, S. K. 1984. Responses of Wintering Bald Eagles to Boating Activity, *Journal of Wildlife Management*, Vol 48, pp 999-1004.

Lagler, K. F., Bardaih, J. E., and Miller, R. R. 1962. Ichthyology, John Wiley & Sons, New York.

Laughlin, D. R., and Werner, E. E. 1980. Resource Partitioning in Two Coexisting Sunfish: Pumpkin-Seed *(Lepomis gibbosus)* and Northern Longear Sunfish (*Lepomis megalotis peltastes), Canadian Journal of Fisheries and Aquatic Sciences*, Vol 37, pp 1411-1420.

Lee, M. T., Bogner, W. C., and Fitzpatrick, W. P. 1981. Water and Sediment Inputs to Selected Side Channels Associated with River Traffic, Paper presented at the 14th Annual Mississippi River Research Consortium, April 1981, La Crosse, WI.

Link, L. F., Jr., and Williamson, A. N., Jr. 1976. Use of Automated Remote Sensing Techniques to Define the Movement of Tow Generated Suspended Material Plumes on the Illinois and Upper Mississippi Rivers, Technical Report M-76-6, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Liou, Y. C., and Herbich, J. B. 1976. Sediment Movement Induced by Ships in Restricted Waterways, Report No. 188, US Army Engineer District, Detroit, MI.

Lubinski, K. S., Seagle, H. H., Bhowmik, N. G., Adams, J. R., Sexton, M. A., Beohnerkempe, J., Allgire, R. L., Davis, D. K., and Fitzpatric, W. 1981. Information Summary of the Physical, Chemical, and Biological Effects of Navigation, Upper Mississippi River Basin Commission, Grafton, IL.

Lund, J. W. G. 1969. Phytoplankton, Eutrophication: Causes, Consequences, Correctives, G. A. Rohlich, ed., National Academy of Sciences, Washington, DC.

Mansueti, R. J. 1961. Effects of Civilization on Striped Bass and Other Estuarine Biota of Chesapeake Bay and Tributaries, *Proceedings of the Gulf Caribbean Fisheries Institute*, 14th Annual Session, Annapolis, MD.

McCabe, G. O., and O'Brien, W. J. 1983. The Effect of Suspended Silt on Feeding and Reproduction of *Daphnia pulex*, *American Midland Naturalist*, Vol 110, pp 324-337.

McNown, J. S. 1976. Sinkage and Resistance for Ships in Channels, *Journal of the Waterways Harbors and Coastal Engineering Division*, No. WW3.

Morgan, R. P., Ulanowicz, R. E., Rasin, V. J., Noe, L. A., and Gray, G.B. 1976. Effects of Shear on Eggs and Larvae of Striped Bass, *Morone saxatilis* and White Perch, *Morone americana*, *Transactions of the American Fisheries Society*, Vol 106, pp 149-154.

Mueller, G. 1980. Effects of Recreational River Traffic on Nest Defense by Longear Sunfish, *Transactions of the American Fisheries Society*, Vol 109, pp 248-251.

Muller, K. 1974. Stream Drift as a Chronobiological Phenomenon in Running Water Ecosystems, *Annual Review of Ecology and Systematics*, Vol 5, pp 309-323.

Muncy, R. J., Atchison, G. J., Bulkley, R. V., Menzel, B. W., Perry, L. G., and Summerfelt, R. C. 1979. Effects of Suspended Solids and Sediment on Reproduction and Early Life of Warmwater Fishes: A Review, US EPA Report 600/3-79-042, Corvallis Environmental Research Laboratory, Corvallis, OR.

Nielsen, L. A., Sheehan, R. J., and Orth, D. J. 1986. Impacts of Navigation on Riverine Fish Production in the United States, *Polskie Archiwum Hydrobiologia*, Vol 34, pp 277-294.

Ofuya, A. O. 1970. Shore Erosion Ship and Wind Waves in the St. Clair, Detroit and St. Lawrence Rivers, Report No. 21, Department of Public Works of Canada, Design Branch, Ontario, Canada.

Otto, N. E., and Enger, E. P. 1960. Some Effects of Suspended Sediments on Growth of Submersed Pondweeds, General Laboratory Report #227, United States Department of Interior, Bureau of Reclamation, Division of Engineering Laboratories, Denver, CO.

Payne, B. S., and Miller, A. C. 1987. Effects of Current Velocity on the Freshwater Bivalve *Fusconaia ebena*, *American Malacological Bulletin*, Vol 5, pp 177-179.

Pearson, W. D., Killgore, K. J., Payne, B. S., and Miller, A. C. 1989. Environmental Effects of Navigation Traffic: Studies on Fish Eggs and Larvae, Technical Report EL-89-15, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Peddicord, R. K., McFarland, V. A., Belfiori, D. P., and Byrd, T. E. 1975 Dredge Disposal Study, San Francisco Bay and Estuary: Appendix G. Effects of Suspended Solids on San Francisco Bay Organisms, US Army Engineer District, San Francisco, CA.

Pennak, R. W. 1978. *Fresh-Water Invertebrates of the United States*, John Wiley & Sons, New York.

Peterson, G. A. 1983. A Pilot Study to Evaluate the Winter Fishery Biology of Pool 18 of the Upper Mississippi River, US Fish and Wildlife Service, Rock Island, IL.

Poe, T. P., Edsall, T. A., and Hiltunen, J. K. 1979. Effects of Ship-Induced Waves in an Ice Environment of the St. Mary's River Ecosystem, Environmental Evaluation Work Group, Winter Navigation Board, Michigan.

Rabeni, C. F., and Gibbs, K. E. 1980. Ordination of Deep River Invertebrate Communities in Relation to Environmental Variables, *Hydrobiologia*, Vol 74, pp 67-76.

Rasmussen, J. L. 1983. A Summary of Known Navigation Effects and a Priority List of Data Gaps for the Biological Effects of Navigation on the Upper Mississippi River, prepared for US Army Corps of Engineers, Rock Island District, under Letter Order No. NCR-LO-83-C9, Rock Island, IL.

Ritchie, J. C. 1972. Sediment, Fish, and Fish Habitat, *Journal of Soil and Water Conservation*, Vol 27, pp 1-124.

Robbins, W. H., and MacCrimmon, H. R. 1974. The Black Bass in America and Overseas, Biomanagement Management and Research Enterprises, Sault Sainte Marie, Canada.

Robinson, W. E., Wehling, W. E., and Morse, M. P. 1984. The Effect of Suspended Clay on Feeding and Digestive Efficiency of the Surf Clam, *Spisula solidissima* (Dillwyn), *Journal of Experimental Marine Biology and Ecology*, Vol 74, pp 1-12.

Rosen, R. A., and Hales, D. C. 1980. Occurrence of scarred paddlefish in the Missouri River, South Dakota-Nebraska, *Progressive Fish-Culturist*, Vol 42, pp 82-85.

Rosenthal, H., and Alderdice, D. F. 1976. Sublethal Effects of Environmental Stressors, Natural and Pollutional, on Marine Fish Eggs and Larvae, *Journal of the Fisheries Research Board of Canada*, Vol 33, pp 2047-2065.

Seagle, H. H., and Zumwalt, F. H. 1981. Evaluation of the Effects of Tow Passage on Aquatic Macroinvertebrate Drift in Pool 26, Mississippi River, Upper Mississippi River Basin Commission, Minneapolis, MN.

Sherk, J. A., O'Connor, J. M., and Neuman, D. A. 1972. Effect of Suspended and Deposited Sediments upon Estuarine Organisms; Phase I, Reference No. 72-9E, Natural Resource Institute, University of Maryland, Chesapeake Biological Laboratory, Solomon, MD.

________. 1974. Effect of Suspended and Deposited Sediments upon Estuarine Organisms; Phase II, Reference No. 74-20, Natural Resource Institute, University of Maryland, Solomon, MD.

Sigler, J. W., Bjornn, T. C., and Everest, F. H. 1983. Effects of Chronic Turbidity on Density and Growth of Steelheads and Coho Salmon, *Transactions of the Fisheries Society*, Vol 113, pp 142-150.

Simons, L. 1981. Water Quality in the Upper Mississippi River System Affected by Sediment Resuspended Due to Navigation Activities, Upper Mississippi River Basin Commission, Minneapolis, MN.

Simons, D. B., Chen, Y. H., Li, R. M., and Ellis, S. S. 1981a. Assistance in Evaluation of the Existing River Environment and in Assessment of Impacts of Navigation Activity on the Physical and Biological Environment In the Upper Mississippi River System, Contract Report for the Environmental Work Team, Upper Mississippi River Basin Commission, Minneapolis, MN.

Simons, D. B., Li, R. M., Chen, Y. H., and Ellis, S. S. 1981b. Working Paper 1 for Task C: Water Quality in the Upper Mississippi River System Affected by Sediment Resuspension Due to the Navigation Activities, Contract Report for the Environmental Work Team, Upper Mississippi River Basin Commission, Minneapolis, MN.

Simons, D. B., Li, R. M., Chen, Y. H., Ellis, S. S., and Chang, T. P. 1981c. Working Paper II for Task D: Investigation of Effects of Navigation Traffic Activities on Hydrologic, Hydraulic, and

Geomorphic Characteristics, Contract Report to the Environmental Work Team, Upper Mississippi River Basin Commission, Minneapolis, MN.

Smith, L. L., Kramer, R. H., and Oseid, D. M. 1966. Long-term Effects of Conifer-Groundwood Paper Fiber on Walleyes, *Transactions of the American Fisheries Society*, Vol 95, pp 60-70.

Sorenson, D. L., McCarthy, M. M., Middle-Brooks, E. J., and Porcella, D. G. 1977. Suspended and Dissolved Solids Effects on Freshwater Biota: A Review, Environmental Research Laboratory, US EPA Report 600/3-7-042, Corvallis, OR.

Sorenson, R. M. 1967. Investigation of Ship-Generated Waves, *Journal of Waterways and Harbor Division*, ASCE 93 (WW1), Paper 5102, pp 85-99.

Sparks, R. E. 1975. Possible Biological Impacts of Wave Wash and Resuspension of Sediments Caused by Boat Traffic in the Illinois River, US Army Engineer District, St. Louis, MO.

Sparks, R. E., Bellrose, F. C., Paveglio, F. L., Sandusky, M. J., Steffeck, D. W., and Thompson, C. M. 1979. Fish and Wildlife Habitat Changes Resulting from Construction of a Nine-foot Channel on Pools 24, 25, and 26 of the Mississippi River and the Lower Illinois River, Illinois Natural History Survey, Havana, IL.

Sparks, R. E., Thomas, R. C., and Schaeffer, D. J. 1980. The Effects of Barge Traffic on Suspended Sediments and Turbidity in the Illinois River, Report for the US Fish and Wildlife Service, Rock Island Field Office, IL.

Stalmaster, M. V., and Newman, J. R. 1978. Behavioral Responses of Wintering Bald Eagles to Human Activity, *Journal of Wildlife Management*, Vol 42, pp 506-513.

Stefan, H. G., and Riley, M. J. 1985. Mixing of a Stratified River by Barge Tows, *Water Resources Research*, Vol 21, pp 1085-1094.

Stelczer, K. 1981. *Bed Load Transport Theory and Practice*, Water Resource Publications, Littleton, CO.

Stern, E. M., and Stickle, W. B. 1978. Effects of Turbidity and Suspended Material in Aquatic Environments, Technical Report D-78-21, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Swale, E. M. F. 1964. A Study of the Phytoplankton in a Calcareous River, *Journal of Ecology*, Vol 52, pp 433-446.

Swenson, W. A., and Matson, M. L. 1976. Influence of Turbidity on Survival, Growth, and Distribution of Larval Herring *(Coregonus artidii)*, *Transactions of the American Fisheries Society*, Vol 105, pp 541-545.

Thompson, D. H. 1977. Declines in Populations of Colonial Waterbirds Nesting Within the Floodplain of the Upper Mississippi River, *Proceedings of the 1977 Conference of the Colonial Waterbird Group*, sponsored by the Colonial Waterbird Group, Department of Biological Sciences, Northern Illinois University, and the Kishwaukee Audubon Society, Dekalb, IL.

Thompson, D. H., and Landin, M. C. 1978. An Aerial Survey of Waterbird Colonies Along the Upper Mississippi River and the Interrelationship to Dredged Material Deposits, Technical Report D-78-13, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Thornburg, D. D. 1971. Flock Behavior of Diving Ducks on Keokuk Pool, Mississippi River, M.S. thesis, Iowa State University, Ames, IA.

_______. 1973. Diving Duck Movements on Keokuk Pool, Mississippi River, *Journal of Wildlife Management*, Vol 37, pp 382-389.

Tremblay, J. and Ellison, L. N. 1979. Effects of Human Disturbance on Breeding of Black-crowned Night Herons, *Auk*, Vol 96, pp 364-369.

Upper Mississippi River Basin Commission. Environmental Work Team. 1981a. Comprehensive Master Plan for the Management of the Upper Mississippi River System: Draft Executive Summary to The Environmental Report, prepared for the Upper Mississippi River Basin Commission by D. McGuiness and Associates, Hastings, MN.

_______. 1981b. Comprehensive Master Plan for the Management of the Upper Mississippi River System: Environmental Report, prepared for the Upper Mississippi River Basin Commission by D. McGuiness and Associates, Hastings, MN.

_______. 1981c. Comprehensive Master Plan for The Management of the Upper Mississippi River System: Technical Report D-Environmental Report, prepared for the Upper Mississippi River Basin Commission by D. McGuiness and Associates, Hastings, MN.

Vineyard, G. L., and O'Brien, W. J. 1976. Effects of Light and Turbidity on the Reactive Distance of Bluegill (*Lepomis macrochirus*), *Journal of the Fisheries Research Board of Canada*, Vol 33, pp 2845-2849.

Vos, D. K., Ryder, R. A., and Graul, W. D. 1985. Response of Breeding Great Blue Herons to Human Disturbance in North Central Colorado, *Colonial Waterbirds*, Vol 8, pp 13-22.

Wallen, I. E. 1951. The Direct Effect of Turbidity on Fishes, *Bulletin, Oklahoma Agricultural and Mechanical College*, Vol 48, pp 1-27.

Walne, P. R. 1972. The Influence of Current Speed, Body Size and Water Temperature on the Filtration Rate of Five Species of Bivalves, *Journal of the Marine Biological Association of the United Kingdom*, Vol 52, pp 345-374.

Wang, J. C. S., and Tatham, T. R. 1971. A Study of the Relationship of Suspended Sediments and Fish Eggs in the Upper Chesapeake Bay and Its Contiguous Waters, with Special Reference to Striped Bass, Ichthyological Associates, Middle, DE.

Waters, T. F. 1972. The Drift of Stream Insects, *Annual Review of Entomology*, Vol 17, pp 253-272.

Way, C. M., Hornbach, D. J., Miller-Way, C. A., Payne, B. S., and Miller, A. C. Dynamics of Filter-Feeding in *Corbicula fluminea* (Bivalvia: Corbiculidae), in preparation, *Canadian Journal of Zoology*.

Werschkul, D. F., McMahon, E., and Leitschuh, M. 1976. Some Effects of Human Activities on the Great Blue Heron in Oregon, *Wilson Bulletin*, Vol 88, pp 660-662.

Wuebben, J. L., Brown, W. M., and Zabilansky, L. J. 1984. Analysis of Physical Effects of Commercial Vessel Passage through the Great Lakes Connecting Channels, Cold Regions Research and Engineering Laboratory, Hanover, NH.

Yousef, Y.A., McLellon, W. M., and Zebuth, H. H. 1980. Changes in Phosphorous Concentrations Due to Mixing by Motorboats in Shallow Lakes, *Water Research*, Vol 14, pp 841-852.

Yousef, Y. A., McLellon, W. M., Fagan, R. H., Zebuth, H. H., and Larrabee, C. R. 1978. Mixing Effects Due to Boating Activities in Shallow Lakes, Technical Report ESEI No. 78-1d, Florida Technical University Environmental Systems Engineering Institute, Orlando, FL.

APPENDIX A: PHYSICAL EFFECTS OF NAVIGATION TRAFFIC

Drawdown

1. The passage of commercial traffic along restricted navigation channels results in a temporary decrease in water level, a phenomena called drawdown. Factors affecting drawdown include vessel displacement, velocity, direction, and channel morphometry. Drawdown could cause temporary atmospheric exposure of benthic organisms along shoreline areas. It has been determined that vessel speed is the most important determinant of the magnitude of drawdown; the reduction of vessel speed by only 1-2 mph* will reduce drawdown by an amount equal to the difference between a class 5 and class 10 vessel (Wuebben, Brown, and Zabilansky 1984).**

2. In a study of drawdown and sediment transport Demissie and Osakada (1981) collected depth-integrated suspended sediment samples at three locations on a river transect following vessel passage. It was noted that drawdown brought sediment out of channel borders and into the navigation channel. A discussion of drawdown and wave action following vessel passage appears in Carruthers (1966).

Wave Wash

3. Gates and Herbich (1977) determined that the height of a ship-generated wave is mainly the function of vessel speed. Helwig (1969) stated that the bow and stern of a ship are responsible for most of a ship's wave-making ability. An empirical relationship for predicting ship wave heights in a restricted channel (irrespective of geometry) was presented by Balanin and Bykov (1975). McNown (1976) determined that vessel length is usually insignificant in determining the extent of water drawdown, and Stelczer (1981) discussed scour velocities necessary to move different-sized sediment particles.

4. Bhowmik, Demissie, and Osakada (1981) investigated maximum wave heights for 41 tow passages in the field; they determined that waves varied from 0.1 to 1.05 ft and that maximum drawdown ranged from 0.05 to 0.69 ft. Maximum wave height and drawdown depend on the blockage factor, velocity, and length of the vessel. These workers noted that observed wave heights were significant enough to cause bank erosion.

5. Physical effects studies of ship-generated waves have been reported by Sorenson (1967) and Fuehrer and Romisch (1977). In the former study maximum ship-generated wave heights were measured at various distances from the sailing line. In the study by Fuehrer and Romisch (1977) model investigations and mathematical equations addressed problems of: (a) distribution of the displacement current of a ship during navigation in canals and channels of limited width and depth; (b) the squat of ships in canals and channels; and (c) the damages to waterways and hydraulic structures caused by the action of propeller jets.

6. Ofuya (1970) used graphical techniques to estimate decay of wave heights with respect to distance from the sailing line. It was reported that a direct relationship between ship wave characteristics and sediment transport from erosion did not exist. Hagerty, Spoor, and Ullrich (1981) assessed the problem of bank stability along the Ohio River. They indicated that erosive mechanisms were complex and episodic; however, the principal causative agent was floods. It was concluded that waves generated by tow and recreational vessels have little effect on bank stability, although land use changes can affect slope stability and erosion. Hurst and Brebner (1969)

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

** See references at the end of the main text.

evaluated shore erosion and protection mechanisms on the St. Lawrence River in Canada. They determined that bank erosion problems were mainly the result of vessel speed and size of the waterway. Physical characteristics of waterway banks (including grain size, strength, moisture content, and porosity of soil and rock) were discussed in relation to vessel waves by Camfield, Ray, and Eckert (1980). Johnson (1969) evaluated the effects of ship waves on recreational beaches.

7. In a study by Bhowmik, Demissie, and Osakada (1981) wave height, velocity, and suspended sediments were measured during passage of barges. All three parameters showed significant changes following vessel passage. In addition they determined that the total net input of sediments and nutrients into side channels was very small and often nonexistent following passage of a barge.

Turbulence

8. The passage of a commercial vessel through a waterway causes a brief change in water velocity that is usually accompanied by rapid drawdown and surge. Wuebben, Brown, and Zabilansky (1984) reported a three-fold increase in bottom velocity and a 360-deg rotation in current direction immediately following commercial vessel passage in the St. Mary's River, Michigan. Eckblad (1981) determined that downbound tows in the Upper Mississippi River caused current velocity to double.

9. Propeller movement causes turbulence which can be defined as a measurable velocity in more than a single direction. Turbulence can create waves and resuspend sediments. The effect of turbulence on sediment resuspension is related to water depth and particle size, speed and frequency of the vessel, and horsepower of the tug (Karaki and Van Hoften 1974; Johnson 1976; Yousef, McLellon, and Zebuth 1980).

10. Turbulence can result in a temporary increase in water velocity, or in certain occasions, a change in direction of current. The following water velocity changes have been recorded as a result of vessel passage: 0.5-1.0 fps (Upper Mississippi River Basin Commission (UMRBC) Environmental Work Team 1981a, b, and c); 0.7 fps (Herricks and Gantzer 1980); changes in ambient velocities of from 10 to 100 percent (UMRBC Work Team 1981c); and changes in velocity of 55-64 percent at the surface and mid-depth, respectively (Johnson 1976). A commercial vessel headed downstream can reverse the current for short periods of time.

Sediment Resuspension

11. Passage of a commercial navigation vessel causes turbulence and waves which can cause resuspension of sediments. Sediments usually remain suspended for 30 min although suspensions lasting 60-90 min have been reported (Bhowmik, Demissie, and Osakada 1981). Change in water velocity at the bottom must exceed those velocities necessary to suspend particles (0.1 mm sand will not settle when velocities exceed 0.8 fps). In addition, material will remain suspended if water velocity is above particle-settling velocity.

12. The hull compression wave and propeller vortices (or propeller wash) affect sediment resuspension. These forces decline with increased distance between the ship and bottom. Important factors include hull design and size (Johnson, J. W., 1958; Das 1969), vessel speed (Berger Associates, Ltd. 1980), and channel morphometry (Hay 1968; Liou and Herbich 1976).

13. Following tow passage, increases in suspended solids of 19 g/m^3 (Sparks, Thomas, and Schaeffer 1980), and up to 2,000 g/m^3 (which returned to ambient levels in 35 min) have been reported (Academy of Natural Sciences of Philadelphia 1980). It was determined that sediment inputs into side channels were relatively small compared with the ambient main channel conditions (Lee et al. 1981). Effects of vessel passage on changes in suspended solids levels have been reported by Sparks, Thomas, and Schaeffer (1980); Johnson (1976); Claflin et al. (1982); Link and Williamson (1976); and Karaki and Van Hoften (1974).

14. Turbidity relates to the ability of water to transmit light; it can affect behavior and distribution of fishes and zooplankton. Suspended sediment refers to particulate matter that cannot be filtered from a water sample. The latter can smother eggs, and interfere with respiration of fishes and invertebrates. Unfortunately, many workers use these terms interchangeably, and often turbidity is measured when effects are brought about by particulate matter.

Sedimentation

15. Sediment resuspended by a tow can settle in the channel border or in backwater areas where the current is reduced. Studies on the effects of tow passage on sedimentation rates in backwaters have been conducted by Bhowmik et al. (1981b), and Simons et al. (1981a, b, and c). In considering the effects of sediment movement into backwaters, one must consider that deposition and scouring affect backwaters during periods of high water.

Impingement

16. A moving propeller can strike aquatic organisms as the tow moves through the water. Fishes and invertebrates in the water column are often affected. If the water is shallow, propellers can physically disrupt the substrate and organisms in the top few centimetres, such as mussels. A moving hull causes friction and shear forces on fish eggs, larvae, and other small organisms (Morgan et al. 1976). Equations to calculate resistance of a ship's hull to friction in open water are presented in Comstock (1967).

Effects of Winter Conditions

17. The proposed extension of commercial navigation (possibly to include year-round use) in northern waterways has generated additional concern over the environmental effects of navigation. Few environmental studies have been completed on this topic, and existing data are difficult to interpret because of the lack of good baseline data.

18. Navigation along ice-covered waterways results in physical effects similar to those caused by navigation along ice-free waterways. However, the effects of commercial traffic could be greater during the winter because of increased shoreline erosion caused by abrading ice. This ice can scour the river bottom. Alger (1979) found that winter navigation had effects on current similar to those of summer navigation; the magnitude of these effects depended upon vessel speed, size, and direction of travel. Turbulence generated by boat passage increases turbidity; Alger (1979) reported that the magnitude of turbidity caused by passage could be greater in the winter than in summer because of greater effects of ice flows and erosive forces on shorelines and benthic sediments in shallow water. Poe, Edsall, and Hiltunen (1979) also found commercial traffic to increase turbidity in the St. Mary's River during February and March. Alger (1979) reported that increased turbidity could be of greater ecological importance during the winter than during ice-free conditions, since ambient turbidity during conditions of total ice cover is usually low. Additional studies on the physical effects of winter are reported by Hubert, Darnell, and Dalk (1983).

Changes in Water Quality

19. Shifts in oxygen tension in the water column have been associated with tow-induced increases in suspended sediment concentrations (Lubinski et al. 1981). Simons et al. (1981) reported that barge passage could induce a 50-percent decrease in dissolved oxygen at the surface of the water, but virtually no effect was found at a depth of 3 m. Further, it was found that decrease in oxygen tension returned to near ambient levels within 60 min. Similar phenomena were reported for the Illinois River (Sparks 1975) and the Kaskaskia River (Herricks and Gantzer 1980; Herricks et al. 1982). Conversely, other authors have reported slight increases in dissolved oxygen concentrations following tow passage (Johnson 1976; Berger Associates, Ltd. 1980).

20. Stefan and Riley (1985) noted that thermal stratification in waterways could be disrupted by the passage of barges. Yousef et al. (1978) investigated the mixing effects of recreational boats with small motors (from 28 to 165 hp) in small bodies of water.

Auditory/Visual Disturbance

21. An important potential impact of navigation traffic along major waterways is visual and auditory disturbance of nongame birds, especially wintering bald eagles and colonially nesting waterbirds such as herons, egrets, and cormorants. However, there are few direct studies concerning navigation traffic; therefore, impacts must be inferred from studies of other kinds of human intrusion such as recreational boating.

General Impact Studies

22. General discussions on the physical effects of commercial navigation traffic appear in Johnson (1976b); Bhowmik et al. (1981a), Bhowmik, Demissie, and Osakada (1981); and Bhowmik et al. (1981b).

APPENDIX B: BIOLOGICAL PROGRAM INFOR' 'ATION

Invertebrate Drift

1. The downstream movement of benthic (bottom-dwelling) invertebrates in flowing water is referred to as invertebrate drift. Drift has been categorized as constant, behavioral, or catastrophic (Waters 1972; Muller 1974; Eckblad, Volden, and Weilgart 1984).

Constant drift

2. Constant drift is the species composition and relative abundances of benthos that are usually found in the water column. Constant drift results from random interactions between individuals, and also is a function of community composition, individual species abundances, and habitat characteristics.

Behavioral drift

3. Behavioral drift is a means of moving from one habitat to another. It is affected by population density and community composition and generally exhibits diurnal fluctuations. Typically the greatest pulse of drifting insects occurs at night. It has been hypothesized that drift at night lessens the risk of predation by visually oriented predators. Other conditions resulting in lowered incident light levels during the day are positively correlated with increased drift (Gammon 1970; Ciborowski, Pointing, and Corkum 1977).

Catastrophic drift

4. Catastrophic drift is the downstream transport of unusually large numbers of benthic organisms. In such instances there are shifts not only in abundances, but also in the species composition of the drif community. Catastrophic drift can be brought about by changes in temperature, turbidity, or from habitat disruption.

5. In a study by Beckett et al. (1985) total macroinvertebrates drifting in the Lower Mississippi River ranged from 22 to 70 per 100 m^3. It was estimated that approximately 0.5 billion macroinvertebrates passed a point during a 24-hr period in May. There are no data on the extent to which predators depend on drift as compared with organisms in the substrate or on plants or other objects. However, as the above data indicate, there is a large invertebrate biomass available for predators in the water column. In addition, drifting invertebrates are potential recolonists of new or existing habitats. In studies on the Lower Mississippi River, workers have found that newly deposited sediments are colonized very quickly by invertebrates known to be present in drift.

Relationship between drift and commercial traffic

6. In a study of invertebrate drift in the Upper Mississippi River following passage of commercial traffic, Eckblad (1981) reported that macroinvertebrate drift increased at the 9-ft depth following passage of an upbound vessel. However, there was not a statistically significant difference between pre- and post-tow drift densities. Eckblad (1981) determined that a greater number of replicate samples would be required to show statistically significant differences in drifting organisms before and after passage of commercial navigation vessels.

7. Seagle and his associates performed a series of studies in pool 26 of the Upper Mississippi River (Seagle and Zumwalt 1981). The authors concluded that there "...was no consistent pattern showing an increase or decrease in macroinverte' rate drift density or number of taxa present resulting from tow passage." They went on to conclude that river discharge, invertebrate life cycle events, and diel cycles are the main factors that structure invertebrate drift. They found no evidence of macroinvertebrates being swept from wing dams because of passing tows or of

tow-induced increase in detritus density when drift samples were taken from the main channel border habitats. While they found higher densities of detritus in the main channel after tow passage, they could not determine whether this was the result of resuspension of bottom detritus or if this material was concentrated from elsewhere in the water column.

8. The design and execution of field studies on drift in a large waterway is difficult. Seagle and Zumwalt (1981) stated: "Because of the continually high discharge during the study period, it is not clear whether the results of this study are representative of the effects navigation may have on macroinvertebrate drift under all river conditions and over long periods of time." This demonstrates the difficulty of conducting these studies but does not indicate that commercial traffic is a specific cause of unusually high drift in navigable waterways.

9. As discussed by Beckett et al. (1985), and Seagle and Zumwalt (1981), drift has annual periodicity with maximum values occurring in spring. Drift densities are usually reduced in the winter season. Previous workers have noted drift during winter resulting from tow passage (e.g., US Fish and Wildlife studies on the St. Mary's River). During winter drifting organisms are susceptible to predation, although predators may also be sluggish and are not as active as they are in spring or summer. Dislodged invertebrates may be unable to regain cover easily especially if they are swept into the channel. Since they are a potential food source for aquatic and terrestrial animals (and will provide offspring when winter is over) a large reduction in benthos could be detrimental to the system. However, there are few published accounts of well-designed studies to evaluate the impacts of winter navigation on invertebrate drift.

10. When interpreting results of large-river drift studies it is important to realize that navigation traffic and other man-made activities influence the design, conduct, and outcome of the research. It would take a well-designed study, and a fortuitous set of circumstances (i.e., temporary suspension of all navigation traffic) to precisely define effects of commercial traffic on invertebrate drift.

Summary

11. There have been no studies that report a statistically significant increase in invertebrate drift following passage of commercial vessels. In addition, it must be remembered that densities of drifting invertebrates in large rivers can be very high (see above). Although it could be argued that these are the result of ambient levels of commercial traffic, there is no scientific evidence for this statement. In addition, it would be extremely difficult to quantify the amount of drift in a waterway that could be attributed to commercial traffic.

12. Invertebrates dislodged from the substrate by commercial vessels can enter the water column where they provide food for fishes or other predators. Based upon the nature of invertebrate drift in lotic systems, and the evidence from field studies, we find no evidence that commercial navigation traffic increases ambient levels of drift in waterways. Invertebrate drift as a natural phenomenon in large waterways has not been shown to be affected by the passage of commercial vessels.

Winter conditions

13. As discussed by Beckett et al. (1985) and Seagle and Zumwalt (1981), invertebrate drift in large rivers has annual periodicity with maximum values occurring in spring. Drift densities are usually reduced in the winter season. It is possible that invertebrates could be brought into the water column during the winter by turbulence from commercial vessels. During the winter drifting organisms are susceptible to predation, although predators can also be sluggish and are not as active as they are in spring and summer. There have been no well-designed field studies to document the impacts of winter navigation on invertebrate drift.

Drawdown

14. The effects of drawdown on invertebrates have not been studied in large rivers. However, the effects of drawdown on drift are probably negligible.

Wave wash

15. The direct effects of wave wash on invertebrate drift have not been studied in large rivers. It is possible that wave wash could suspend benthic macroinvertebrates located in nearshore areas and/or maintain macroinvertebrates in a suspended state if navigation traffic effects are pronounced.

Turbulence

16. The effects of turbulence on invertebrate drift have not been studied in large rivers. It is possible that navigation-induced turbulence could increase the amount of drift by suspending benthic macroinvertebrates.

Impingement

17. The effects of impingement on invertebrate drift have not been studied in large rivers. It is possible that the macroinvertebrates in the water column suffer considerable mortality by the props of passing tows. However, the effects of this type of mortality on the population demography of a given species are unknown.

Sediment resuspension

18. The effects of sediment resuspension on invertebrate drift have not been studied in large rivers. Sediment resuspension itself probably has no effect on drift. However, it is probable that benthic macroinvertebrates are passively suspended along with other benthic particles during sediment resuspension.

Sedimentation

19. The effects of sedimentation on invertebrate drift have not been studied in large rivers. However, there is probably no effect since sedimentation concerns deposition of materials on the benthos.

Water quality

20. The effects of water quality on invertebrate drift have not been studied in large rivers.

Auditory/visual disturbance

21. The effects of auditory/visual disturbance on invertebrate drift have not been studied. However, there is probably no effect caused by this type of disturbance.

Macroinvertebrates

22. For this discussion, macroinvertebrate refers to a very diverse assemblage of riverine organisms. The term "macro" refers to the macroscopic size of these organisms and their ability to be retained in standard sampling sieves. These organisms can be contrasted to the "microscopic invertebrates" such as phytoplankton and zooplankton. The macroinvertebrates include the aquatic larval stages of many terrestrial insect orders: Ephemeroptera (mayflies), Odonata (dragonflies), Plecoptera (stoneflies), Megaloptera (alderflies, dobsonflies), Neuroptera (lacewings), Trichoptera (caddisflies), Coleoptera (beetles), and Diptera (chironomids, simuliids, etc.). In addition the adult forms of many insects are either fully aquatic or semi-aquatic (e.g., dytiscid beetles). Two large groups of macroinvertebrates, the freshwater bivalves and gastropods, are treated in a separate

discussion. Other common macroinvertebrate taxa in rivers include: (a) oligochaetes - worms in the phylum Annelida which generally live in soft substrates and digest detritus; (b) leeches - organisms in the phylum Annelida that are predatory on other macroinvertebrates and small vertebrates; (c) crayfish - organisms in the class Crustacea; (d) amphipods - organisms in the class Crustacea which feed on aquatic plant material; (e) bryozoans - organisms in the phylum Ectoprocta which are colonial, live attached to hard, submerged substrates and are suspension feeders (utilizing a characteristic feeding organ known as a lophophore); (f) hydra - a solitary, predacious organism in the phylum Coelenterata - these organisms are related to the marine sea anemones and can be found attached to a hard, submerged substrate; and (g) sponges - colonial organisms in the phylum Porifera which are found in amorphous masses attached to hard, submerged substrates - these organisms use characteristic cells (choanocytes) for suspension feeding. Other macroinvertebrates exist in rivers, but little is known of their ecology. For further information of a specific nature on invertebrates see texts by Barnes (1987) and Pennak (1978).

23. Generalities concerning this group are few. The various macroinvertebrates are found in widely varying riverine habitats, tolerate disparate environmental conditions, and occupy niches which span several trophic levels. Many macroinvertebrates are scrapers and/or shredders and depend upon a supply of either rooted macrophytes or phytoplankton attached to rocks for food. These forms are confined to the shallow, marginal areas of a river that have adequate light penetration. Any disturbance that interferes with the growth of plant materials (turbulence, sediment resuspension, sedimentation) can adversely affect the ecology of these organisms. Some macroinvertebrates are capable of withstanding severe environmental conditions and are capable of thriving in waters with low oxygen concentrations and poor light penetration (e.g., chironomids). Many caddisflies require a swift, well-oxygenated, non-turbid current for effectively capturing food particles on the mucus nets that they build. Macroinvertebrates like many stoneflies and megalopterans are predators and feed not only on other macroinvertebrates but on small vertebrates as well (e.g., fish larvae). Any discussion of the physical effects of navigation traffic on a specific macroinvertebrate will necessitate being very restrictive in its interpretation and interpolation to other species.

Drawdown

24. Various authors (Sparks 1975; Berger Associates, Ltd. 1980; Lubinski et al. 1981) have commented that the biological effects of drawdown are probably not severe, although there have been few studies on this topic. Drawdown will have a more pronounced effect upon side channels or shallow wetland areas adjacent to navigation channels than on deep channels. In addition, drawdown is of most concern in narrow channels (i.e., channel width less than 1,000 ft). It has been suggested that the sudden influx and outflow of water caused by passage of commercial vessels could result in a disruption of the life cycle of immature fish, benthic invertebrates, or other aquatic organisms (Sparks 1975; Lubinski et al. 1981; Eckblad, Volden, and Weilgart 1984). However there have been no field studies to substantiate these claims.

Wave wash

25. There are no available studies on the effect of wave wash on macroinvertebrates.

Turbulence

26. Current velocity is considered to be one of the most important factors for organisms found in flowing water systems (Hynes 1970). Rabeni and Gibbs (1980) noted that the principal factor affecting the distribution of benthic community types was current velocity. Abrupt shifts in current direction or velocity can adversely affect benthic organisms adapted to life within restricted current ranges. Temporary fluctuations in current direction induced by tow passage can have effects upon benthic species such as trichopterans that have food capture nets that work well only within a restricted current range (Rabeni and Gibbs 1980) and orientation. It has been suggested that these

nets could collapse under conditions of low flow, or rupture if subjected to high-velocity currents. However, there have been no field studies on this topic. It is also possible that the hydromechanical forces associated with tow-induced turbulence may dislodge organisms such as grazers feeding on periphyton covered rocks. A major effect of tow-induced turbulence on benthic macroinvertebrates concerns the possibility of catastrophic drift (see section on macroinvertebrate drift).

Impingement

27. There is no information available at the present time concerning the effects of impingement on macroinvertebrates. Because most invertebrates of concern are bottom dwelling, it is unlikely that these organisms would ever encounter tow propellers. However, the discussion on invertebrate drift deals with a special group of organisms that may be impacted by impingement.

Sediment resuspension

28. Tow-induced turbulence results in a short-term increase in suspended sediment. While increases in turbidity associated with navigation traffic can be substantial, it is doubtful that they are of sufficient duration and magnitude to be lethal to most benthic species. Gray and Ward (1982) reported that 2-week exposures to suspended sediment of 300 mg/L were sufficient to reduce by 90 percent two chironomid populations. Lethal suspended sediment concentrations are generally greater than those usually found associated with barge traffic.

29. Recently Payne et al. (1987) have shown in the laboratory that periodic short-term exposures to suspended solids concentrations of 600-700 mg/L decreased food clearance, respiration, and excretion rates in three bivalve species by 26, 59, and 39 percent, respectively. In more stressed situations, individuals stopped feeding, and turned to utilization of stored carbohydrate or lipid reserves. This was the first laboratory study to examine the physiological effects of periodic, short-term, sublethal disturbances of suspended sediments on freshwater mussels.

Sedimentation

30. Settling of suspended solids could have severe impacts upon benthic communities through fouling of respiratory surfaces and burial of eggs (Sparks 1975). Sediment can affect substrate composition, which in turn can affect benthic community structure. Low levels of sediment have not been noted to greatly affect benthic communities (Rabeni and Gibbs 1980), although sites with heavy sedimentation exhibited severely decreased density of organisms (Chutter 1969; Cordone and Kelly 1961). However, there have been no field studies in which sediment deposition, caused by commercial traffic, has altered benthic communities.

Winter conditions

31. There is no information available at the present time on the effect of winter conditions on macroinvertebrates.

Water quality

32. The transient and often negligible changes in water quality induced by tow passage probably have little effect on macroinvertebrates. There is no information available at the present time concerning the effects of tow-induced changes in water quality on macroinvertebrates.

Auditory/visual disturbance

33. This topic is not relevant to macroinvertebrates.

Riverine Fishes

34. Principal game fishes in large rivers are freshwater drum, channel catfish, crappie, bluegill, green sunfish, white bass, blue catfish, flathead catfish, warmouth, bullhead, and largemouth bass. Emerald shiner and the American and gizzard shad are common nongame species. In large river systems the most important spawning areas are usually associated with shallow shoreline areas, side channels, near islands, or other slack-water habitats. The freshwater drum is the only fish that spawns in the main channel of large rivers. All other species of fishes spawn in protected areas and their larvae are then carried into the main channel.

35. Emphasis has been placed on the impacts of navigation traffic on fishes because of their commercial and economic importance. Various workers have studied both sublethal and lethal responses of different life stages to stresses that could be associated with navigation traffic. The importance of the sublethal responses (as defined by Rosenthal and Alderdice 1976) has been discussed in some of these studies, and as such may be of more importance than those studies examining only lethal responses.

Impingement

36. Disturbance, or direct physical impact by a propeller or boat hull has caused injury and death to fish in navigable waters. Rosen and Hales (1980) reported that for 458 paddlefish (*Polydon spatula*) examined, 36 percent were scarred and concluded that the main cause of scarring was collision with boats. They hypothesized that this high incidence of injury could be related to the escape behavior of this species. Increased swimming speed and body morphology could combine to force paddlefish to rise when startled, thereby increasing the chance of collision. In a radiotelemetry study on 17 paddlefish, Southhall (1982) recorded nine deaths, two as a result of collisions or suspected collisions with commercial navigation vessels. Hubert (undated) described a situation when paddlefish were cut in half by a propeller of a tow. The question central to this issue, and one not addressed easily by experimental work, is whether or not these instances of mortality are detrimental to long-term survival of the species. The apparent decline of paddlefish during this century is certainly the result of a variety of disturbances, such as sedimentation, loss of gravel riffles for spawning, and commercial and recreational fishing.

Turbulence

37. Larval fish and eggs are probably more susceptible to collisions with recreational and commercial traffic and disruption from turbulence than are adult fish, simply because they lack avoidance mechanisms. The location of the eggs and larvae relative to the navigation channel will affect their survival. For example, species such as bluegill, which normally inhabit side channels and backwaters, would be minimal. However, the survival of pelagic eggs for species such as the drum, could be more directly affected by commercial traffic. Holland and Sylvester (1983) indicated that factors such as seasonality, spatial orientation, and periodicity of vessel passage can affect risk of injury by collision. Morgan et al. (1976) found that the shear forces needed to cause 50-percent egg mortality for white perch and striped bass was five times greater than what most eggs would be exposed to during ship or tow passage (425 versus 78 dynes/cm^2). In the case of the striped bass (*Morone saxatilus*) or in other species with buoyant eggs, it could be argued that low levels of turbulence could enhance survival by keeping eggs suspended.

38. Tow passage could affect fish species with pelagic eggs and nest- or brood-guarding behavior by a different mechanism. Mueller (1980) found that boat passage at slow speeds (1 m/sec) caused male longear sunfish to leave their nests, increasing risks of predation. Higher speeds did not have an increased behavioral effect on the fish, but they were more physically destructive to nests.

Sedimentation

39. Any increased levels of sedimentation can affect fishes by smothering eggs, and interfering with respiration. However, there are no studies that directly address this effect in large rivers.

Sediment resuspension

40. Three different studies (Wallen 1951; Sherk, O'Connor, and Neuman 1972; Peddicord et al. 1975) have shown that for a number of macroinvertebrate species no significant mortality resulted from exposure to suspended solids concentration of slightly less than 1 g/L for durations of less than 24 hr.

41. Both indirect and direct effects of sedimentation upon various life stages of fishes have been reported in the literature. In most cases, the effects appear to be more pronounced on eggs, larvae, and juveniles than adults. The limited dispersal ability of immature life stages could expose them to higher concentrations of suspended solids for longer periods of time increasing negative effects. Rosenthal (1971) found a 40-50 percent increase in egg mortality of the herring (*Clupea harengus*) when exposed to red clay suspensions of 1.0, 2.0, 5.0, and 10.0 mg/L. The clay adhered to the egg membranes, interfering with the diffusion of gases. Increased embryonic mutations were correlated with increased suspended sediments. Pelagic eggs were reported to be more resistant to high sediment levels than benthic eggs (Mansueti 1961) such as those of the walleye, *Stizostidion vitreum*, and the lake whitefish, *Coregonus clupeaformis*. Benthic egg mortality is likely a result of burial rather than suspended sediment in the water column (Johnson 1961; Fudge and Bodaly 1984).

42. Settled sediment can influence hatching or incubation of fish eggs. Morgan et al. (1976) reported a lengthened incubation time for striped bass and white perch when exposed to more than 1,500 mg/L suspended solids. Wang and Tatham (1971) reported delays in the hatching of eggs from yellow perch, white perch, striped bass, and American shad when exposed to 100-500 mg/L of suspended solids.

43. Susceptibility of larvae to increasing suspended sediment concentrations was reported by Morgan et al. (1976). In their study, mortality varied from 27.3 to 29.3 percent when exposed to 1,626-5,380 mg/L of suspended solids for 24 hr.

44. Various workers, and several reviews (Muncy et al. 1979; Sorenson et al. 1977; Stern and Stickle 1978) examined effects of turbidity (resulting from sediment resuspension) upon fishes. As past studies indicated, distribution and productivity of fishes are often correlated with turbidity levels (e.g., Ritchie (1972)). Individual response is dependent upon species tolerance and life requisites.

45. Among most species it is doubtful that the magnitude and duration of tow-induced turbidity are sufficient to cause any significant, acute mortality among healthy adult fish. Turbidity impacts could be further diminished by the presence of less turbid areas that fish can migrate to, escaping harmful conditions.

46. Behavior modifications in foraging and spawning in water with high levels of suspended solids have been observed in freshwater fish (Muncy et al. 1979). Vinyard and O'Brien (1976) reported that the bluegill (*Lepomis machrochirus*) exhibited decreasing reaction distances to prey as turbidity increased (1.0-30.0 Jackson turbidity units). Buck (1956) and Smith, Kramer, and Oseid (1966) reported that fish inhabiting turbid waters were stunted, and suggested that this could be partially the result of reduced foraging efficiency. Sigler, Bjorne, and Everest (1983) in a study on salmonid fishes found that steelhead (*Salmo gairdeni*) and Coho salmon (*Oncorhynchus kisutch*) exhibited reduced growth rates in turbid water. Turbidity as low as 25 nepholometer turbidity units (NTUs) for a period of 2 weeks caused significant reductions in growth rates. Density was also

affected by turbidity; clear waters had twice the density of turbid waters. The authors concluded that the differences in density were attributed to active migration of fish out of turbid waters.

47. Swenson and Matson (1976) found no mortality in larval lake herring (*Coregonus artedii*) when exposed to 1.0-28.0 mg/L of suspended solids. The larvae exhibited some vertical displacement under turbid conditions that may have been a response to light attenuation. Johnson and Widish (1982) in their study of larval herring (*Clupea harengus*) found foraging efficiency to be positively correlated with light intensity in clear water. Similar results were obtained by increasing the suspended sediment load from 0.0 to 20.0 mg/L. The negative effects of high sediment levels on predation efficiency (using *Artemia* nauplii as prey) was ameliorated by larval size. Under turbid conditions, large larvae were more efficient in capturing prey than smaller forms.

48. Reduced spawning by largemouth bass has been correlated with increasing turbidity (Chew 1969; Robbins and MacCrimmon 1974). However, not all fish avoid turbid areas while spawning; Cross (1967) reported that bullheads spawned in turbid waters.

49. Physiological responses to increased turbidity have been reported for several species of fish. Horkel and Pearson (1976) found that at 25° C, turbidities of 898 FTU (Formazine Turbidity Unit) caused a 50-70 percent increase in ventilation rates (without a concurrent increase in oxygen consumption) in the green sunfish (*Lepomis cyanellus*). This increase in opercular activity could be an effort to keep the gills free of silt. Energetic demands of such activity could decrease individual growth rates. An associated response to high turbidity, coughing, was first described by Heimstra, Damkot, and Benson (1969) in the largemouth bass and green sunfish. They proposed that this was a mechanism by which gill chambers were kept clean. Carlson (1984) observed coughing in bluegill sunfish when first exposed to turbidity increases greater than 100 NTUs.

50. Sherk, O'Connor, and Neuman (1972, 1974) found that Fuller's earth and Kaolin turbidities affected oxygen consumption rates and other physiological and histological responses. Gills of white perch exhibited tissue damage and excessive mucus production when exposed to high levels of suspended sediments.

51. Rainbow trout (*Salmo gairdneri*) and other species of trout have exhibited tissue damage under conditions of high suspended sediments. Increased sediments can cause a thickening of epithelial cells and adhesion between filaments of fish gills. Other authors who noted the detrimental effects of sedimentation upon benthic eggs include Johnson (1961), and Fudge and Bodaly (1984).

52. Although increased suspended sediment levels can be detrimental, these increases can be brought about by natural conditions. No data have been presented in the scientific literature on effects of traffic-induced sediment resuspension on the physiological or histological condition of adult fishes.

Drawdown

53. The impact of tow-related drawdown on fishes remains largely unknown. Kennedy et al. (1981) hypothesized that larval fishes that congregate in shallow water could be stranded by drawdown. There have been no field studies on the effects of drawdown on fish eggs.

54. Drawdown could have a great effect on benthic eggs. Hubert (undated) indicated that 26 of the 36 fish species collected in pool 9 spawn in the shallows where the eggs could be affected by drawdown. Holland and Sylvester (1983) in a laboratory experiment found that short-term, atmospheric exposure (2 min) at frequent intervals (once every hour or every 3 hr) caused significant reductions in the survival of walleye and northern pike eggs. In both cases, survival decreased from 80 to 50 percent in walleye and to 5 percent in northern pike. However, in a study conducted at the US Army Engineer Waterways Experiment Station no significant mortality was found in eggs of channel catfish exposed to the atmosphere for up to 24 hr (Pearson et al. 1989).

Winter conditions

55. It has been suggested that winter navigation could have a detrimental impact upon catfish because of their seasonal shift in behavior. Catfish are lethargic during the winter (Hawkinson and Grunwald 1979; Peterson 1983) and are often found lying on the river bottom. They are usually found behind obstructions to the current, where position can be maintained with a minimum of activity. Hawkinson and Grunwald (1979) suggest that this behavior places them in risk of collision with passing vessels. Most fish species become relatively inactive during the winter and have a reduced ability to avoid navigation-induced perturbations. However, there have been no field studies on this navigation effect.

Wave wash

56. There is no information available on the effects of wave wash on the fishes of large rivers.

Water quality

57. There is no information available on the effects of navigation-induced changes in water quality on the fishes of large rivers.

Auditory/visual disturbance

58. There is no information available on the effects of auditory/visual disturbance on the fishes of large rivers.

Waterfowl

59. The family Anatidae consists of more than 40 species of North American waterfowl, including geese (Anserini), swans (Cygnini), mergansers (Mergini), diving ducks (Aythyini), surface-feeding ducks (Anatini), wood ducks (Cairinini), and ruddy ducks (Oxyurini). Many of these are found along major rivers and inland waterways. Waterfowl use rivers, backwaters, sloughs, and adjacent upland habitats for nesting, brood rearing, resting, and feeding. Nearly all waterfowl are migratory so that a particular area might serve as breeding, wintering, or migratory habitat for a variety of species.

60. The surface-feeding or dabbling ducks, such as mallards, pintails, and teal, inhabit shallow marshes or sloughs where they feed on aquatic vegetation by "tipping up" with their tails pointing skyward. Wood ducks prefer acorns that they gather in flooded forests. The diving ducks, such as canvasbacks, redheads, and scaup, forage in the deeper waters of rivers and lakes where they dive for plants and bottom-dwelling animals. Common and hooded mergansers eat mainly small fish and crustaceans. Both geese and swans consume vegetation, but swans prefer the leaves and tubers of aquatic plants whereas geese prefer to graze on grasses, forbs, and cereal grains in upland areas.

61. Waterfowl build their nests on a variety of areas, including on or near the ground on dry uplands, islands, tree stumps, muskrat houses, and artificial structures (dabblers, geese, and swans); on piles of vegetation surrounded by water or on floating mats anchored to emergent vegetation (divers); and in cavities in trees or nesting boxes (wood ducks and hooded mergansers). Newly hatched birds leave the nest almost immediately and are led to shallow, protected areas where they feed mainly on invertebrates. Adult females of most species show remarkable fidelity to particular nesting areas; if the habitat remains suitable, they will return repeatedly to the same location.

Sedimentation

62. Suspended sediment from various sources, including commercial navigation, can settle out in the slack water of sloughs and side channels. Along the Upper Mississippi and Illinois rivers,

sedimentation has decreased the area of backwater habitats and adversely affected the growth of aquatic plants (Sparks et al. 1979). These changes have caused declines in the use of these habitats by widgeon, green-winged teal, and lesser scaup. On the other hand, sedimentation from natural causes has produced mud flats that are used for foraging by shorebirds; and moist-soil plants that volunteer or are seeded on mudflats attract mallards, Canada geese, and snow geese (Sparks et al. 1979).

63. Eckblad et al. (1977) concluded that further decreases in depth due to sedimentation in Big Lake, pool 9, Upper Mississippi River, would shift the benthic fauna from predominantly fingernail clams and naiads of mayflies to predominantly chironomids, oligochaetes, and gastropods. These changes would be detrimental to diving ducks that feed on fingernail clams.

Winter conditions

64. There is no evidence of adverse impacts to waterfowl as a result of winter navigation on northern waterways. Fawks and Ingram (1976, cited in ERT/Ecology Consultants, Inc. 1979) report that common goldeneyes and common mergansers often use open water below dams and powerplants on the Upper Mississippi River during winter; these species may benefit from the ice-free feeding areas provided by the operation of the waterway.

Auditory/visual disturbance

65. Disturbance of resting or feeding waterfowl, particularly diving ducks, by ships or tows is a concern along navigable waterways, especially those along major waterfowl migration routes. Too much disturbance might disrupt normal feeding and increase energy expenditures during a time when the birds' energy reserves are already being taxed by the demands of migration. Although there is evidence that human disturbance alters the movements and distribution patterns of waterfowl, there is no evidence that commercial traffic contributes significantly to the disturbance problem.

66. Thornburg (1971, 1973) studied local movements of diving ducks during the fall on pool 19 of the Upper Mississippi River. The birds' distribution patterns were related primarily to the abundance of benthic organisms used for food. Although the middle and upper sections of the pool contained the best feeding areas, intense hunting during the day forced many birds to retreat to the lower section where they rafted in large numbers in the relatively undisturbed open parts of the pool. After shooting hours, they returned to the upper and middle sections to feed. Deliberate harassment of rafting ducks by pleasure boaters and hunters caused occasional mass movement of diving ducks away from pool 19 (Thornburg 1971); however, there was no indication that commercial navigation traffic was responsible.

Drawdown

67. There is no evidence of adverse impacts to waterfowl as a result of drawdown produced by commercial navigation traffic.

Wave wash

68. There is no evidence of adverse impacts to waterfowl as a result of wave wash produced by commercial navigation traffic.

Turbulence

69. There is no evidence of adverse impacts to waterfowl as a result of turbulence produced by commercial navigation traffic.

Sediment resuspension

70. There is no evidence of adverse impacts to waterfowl as a result of sediment resuspension produced by commercial navigation traffic.

Impingement

71. There is no evidence of adverse impacts to waterfowl as a result of impingement with commercial navigation traffic.

Water quality

72. There is no evidence of adverse impacts to waterfowl as a result of changes in water quality produced by commercial navigation traffic.

Other Birds

73. There are hundreds of species of birds in North America, not counting waterfowl, that may use riparian habitat along navigable waterways. Most are primarily upland species that are affected little by commercial and recreational boat traffic. However, many species depend on food resources, nesting sites, or protective cover that exist only in or adjacent to water. These species could be affected if navigation activities disrupt their critical habitats.

74. Bird species that are dependent upon inland water bodies include bald eagles, ospreys, and kingfishers; certain gulls and terns; sandpipers, stilts, and avocets; rails, coots, and gallinules; grebes and loons; cormorants and anhingas; and several species of herons, egrets, and bitterns. Despite their diversity and widespread distribution, there is no literature on the effects of navigation traffic on most of these species.

75. Attention has focused on a small number of species that are conspicuous, and of great public interest, such as bald eagles and colonially nesting herons, egrets, and cormorants. Eagles feed largely on fishes that they catch or obtain as carrion. They build huge, stick nests in prominent trees along rivers, lakeshores, and coastlines. Eagles are perhaps most conspicuous and vulnerable during winter, when they congregate to feed along ice-free sections of rivers and navigable waterways.

76. Great blue herons, great egrets, and black-crowned night-herons form single- or mixed-species nesting colonies immediately adjacent to a river, lake, or marsh. They feed by stalking fish, frogs, crayfish, and other animals in shallow areas. Double-crested cormorants dive for fish in deeper water and nest in colonies either on the ground or in trees. Colonial waterbirds in general may be vulnerable to human disturbance in or near their nesting colonies, or to changes in aquatic habitats that reduce their ability to capture food.

Sediment resuspension

77. Resuspension of sediments by commercial traffic causes turbidity that could reduce the foraging success of visual predators such as herons, egrets, and ospreys. For example, Grubb (1977) found that ospreys on a Florida lake made fewer successful dives/minute when the water surface was rippled than when it was smooth; the decline in foraging success was independent of wind speed and was attributed to poor visibility. Reduced foraging success results in a lower rate of energy gain per unit of energy expended, which may affect the survival or productivity of birds during times of food stress (Grubb 1977).

Winter conditions

78. There is no evidence of adverse impacts to birds as a result of winter navigation activities on northern waterways. In fact, the initial construction of locks, dams, and powerplants, and the

operation of the waterway, may have benefited wintering bald eagles on the Upper Mississippi River by providing ice-free areas that can be used for foraging (ERT/Ecology Consultants, Inc. 1979).

Auditory/visual disturbance

79. **Eagles.** Wintering bald eagles in Washington avoided river reaches with high levels of human activity but tolerated moderate activity (Stalmaster and Newman 1978). When disturbed, birds did not return to the same feeding area for several hours. Eagles feeding on the ground almost always flushed when approached by a single canoe; the average flushing distance was about 250 m although 22 percent of birds flushed at more than 350 m (Knight and Knight 1984). Birds perched in trees flushed less often and 93 percent of flushes occurred at distances less than 250 m. Knight and Knight (1984) speculated that disturbance of wintering eagles may disrupt feeding, increase energy expenditures, and alter social behavior important in foraging.

80. Bald eagles nesting along lake shores in the Chippewa National Forest in Minnesota avoided areas near houses and nested closer to water when houses were absent (Fraser, Frenzel, and Mathisen 1985). The approach of a single pedestrian flushed birds from the nest at distances up to 991 m, and 91 percent of flushes occurred at distances more than 200 m. Birds flushed sooner upon repeated disturbance and, thus, did not habituate to the approach of a human.

81. **Colonial waterbirds.** Nesting colonies of great blue herons and great egrets along the Upper Mississippi River tended to be located (a) below dams, where forest remnants were more common, (b) near shallow lakes or sloughs that served as feeding areas, (c) less than 100 m from water, and (d) away from human disturbance (Thompson 1977; Thompson and Landin 1978). Colonies tended to be in tall trees with dense undergrowth, and were located more than 160 m from the edge of the navigation channel or from traveled roads. None were on islands completely surrounded by easily navigable water.

82. The strength of response to disturbance varied with the stage of the nesting season in a Colorado great blue heron rookery (Vos, Ryder, and Graul 1985). The birds were most sensitive in late February and early May during nest initiation and courtship, slightly less sensitive during laying and incubation, and more tolerant in May after there were young in the nest. Nesting herons flushed more readily in response to a person approaching the heronry than to nearby recreational boating activity, to which they may habituate if not threatened. Vos, Ryder, and Graul (1985) recommended a restricted buffer zone 250 m wide on land and 150 m in water to protect against the types of disturbance they studied; the buffer zone should be enforced from mid-February through August.

83. There is no direct evidence that disturbance due to navigation traffic affects productivity or survival of colonial waterbirds. However, human intrusions into nesting colonies of black-crowned night herons (Tremblay and Ellison 1979) and double-crested cormorants (Ellison and Cleary 1978) in the St. Lawrence estuary inhibited laying, caused nest abandonment, increased losses of eggs and young to predators, and discouraged late nesters. In great blue heron colonies in Oregon that were disturbed by logging or road building within 0.5 km, 67 percent of nests were active compared with 93 percent in undisturbed colonies (Werschkul, McMahon, and Leitschuh 1976). Furthermore, Bjorklund (1975) and Werschkul, McMahon, and Leitschuh (1976) found that the distribution of nesting activity within a heronry tended to shift away from sources of disturbance.

Sedimentation

84. There is no evidence of adverse impacts to birds other than waterfowl as a result of sedimentation produced by commercial navigation traffic.

Water quality

85. There is no evidence of adverse impacts to birds other than waterfowl as a result of changes in water quality produced by commercial navigation traffic.

Impingement

86. There is no evidence of adverse impacts to birds other than waterfowl as a result of impingement with commercial navigation traffic.

Turbulence

87. There is no evidence of adverse impacts to birds other than waterfowl as a result of turbulence produced by commercial navigation traffic.

Drawdown

88. There is no evidence of adverse impacts to birds other than waterfowl as a result of drawdown produced by commercial navigation traffic.

Wave wash

89. There is no evidence of adverse impacts to birds other than waterfowl as a result of wave wash produced by commercial navigation traffic.

Mammals

90. There are two groups of mammals whose populations may be affected by navigation traffic along inland waterways. The first consists of the aquatic and semi-aquatic furbearers (e.g., beaver, muskrat, otter, mink, and raccoon) that feed and reproduce in aquatic and shoreline habitats. The second consists of large, highly mobile animals, such as deer, coyotes, and foxes, that must cross major waterways in their normal daily and seasonal movements.

91. Beavers and muskrats generally live in dens that they dig in banks along streams or lakes. In marshes or sloughs with fairly stable water levels, or in the absence of suitable banks, beavers build lodges out of sticks and muskrats build houses out of aquatic plants. Both species are herbivorous; beavers seem to prefer the bark and shoots of woody plants whereas muskrats feed primarily on shoots, roots, and tubers of aquatic species. The river otter and mink are carnivores. The otter's diet consists mainly of fish; the mink consumes a more varied diet consisting of fish, mammals, birds, crustaceans, amphibians, reptiles, and insects. Both carnivores often use the abandoned dens of other furbearers. The omnivorous and opportunistic raccoon is seldom found far from water where it catches crayfish in shallow areas. Hollow trees are the most common den sites. Potential impacts to aquatic furbearers include destruction of dens through erosion, wave wash, or changes in water levels, and changes in the productivity of shallow aquatic habitats that reduce the availability of plant or animal foods.

92. Wide-ranging, upland mammals, such as members of the deer (Cervidae) or dog (Canidae) families, often engage in long-distance movements to exploit distant resources or disperse to new areas. In the northern United States white-tailed deer regularly migrate between their summer range and restricted yarding areas that provide food and protective cover during winter. Animals may have to cross frozen rivers and waterways to reach traditional wintering areas. Commercial navigation traffic, particularly during winter, has the potential to disrupt these movements and affect the survival of these animals.

Sedimentation

93. River-borne sediment from various sources settles out in side channels, backwaters, and sloughs where current is diminished, reducing water depth and affecting aquatic plants and benthic organisms. In Big Lake (pool 9, Upper Mississippi River), Eckblad et al. (1977) estimated that 76 cm of sediment had accumulated between 1896 and 1973; the recent (1964-74) sedimentation rate averaged 1.7 cm/year. At that rate, the projected life span of Big Lake was only 43-61 years. Tow traffic contributes to backwater sedimentation but it is not known to what extent (Bhowmik et al. 1981b).

94. Sedimentation affects aquatic mammals by destruction or alteration of habitat. On the Illinois River, the loss of aquatic and marsh plants was apparently due to sedimentation, increased turbidity, and softness of newly deposited sediments that prevented plant establishment (Bellrose, Paveglio, and Steffect 1979). On pool 9 of the Upper Mississippi River, Clark and Clay (1985) found that shallow water and finer sediments reduced the vigor of *Sagittaria* beds, a major muskrat food source. On the other hand, Eckblad et al. (1977) concluded that the immediate effect of decreasing depth due to sedimentation in Big Lake would be to encourage *Sagittaria* and other emergent plants at the expense of fingernail clams. Muskrat survival rates were found to be lower in shallow areas of pool 9 due to increased trapping pressure (Clark 1981).

Sediment resuspension

95. Turbidity due to resuspension of sediments following passage of a commercial vessel may affect aquatic mammals indirectly through alteration of food supplies in important backwater habitats. On the Upper Mississippi River, tow passage increased turbidity of water entering side channels 5-10 min later (Eckblad 1981); increases were greatest in shallow side channels where wave wash may have resuspended near-shore sediments. Turbidity decreases the depth of penetration of light and therefore affects the distribution and survival of aquatic plants that may be important to wildlife (Bellrose, Paveglio, and Steffect 1979). However, Clark (1981) concluded that small increases in turbidity were unlikely to affect emergents like *Sagittaria*, an important food item of muskrats.

Wave wash

96. Erosion of riverbanks due to wave wash from commercial navigation traffic potentially can impact furbearer populations by destroying burrows or altering vegetation (Upper Mississippi River Basin Commission (UMRBC) Environmental Work Team 1981a), but there is no evidence that this is a significant problem. Clark (1981) found that two areas on pool 9, Upper Mississippi River that differed in exposure to waves did not differ in density or biomass of *Sagittaria*, an important food of muskrats. Instead, *Sagittaria* distribution was related more to water depth. There was also no difference in reproductive performance of muskrats in the two areas (Clark 1981).

Winter conditions

97. Open channels caused by the passage of tows or ships through ice-bound waterways are potential barriers to movement by large and medium-sized mammals. On the St. Mary's River, Michigan, the outlet from Lake Superior, white-tailed deer turned back from recently created ship channels and avoided the slippery new ice that formed when channels refroze (Fuller and Robinson 1982). On the other hand, coyotes and foxes readily crossed refrozen channels as soon as the ice would support their weight. Canids apparently were not deterred by slick ice. Fuller and Robinson (1982) speculated that deer may suffer higher mortality during winter if they are unable to move across shipping lanes to important yarding areas or to escape human disturbance. Some deer may be killed by falls on slippery ice or by drowning after breaking through thin ice (Fuller and Robinson 1982).

Water quality

98. There is no evidence of adverse impacts to mammals as a result of changes in water quality produced by commercial navigation traffic.

Impingement

99. There is no evidence of adverse impacts to mammals as a result of impingement with commercial navigation traffic.

Turbulence

100. There is no evidence of adverse impacts to mammals as a result of turbulence produced by commercial navigation traffic.

Drawdown

101. There is no evidence of adverse impacts to mammals as a result of drawdown produced by commercial navigation traffic.

Auditory/visual disturbance

102. There is no evidence of adverse impacts to mammals as a result of auditory or visual disturbance produced by commercial navigation traffic.

Aquatic Vascular Plants

103. Aquatic macrophytes comprise an integral part of freshwater systems and influence biological, physical, and chemical conditions. They are a dynamic component of the environment, with biomass and areal cover changing seasonally and in response to climatological events. The physical presence of stems, leaves, and roots affects currents, water depth, and deposition and erosion of sediments. Aquatic macrophytes also create structural complexity within habitats by providing refugia and substratum for a wide variety of organisms including phytoplankton, zooplankton, protozoans, macroinvertebrates, and gastropods (Pennak 1953).

104. The increased density and diversity of invertebrates associated with aquatic plants has beneficial effects on fish. Killgore (1979) reported that largemouth bass and other game species were usually concentrated in *Hydrilla* beds located in shallow water. Holland and Lester (1984) found that average catches of northern pike from areas with submersed vegetation were more than 10 times greater than those from sites with no vegetation. Laughlin and Werner (1980) reported that numbers of small-sized longear sunfish and bluegill were positively correlated with height of vegetation and that few adults of either species used areas devoid of aquatic plants. The presence of aquatic vegetation can directly influence fish reproduction. Fish that release their eggs over aquatic vegetation or tree roots include northern pike, carp, goldfish, and golden shiners. While nest builders (sunfishes, largemouth bass, crappie, rock bass, warmouth, bowfin, and most bullheads) sometimes lay eggs on mud, sand, or silt, they usually choose sites with vegetation (Lagler, Bardaih, and Miller 1962).

105. Submersed aquatic plants are a common feature in shallow, slack water habitats associated with large river systems. Plants can be found in protected areas close to islands, in sloughs, mouths of small creeks, as well as lakes and ponds close to shore. Species that are common in large river habitats include *Potamogeton, Elodea, Ceratophyllum, Myriophyllum, Najas, Zannichellia,* and *Vallisneria.* Additional information on aquatic plants in large river systems can be found in Clark and Clay (1985), and Otto and Enger (1960).

106. There have been no specific studies on effects of commercial navigation traffic on submersed aquatic plants. However, possible effects of traffic on aquatic plants can be obtained from knowledge of their life requisites, and data on the physical effects of commercial traffic.

Drawdown

107. Prolonged periods of drawdown (reduction in water levels for several weeks) is used to control nuisance aquatic plants in reservoirs. However, the short period of drawdown caused by a commercial tow (i.e., less than 5 min), is not sufficient to cause any significant damage to aquatic plants. There have been no direct studies on the effects of drawdown on aquatic plants in large rivers.

Wave wash

108. Waves created by commercial vessels can cause elevated suspended solid levels in shallow areas near shore. If this causes a reduction of the photic zone for extended periods of time, then aquatic plants could be stressed. Wave-wash-induced erosion of shorelines could also negatively impact aquatic plants in marginal areas. In addition, wave wash could alter the hydromechanical environment around a plant so as to adversely affect associated organisms. However, there have been no studies on the effects of wave wash on aquatic plants in large rivers.

Turbulence

109. Turbulence created by commercial vessels can cause elevated suspended solid levels in shallow areas near shore. If this causes a reduction of the photic zone for extended periods of time, then aquatic plants could be stressed. Any turbulence that induces erosion of shorelines or a disruption of the substrate would negatively affect plants in marginal areas. In addition, turbulent hydrodynamic forces around a plant could not only impact the structural integrity of a plant, but also the distribution and abundance of associated organisms. However, there have been no studies on the effects of wave wash on aquatic plants in large rivers.

Impingement

110. Since aquatic plants are usually located along shorelines or in shallow areas outside of the navigation channel, it is unlikely that they would be directly damaged by commercial navigation traffic.

Sediment resuspension

111. Turbulence and wave wash created by commercial vessels can cause elevated suspended solid levels in shallow areas near shore. If this causes a reduction in the photic zone for extended periods of time, the aquatic plants could be stressed. Otto and Enger (1960) reported on the effects of suspended sediments on aquatic plants. There have been no studies on the effects of sediment resuspension caused by commercial traffic on aquatic plants in large waterways.

Sedimentation

112. Turbulence and wave wash created by commercial vessels can cause elevated suspended solid levels. If this material settles on aquatic plants their photosynthetic capabilities could be reduced or the plants could be damaged by burial. In addition, any associated or attached organisms could be adversely affected by sediment deposition. Otto and Enger (1960) reported on the effects of suspended sediments on aquatic plants. There have been no studies on the effects of sedimentation caused by commercial traffic on aquatic plants in large waterways.

Winter conditions

113. Aquatic plants die back in the fall throughout most of the United States. Movement of commercial traffic under conditions of ice should have no effect on dormant aquatic plants. There are no published studies available on these effects.

Water quality

114. Although dissolved oxygen levels can decrease following passage of a commercial vessel, these changes have not been shown to negatively affect aquatic plants.

Auditory/visual disturbance

115. This category is not applicable for this group of organisms.

Plankton

116. Plankton represent a diverse group of organisms in fresh water including both plants (phytoplankton) and animals (zooplankton). Plankton are characterized by small (often microscopic) organisms that are either permanent or temporary residents in the water column. Planktonic movement is determined by the direction and velocity of the currents. Some planktonic organisms have a limited capacity for short-term, active movements in the water column. One special group of transient organisms found in the plankton (and considered under a separate discussion) is known as invertebrate drift. These organisms normally reside in the benthos and are either actively or passively dislodged from their habitats into the water column. Another large group of transient planktonic organisms are the larvae of certain fish species. This group of organisms is considered under a separate discussion. The permanent members of the freshwater planktonic community span several trophic levels. The phytoplankton are small, usually single-celled plants. These organisms actively photosynthesize and are confined to the euphotic layers of the water column. Common phytoplankton in large rivers are diatoms, green algae, and blue-green algae (actually not a plant at all, but a primitive cell type related to bacteria). The zooplankton are small, usually simple animals. There are both herbivorous forms that feed on phytoplankton (e.g., cladocerans, copepods) and predators that feed on other zooplankton (e.g., some cladocerans).

Sediment resuspension

117. **Phytoplankton.** The passage of commercial tows and the resulting increases in suspended solids could negatively affect oxygen production by photosynthetic organisms. Dorris, Copeland, and Lauer (1963) found that in the Middle Mississippi River primary productivity was greatest during times of low flow and low turbidity. Swale (1964) and Lund (1969) stated that turbidity from detritus limited phytoplankton productivity in the River Lee. However, it is not known what effect short pulses of increased turbidity (such as those caused by barge passage) have on primary productivity in large waterways. However, the major source of energy for riverine plankton is from organic matter that originates outside the system, such as leaves, twigs, and sediments of terrestrial origin.

118. **Zooplankton.** Increased suspended solids can affect ingestion rates and the percentage of usable food per unit material ingested for zooplankton. Arruda, Marzolf, and Faulk (1983) found that an inorganic suspended sediment concentration of 50-100 mg/L caused a 99-percent decrease in algal carbon ingestion for *Daphnia parvula* and *D. similis*. These data are consistent with those of an earlier study (European Inland Fisheries Advisory Commission (EIFAC) 1964) that reported lowered fecundity at elevated concentrations of suspended kaolinite (82 and 102 mg/L as compared with 39 mg/L). In a related study, McCabe and O'Brien (1983) found that high levels of sediments decreased the fecundity of *Daphnia* sp. However, Arruda, Marzolf, and Faulk (1983) found that suspended sediment with adsorbed organic compounds could be used as a food source. McCabe

and O'Brien (1983) found that for *D. pulex*, increasing concentrations of suspended silt decreased filtering rates from approximately 4 ml/animal/hr to less than 0.3 ml/animal/hr. Using laboratory algal cultures, assimilation efficiencies of *D. pulex* decreased from 80 to 10 percent when the number of cells/ml was increased.

119. Other potential effects of sediment resuspension due to tow passage are two-fold: (a) increased sediment resuspension could lead to a decrease in the euphotic layer, limiting the distribution zone of phytoplankton; and (b) increased suspended material in the water column could decrease the feeding efficiency of filter-feeding zooplankters and decrease the visibility of predacious zooplankters.

Turbulence

120. Gregg and Bergersen (1980) found that the opossum shrimp *Mysis relicta* exhibited increased mortality (up to 50 percent) after 4 days when exposed to increasing levels of turbulence.

Wave wash

121. There is no information available on the effects of wave wash on the plankton in large rivers.

Drawdown

122. There is no information available on the effects of drawdown on the plankton in large rivers.

Sedimentation

123. There is no information available on the effects of sedimentation on the plankton in large rivers. Since sedimentation directly impacts benthic organisms, the effects on the plankton would be minimal or absent.

Winter conditions

124. There is no information available on the effects of sedimentation on the plankton of large rivers.

Water quality

125. There is no information available on the effects of water quality changes on the plankton of large rivers.

Auditory/visual disturbance

126. There is no information available on the effects of auditory/visual disturbance on the plankton of large rivers.

Impingement

127. There is no information available on the effects of impingement on the plankton of large rivers. Although planktonic organisms would routinely encounter the propellers of commercial tows, the extent of actual contact between a planktonic organism and the propeller is unknown. Due to the extremely small sizes of the planktonic organisms, the hydrodynamics of flow around a propeller would affect these organisms in a much different manner than a larger organism (e.g. juvenile or larval fishes). In addition, this would be extremely difficult to study in the field.

Gastropods

128. The freshwater gastropods (aquatic snails and limpets) are a very diverse and ubiquitous group of macroinvertebrates. The class Gastropoda is one of five classes in the phylum Mollusca. The univalve shell is characteristic of the freshwater gastropods. A vast majority of the freshwater gastropods have a spiral (e.g., *Pleurocera, Lymnaea*) or discoidal (e.g., *Helisoma*) shell. In the limpets, however, the shell is in the form of a very low cone (e.g., *Ferrissia*). The shell length of a mature freshwater gastropod ranges from 2 mm to greater than 70 mm. The muscular portion of the snail which protrudes from the shell is known as the foot. The snail uses the foot as a locomotor organ and as an organ of attachment in those habitats having rapid current velocities. Some freshwater snails have external gills (e.g., *Valvata*), but the majority have either internal gills that are specialized folds of the mantle for aquatic respiration or an internal air-filled "lung" which is actually a modified mantle cavity surrounded by a highly vascularized mantle. In those snails with a mantle lung, the edge of the mantle is often elongated into a siphon through which air is obtained at the surface film. The majority of freshwater gastropods are omnivorous grazers. The snails feed on the flora and fauna (known as Aufwuchs) which cover most submerged surfaces such as rocks and plant stems. The snails will frequently feed upon detrital material when it is encountered. The gastropods feed by using a specialized organ known as a radula which is located in the mouth and is similar to a tongue. The radula has a muscular base on which rows of chitinous teeth grow. The snail uses the radula to "rasp" algae and other food materials off a hard surface. The reproductive system varies widely in freshwater gastropods. Many families are hermaphroditic whereas others are dioecious. Some species produce only a few eggs while others can produce hundreds at a time. Generally the eggs are laid in a gelatinous mass which is attached to some substrate surface. The early developmental stages take place within the egg mass, and when the snail leaves the mass it is capable of assuming the adult mode of existence. One family, the Viviparidae, is ovoviviparous and produces well-developed young at birth.

129. Three orders of the Gastropoda are found in North American rivers. The Mesogastropoda includes the families Ampullariidae, Bithyniidae, Hydrobiidae, Viviparidae, Valvatidae, and Pleuroceridae. All except the Valvatidae are dioecious, have an internal gill, and have an operculum (a horny plate attached to the foot which acts as a lid to seal the snail in its shell). The Order Archaeogastropoda, including the family Neritidae, are also dioecious with an internal gill. The Basommatophora, including the families Physidae, Lymnaeidae, Planorbidae, and Ancylidae, are hermaphroditic, have an internal mantle cavity lung, and lack an operculum.

Sedimentation

130. Gastropod populations could be affected by sedimentation associated with navigation traffic. However, many gastropods feed by grazing on Aufwuchs attached to a solid surface such as rocks, logs, or plant stems, whereas bivalves filter particulate material out of the water. Harrison and Farina (1965) found that the eggs of some gastropod species were intolerant of sediment accumulation, and with a total suspended solids concentration of 360 mg/L, the schistosome vector, *Biomphalaria pfeifferia*, did not lay eggs.

Drawdown

131. There is no information available on the effect of drawdown on the gastropods of large rivers.

Wave wash

132. There is no information available on the effect of wave wash on the gastropods of large rivers.

Turbulence

133. There is little information available on the effects of turbulence on the gastropods of large rivers. Way et al. (unpublished manuscript) assessed the distribution of four prosobranch snails in the Ohio River near Mound City, IL. Quantitative samples were taken by SCUBA divers at three sites along a horizontal transect at depths of 2, 4, and 6 m. In addition, measurements of light penetration and current velocity were obtained. Light penetration did not vary significantly between the depth zones, whereas current velocity showed a positive correlation with depth. There was a difference in the depth distribution of the three most abundant of the snails with *Lithasia armigera* density positively correlated with depth, while *L. geniculata* and *Pleurocera canniliculata* densities were inversely correlated with depth. *Lithasia armigera* is heavily armored with spines; *L. geniculata* has a heavy shell but only pustulose ornamentation; *P. canniliculata* has a moderately heavy shell with no ornamentation.

Impingement

134. This topic is not relevant for riverine gastropods.

Sediment resuspension

135. There is no information available on the effect of sediment resuspension on the gastropods of large rivers. A possible indirect impact could arise if sediment resuspension was severe enough to alter the depth of light penetration so that algae and phytoplankton attached to benthic substrates would no longer be able to survive at a given depth. This would indirectly alter the distribution and abundance of those gastropods which rely on Aufwuchs for food.

Winter conditions

136. There is no known impact of navigation traffic under winter conditions on the gastropods of large rivers.

Water quality

137. There is no information available on the effects of navigation-induced water quality changes on the gastropods of large rivers.

Auditory/visual disturbance

138. There is no known effect of navigation-induced auditory/visual disturbance on the gastropods of large rivers.

Bivalves

139. Freshwater bivalve molluscs all belong to the class Pelecypoda, one of the six classes in the invertebrate phylum Mollusca. These organisms are also classified in the group Lamellibranchia. Each name is descriptive, as Pelecypoda or "axe-foot" refers to the characteristic shape of the foot and Lamellibranchia refers to the pair of large feather-like gills used in feeding and respiration by all members of the class. The older name Bivalvia refers to the two valves of the shell with which the clam secretes and in which it lives. All members of the class show a remarkable uniformity in their basic anatomy, and lack the wide range of body morphology found in a group such as the Gastropoda. Three families of freshwater bivalves are commonly found in North American rivers: Unionidae, Corbiculidae, and Pisidiidae. The unionids are the most diverse group with 220-230 species found in a wide variety of riverine habitats. The unionids are the largest of the freshwater bivalves, reaching shell lengths of up to 250 mm (e.g., *Megalonaias gigantea*). The unionids are either monoecious or dioecious, oviparous, and produce a parasitic larvae which develop on a fish host. Depending on the species, unfertilized eggs migrate from the

gonads of the female to the water tubes of all four gills, the outer two gills, or only special parts of the outer gills. Sperm from the male are drawn into the incurrent siphon of a mature female and they pass through the ostia of the gill lamellae and fertilize the eggs in the water tubes. The embryos are retained only for the early developmental stages. The number of embryos present can range from several thousand in the smaller species to more than 3 million in the larger unionids. The embryo develops into a characteristic larval form known as a glochidium. Mature glochidia are released from the female when they are 0.05-0.50 mm in diameter. If the glochidia do not come in contact with the body of a fish within several days, they will die. The glochidia attach to either the gills, fins, or general body surface and subsequently encyst within the host tissue. Some forms are host specific (e.g., *Fusconaia ebena* and skipjack herring); others are capable of infecting several species of fish. The parasitic stage lasts from 10 to 30 days. At the end of the parasitic period, the young mussel breaks out of its cyst, falls to the bottom, and takes up an adult mode of existence.

140. The family Corbiculidae is represented by one species, *Corbicula fluminea*, in the rivers of North America. *Corbicula* was introduced from southeast Asia into the Columbia River drainage system in the 1920's. Since that time, *Corbicula* has become common in all of the major drainages in the United States. *Corbicula* has been characterized as a lotic species which seems to prefer a well-oxygenated, sandy or sandy-gravel substrate. *Corbicula* is smaller than the unionids with adult shell lengths commonly up to 50 mm. *Corbicula* is either a monoecious simultaneous hermaphrodite or a protandric hermaphrodite in which the gonad is at first male but later becomes female. Mature eggs migrate into the inner demibranch where they are fertilized by sperm drawn into the suprabranchial chamber through the inhalant siphon. The fertilized eggs are retained within the inner gill where they undergo the early stages of development. A given inner gill may contain up to several thousand individual larvae in various stages of development. A juvenile form known as a pediveliger is released from the female at a size of approximately 220 m. The juveniles, which do not require a fish host, settle onto the substrate. The young *Corbicula* then secretes a byssal thread by which it attaches itself to some substrate particle and assumes an infaunal existence.

141. The family Pisidiidae is represented by 39 species in three genera (*Sphaerium, Musculium, Pisidium*) in North America. The pisidiids are ubiquitous in freshwater habitats, and one species, *Pisidium casertanum*, is probably the most widespread and common of all freshwater macroinvertebrates. *Musculium transversum*, a common species in large rivers, can reach densities of several hundred thousand per square meter in backwater pools of the Mississippi River. The pisidiids are the smallest of the freshwater bivalves, ranging in adult size from 2 to 25 mm. The pisidiids are simultaneous hermaphrodites and ovoviviparous. Young are brooded in marsupial sacs located on the inner gill. The sacs are outgrowths of primary gill filaments. The young progress through four distinct developmental stages in the marsupium and are eventually released through the exhalent siphon as miniature adults which are capable of assuming the adult mode of existence. This life cycle omits the parasitic larval stage of the unionids and the benthic juvenile stage of *Corbicula*. Because of this ovoviviparous reproductive mode, the number of young produced per individual is considerably less than that produced by either the unionids or *Corbicula*. Typically a mature adult can produce anywhere from 2 to 20 young per brood.

Drawdown

142. There is no information available on the effects of drawdown on riverine bivalves. Studies have shown that different species of unionids have variable responses to aerial exposure. These studies have dealt, however, with exposure caused by seasonal drying of riverbeds in which mussel beds are located. It has been demonstrated that *Corbicula fluminea* can withstand prolonged periods of aerial exposure with little or no mortality. The transient drawdown caused by tow

passage is unlikely to have any effect on riverine bivalves. These organisms can simply "clam up" if temporarily exposed during barge passage.

Sediment resuspension

143. Many authors have suggested that man's activities, including the use of navigable waterways, have had a detrimental effect upon various molluscan species, especially the freshwater bivalves. Several authors (Sparks 1975; Sparks et al. 1979; and Lubinski et al. 1981), have suggested that the decline of unionid molluscs within navigation channels could be the result of navigation traffic. These assertions are based upon perceived habitat preferences of various taxa, and the importance of stable substrate and well-oxygenated water. Personnel in natural resource agencies frequently cite the results of Ellis (1936) who reported that silt accumulations of 0.25-1.0 in. could result in greater than 90 percent mortality among four species of unionids. In the same study it was noted that increased suspended solids resulted in cessation of water pumping and closing of valves for up to 90 percent of the time as opposed to only 50 percent of the time in water with less suspended particulate matter.

144. Recently Payne et al. (1987) have shown in the laboratory that periodic short-term exposure to suspended solids concentrations of 600-700 mg/L will decrease food clearance, respiration, and excretion rates in three unionid species by 26, 59, and 39 percent, respectively. In more stressed situations, individuals stopped feeding and turned to utilization of stored carbohydrate and lipid reserves. This was the first laboratory study to examine the physiological effects of periodic, short-term, sublethal perturbations of suspended sediments on freshwater unionids. Field data from Kat (1982) showed that *Elliptio complanata* from sandy substrates had higher growth rates than did individuals from muddy substrates. Similar data have been reported for marine organisms, where turbidity-induced reductions in organic assimilation have been reported for the bivalve species *Spisula* (Robinson, Wehling, and Morse 1984). Alternately, Kiorboe, Mohlenbwerg, and Nohr (1981) have reported enhanced growth rates among *Mytilus edulis* when exposed to algal cultures containing low concentration of suspended solids (5.0 mg/L) as compared with cultures lacking suspended solids.

145. Way et al. (unpublished) have demonstrated in the laboratory that riverine populations of *Corbicula fluminea* are extremely sensitive to both concentrations of total suspended solids and to suspended particle size. *Corbicula* from three separate river populations exhibited pseudofeces production (an indication of gill overloading) at suspended solids concentrations greater than 25 mg/L. These levels are well above the normal ambient levels encountered in their respective environments (2-20 mg/L). It is possible that increases in suspended solids concentrations due to tow passage could be stressful if levels were above those which induce pseudofeces production. *Corbicula* was also sensitive to suspended particle size, with the filter-feeding rate being inversely related to particle size. *Corbicula* had the highest filter-feeding rates with particle sizes less than 10 m. Scanning electron microscope analyses and mathematical calculations of the gill ultrastructure demonstrated that the ciliary feeding apparatus could efficiently retain only those particles which are less than about 12 m. If the sediments resuspended by tow passage are large particles (greater than 12 m), the filter-feeding apparatus of this clam could be stressed.

Turbulence

146. Concern has been expressed (e.g., Rasmussen 1983) that turbulence could negatively affect growth and survival of freshwater mussels (Unionaceae), a resource with commercial and ecological value. Typically, mussels inhabit channel border areas rather than main navigation channels (Coker et al. 1921); however, physical effects of commercial traffic, while more severe in main channels, also take place in adjacent shallow water.

147. Sustained changes in hydrologic conditions are known to affect pumping and filtration rates of marine lamellibranchs. These molluscs are sensitive to changes in flow (Kirby-Smith

1972; Walne 1972) and to small differences in pressure between the inhalant and exhalent siphons (Hildreth 1976). However, Payne and Miller (1987) determined that juvenile *Fusconaia ebena* were not affected by a 5-min exposure to high velocity flow once per hour, a result directly relevant to evaluating the environmental effects of commercial navigation traffic. Commercial traffic rates in the Upper Mississippi River and Ohio River do not usually exceed one tow per hour. Thus, turbulence caused by routine traffic is not likely to deleteriously affect mussels. Conversely, at sites where barges are fleeted, towboats sometimes work continuously. Potential impacts to mussels by abrupt water velocity changes in fleeting areas need to be evaluated on a site-specific basis.

Wave wash

148. The effects of wave wash probably have little impact on riverine bivalves. Mussel beds are usually located outside the navigation channel.

Impingement

149. This physical effect is only applicable to riverine bivalves in fleeting areas or areas close to barge-loading facilities or docks.

Sedimentation

150. There is no information available on the effects of sedimentation on riverine bivalves. Prolonged periods of sedimentation could have two effects: (a) burial of individual mussels or portions of a mussel bed; and (b) interference with the filter-feeding and respiratory function of the lamellibranch gill.

Winter conditions

151. There is no information available on the impact of navigation-induced effects on riverine bivalves under winter conditions.

Water quality

152. There is no information available on the effect of short-term changes in water quality on riverine bivalves. This effect is probably minimal, however, due to the fact that the bivalves can simply "clam up" during short-term changes in water quality.

Auditory/visual disturbance

153. This topic is not relevant to riverine bivalves.

APPENDIX C: BIBLIOGRAPHY

Aldridge, D., Payne, B. S., and Miller, A. C. 1987. The Effects of Intermittent Exposure To Suspended Solids and Turbulence on Three Species of Freshwater Mussels, *Environmental Pollution*, Vol 45, pp 17-28.

Angino, E. E., and O'Brien, W. J. 1968. Effects of Suspended Material on Water Quality, *International Association of Scientific Hydrology*, Vol 78, pp 120-128.

Battelle Laboratories. 1985. Survey of the Unionid Mollusks of the Ohio River in the Vicinity of the William H. Zimmer Station (Ohio River Miles 442.6 to 445.6), submitted to the Cincinnati Gas and Electric Company, Columbus and Southern Electric Company, and the Dayton Power and Light Company.

Bayne, B. L., Moore, M. N., Willows, J., Livingstone, D. R., and Salkeld, P. 1979. Measurements of the Responses of Individuals to Environmental Stress and Pollution: Studies with Bivalve Molluscs, *Philosophical Transactions of the Royal Society of London*, (Series B), Vol 286, pp 563-581.

Bayne, B. L., Clarke, K. R., and Moore, M. N. 1981. Some Practical Considerations in the Measurement of Pollution Effects on Bivalve Molluscs, and Some Possible Ecological Consequences, *Aquatic Toxicology*, Vol 1, pp 159-174.

Bayne, B. L., and Newell, R. C. 1983. Physiological Energetics of Marine Molluscs, *The Mollusca*, K. M. Wilbur and A. S. M. Saleuddin, eds., Vol. 4, Academic Press, New York, pp 407-515.

Berger Associates, Ltd. 1981a. Analysis of Impact of Navigation on the Tennessee-Tombigbee Waterway, Contract Report for Department of Justice, Washington, DC.

Berger Associates, Ltd. 1981b. Inventory of Potential Structural and Non-Structural Alternatives for Increasing Navigation Capacity - Upper Mississippi River System Plan, Contract Report for Upper Mississippi River Basin Commission, Minneapolis, MN.

Bhowmik, N. G., Demissie, M., and Guo, C. Y. 1982. Waves Generated by River Traffic and Wind on the Illinois and Mississippi Rivers, University of Illinois Water Resources Center Research Report No. 167.

Bhowmik, N., Miller, A. C., and Payne, B. S. Analyzing the Physical Effects of Commercial Navigation Traffic, in preparation, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Bingham, C. R., Cobb, S. P., and Magoun, T. D. 1980. Aquatic Habitat Studies on the Lower Mississippi River, River Mile 480 to 530; Report 4, Diel Periodicity of Benthic Macroinvertebrate Drift, Miscellaneous Paper E-80-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Boyd, W., and Harber, J. G. 1981. Effects of Navigation and Operation/ Maintenance of the Upper Mississippi River System Nine-Foot Channel on Waterfowl Populations, prepared for the Upper Mississippi River Basin Committee, Minneapolis, MN.

Bricelj, V. M., Malouf, R. E., and de Quillfeldt, C. 1984. Growth of Juvenile *Mercenaria mercenaria* and the Effect of Resuspended Bottom Sediments, *Marine Biology*, Vol 84, pp 167-173.

Brown, C. J. D., Clark, C., and Gleissner, B. 1938. The Size of Naiads from Western Lake Erie in Relation to Shoal Exposure, *American Midland Naturalist*, Vol 19, pp 682-701.

Cairns, J. 1968. Suspended Solids Standards for the Production of Aquatic Organisms, *22nd Purdue Industrial Waste Conference, Purdue Engineering Bulletin*, Vol 129, pp 16-27.

Claflin, T. O., Rada, R. G., Smart, M. M., Nielson, D. N., Scheidt, J. K., and Biltgen, B. A. 1981. The Effects of Commercial and Recreational Navigation on Selected Physical and Chemical Variables in Navigation Pool No. 9, Upper Mississippi River, Contract Report to the Environmental Work Team, Upper Mississippi River Basin Commission, Minneapolis, MN.

Claflin, T. O., Rada, R. G., Smart, M. M., Winfrey, M. R., and Peck, J. H. 1982. "The Physical Effects of Commercial Traffic on the Navigable Portion of the Tombigbee River," Contract Report to the Law Firm of Brown, Roady, Bonvillian and Gold, Washington, DC.

Clampett, P. T. 1973. "Substrate as a Factor in the Distribution of Pulmonate Snails in Douglas Lake, Michigan, USA," *Malacologia*, Vol 12, pp 379-399.

Clark, W. R., and Iowa Cooperative Research Unit. 1981. "Assessment of Navigation Effects on Muskrats in Pool 9 of The Upper Mississippi River," report submitted to the US Fish and Wildlife Service and the Upper Mississippi River Basin Commission.

Clarke, A. H. 1982. "The Recognition of Ecophenotypes in Unionidae," *Report of Freshwater Mollusc Workshop, 26-27 October 1982*, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Cline, L. D., Short, R. A., and Ward, J. V. 1982. "The Influence of Highway Construction on the Macroinvertebrates and Epilithic of a High Mountain Stream," *Hydrobiologia*, Vol 96, pp 149-159.

Cook, P., McGraw, D., and Louis Berger and Associates, Inc. 1981. "National Waterways Study Analysis of Navigation Relationships to Other Water Uses," Contract Report for the US Army Corps of Engineers Institute for Water Resources Support Center, Fort Belvoir, VA.

Dietz, A. R., Harrison, R. W., Olson, H. E., Grier, D., and Simpkins, C. 1983. "National Waterways Study - A Framework for Decision Making - Final Report," Report NWS-83-1,US Army Engineer Institute for Water Resources, Water Resources Support Center, Fort Belvoir, VA.

Ecology Consultants, Inc. 1979. "Navigation Effects on the Biological Components of the Upper Mississippi River Aquatic Ecosystem," prepared for the Upper Mississippi River Basin Commission, Minneapolis-St. Paul, MN.

Ellis, M. M. 1931. "Some Factors Affecting the Replacement of the Commercial Freshwater Mussels," *US Bureau of Fisheries*, Vol 1, pp 1-10.

Environmental Science and Engineering. 1981. "Navigation Impact Study, Illinois River, Pool 26, August 1980, Mississippi River, Pool 9, October 1980, Phase III, Task 9," prepared for Illinois Natural History Survey, Grafton, IL.

________. 1988. "Report on the Monitoring Study of Relocated Mussels Near Ripley, Ohio," ESE No. 87-856, submitted to Mussel Mitigation Trust Fund Committee, Columbus, OH, by Environmental Science and Engineering, Inc., St. Louis, MO.

Fuller, S. L. H. 1974. "Clams and Mussels (Mollusca: Bivalvia)," *Pollution Ecology of Freshwater Invertebrates*, C. W. Hart, Jr., and S. L. H. Fuller, eds., Academic Press, New York, pp 215-273.

________. 1978. "Freshwater Mussels (Mollusca, Bivalvia, Unionidae) of the Upper Mississippi River: Observations at Selected Sites Within the 9-Foot Channel Navigation Project on Behalf of the United States Army Corps of Engineers," Academy of Natural Sciences of Philadelphia, PA.

Gardner, W. S., Miller, W. H., III, and Imlay, M. J. 1981. "Free Amino Acids in Mantle Tissues of the Bivalve Amblema Plicata: Possible Relation to Environmental Stress," *Bulletin of Environmental Contaminants and Toxicology*, Vol 26, pp 157-162.

Gradall, K. S., and Swenson, W. A. 1982. "Responses of Brook Trout and Creek Chubs to Turbidity," *Transactions of the American Fisheries Society*, Vol 111, pp 392-395.

Gucinski, H. 1982. "Sediment Suspension and Resuspension from Small-Craft Induced Turbulence," prepared for the US Environmental Protection Agency, Annapolis, MD.

Harmon, W. N. 1972. "Benthic Substrates: Their Effect on Freshwater Mollusca," *Ecology*, Vol 53, pp 271-277.

Holland, L. E. 1983. "Evaluation of Simulated Drawdown Due to Navigation Traffic on Eggs and Larva of Two Fish Species of the Upper Mississippi River," US Fish and Wildlife Service, National Fisheries Research Laboratory, La Crosse, WI.

________. 1986. "Effects of Barge Traffic on Distribution and Survival of Ichthyoplankton and Small Fishes in the Upper Mississippi River," *Transactions of the American Fisheries Society*, Vol 115, pp 162-165.

Horne, F. R., and McIntosh, S. 1979. "Factors Influencing the Distribution of Mussels in the Blanco River of Central Texas," *Nautilus*, Vol 94 pp 119-132.

Jackivicz, T. P., Jr., and Kuzminski, L. N. 1973. "A Review of Outboard Motor Effects on the Aquatic Environment," *Journal of Water Pollution Control Federation*, Vol 45, pp 1759-1770.

Johnson, J. K. 1971. Effect of Turbidity on the Rate of Filtration and Growth of the Slipper Limpet, *Crepidula fornicata* Lamarck, 1799," *Veliger*, Vol 14, pp 315-320.

Killgore, K. J., Miller, A. C., and Conley, K. C. 1987. "Effects of Turbulence on Yolk-Sac Larvae of Paddlefish," *Transactions of the American Fisheries Society*, Vol 116, pp 670-673.

Krumholz, L. A., and Minkley, W. L. 1964. "Changes in the Fish Populations in the Upper Ohio River Following Temporary Pollution Abatement," *Transactions of the American Fisheries Society*, Vol 93, pp 1-5.

Liou, Y. C., and Herbisch, J. B. 1977. "Velocity Distribution and Sediment Motion Induced by Ship's Propeller in Ship Channels," *Proceedings, Hydraulics in the Coastal Zone, ASCE*, College Station, TX.

Loosanoff, B. L., and Tommers, F. D. 1948. "Effect of Silt and Other Substances on Rate of Feeding Oysters," *Science*, Vol 107, pp 69-70.

Lubinski, K. S., Wallendorf, M. J., and Reese, M. C. 1981. "Analysis of Upper Mississippi River System Correlations between Physical, Biological, and Navigation Variables," Upper Mississippi River Basin Commission, Grafton, IL.

Moore, P. G. 1977. "Inorganic Particulate Suspensions in the Sea and Their Effects on Marine Animals," *Annual Reviews of Oceanography and Marine Biology*, Vol 15, pp 225-363.

Nielsen, L. A., Sheehan, R. J., and Orth, D. J. 1986. "Impacts of Navigation on Riverine Fish Production in the United States" *Polskie Arcdhiwum Hydrobiologia*, Vol 34, pp 277-294.

North Star Research Institute. 1973. "EIS of the Northern Section of the Upper Mississippi River, Pool 2," Final Report, US Army Engineer District, St. Paul, MN.

Payne, B. S., Miller, A. C., and Aldridge, D. W. 1987. "Environmental Effects of Navigation Traffic: Laboratory Studies of the Effects on Mussels of Intermittent Exposure to Turbulence and Suspended Solids," Technical Report EL-87-14, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Pitlo, J., Jr. 1987. "Standing Stock of Fishes in the Upper Mississippi River," Upper Mississippi River Conservation Committee, Rock Island, IL.

Rada, R. G., Smart, M. M., Claflin, T. O., Biltgen, B. A., Nielsen, D. N., and Scheidt, J. K. 1980. "A Characterization of Navigation Pool No. 9, Upper Mississippi River, and Site Selections to Determine Impacts of Commercial and Recreational Navigation," prepared for the Upper Mississippi River Basin Commission, Minneapolis, MN.

Rasmussen, J., and Harber, J. G. 1981. "Effects of Navigation and Operation/Maintenance of the Upper Mississippi River System Nine-Foot Channel on Commercial Fish and Fishing," prepared for the Upper Mississippi River Basin Commission, Minneapolis, MN.

Salmon, A., and Green, R. H. 1983. "Environmental Determinants of Unionid Clam Distribution in the Middle Thames River, Ontario," *Canadian Journal of Zoology*, Vol 61, pp 832-838.

Saunders, H. E. 1975. "Hydrodynamics in Ship Design; Volume II," Society of Naval Architects and Marine Engineers, New York.

Sickel, J. 1980. "Correlation of Unionid Mussels with Bottom Sediment Composition in the Altamaha River, Georgia," *American Malacological Bulletin*, Vol 5, pp 10-13.

Sorenson, R. M. 1973. "Water Waves Produced by Ships," *Journal of Waterways, Harbors and Coastal Engineering Division*, ASCE 99 (WW2). pp 245-256.

Sparks, R. E., and Blodgett, K. D. 1985. "Effects of Fleeting on Mussels," report to the Illinois Department of Conservation," Aquatic Biology Technical Report 1985 (8), of the Illinois Natural History Survey.

Starrett, W. C. 1972. "Man and the Illinois River," *River Ecology and the Impact of Man*, R.T. Oglesby, C. A. Carlson, and J. A. McCann, eds., Academic Press, New York.

Stevenson, R. J., Mollow, J. M., Peterson, C. G., and Lewis, J. L. 1986. "Laboratory Simulation of Navigation Traffic Physical Effects on River Plankton," report submitted to the US Army Engineer District, Louisville, KY.

Suloway, L. 1981. "The Unionid (Mollusca: Bivalvia) Fauna of the Kankakee River in Illinois," *American Midland Naturalist*, Vol 105, pp 233-239.

US Fish and Wildlife Service. 1986. Draft Fish and Wildlife Coordination Act Report for: Lock and Dam 26 (Replacement) Second Lock Environmental Impact Statement, Ecological Services Field Office, Rock Island, IL.

Van der Schalie, H. 1941. "The Taxonomy of Naiades Inhabiting a Lake Environment," *Journal of Conchology*, Vol 21, pp 246-253.

Widdows, J. 1978. "Physiological Indices of Stress in *Mytilus edulis*," *Journal of the Marine Biological Association*, Vol 58, pp 125-142.

Widdows, J., Fieth, P., and Worral, C. M. 1979. "Relationship Between Seston, Available Food and Feeding Activity in the Common Mussel *Mytilus edulis*," *Marine Biology*, Vol 50, pp 195-207.

Wilber, C. G. 1983. "Turbidity in the Aquatic Environment," Charles C. Thomas, Springfield, IL.

Wright, T. D. 1982. "Potential Biological Impacts of Navigation Traffic," Technical Report E-82-2, US Army Waterways Experiment Station, Vicksburg, MS.