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INFORMATION SUMMARY OF THE PHYSICAL, CHEMICAL, AND BIOLOGICAL EFFECTS OF NAVIGATION

Submitted to:
The Environmental Work Team
Master Plan Task Force
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INTRODUCTION

This report was prepared as the first part of a review of the currently available information relating to the physical, chemical, and biological effects of the navigation system on the Upper Mississippi River. It is essentially a summary of available information, but also includes a section on information gaps, an expanded version of which will be the heart of the second part of this review. The overall purpose of the two-part review was to provide an assessment of both the available and needed information which will be required to make rational decisions regarding conflicts between navigation interests and other uses of the Upper Mississippi River System (UMRS). The second part of this review will include specific sections on areas of the UMRS susceptible to impacts, state-of-the-art impact measurement, and expanded sections on information gaps and priorities.

Comments from interested agencies on the review draft of this report were received and incorporated in the report, either through modifications of the original text or by including the comments directly as quotations which are highlighted in bold print.

Objectives

There were two objectives to this project. The first was to compile available information applicable or related to the physical, chemical, and biological effects of navigation and the second was to prepare this summary report, including a matrix display of effects, a section on information gaps, and an annotated' bibliography.

Scope

In order to initially cover as many sources of information regarding navigation effects as possible, we investigated literature on river, open water, freshwater, and marine systems both In this country and abroad. Because of the anticipated specific application of this report to the Upper Mississippi River System, however, many of the references that were related to estuarlne or marine systems have been omitted from this report for lack of relevance. Some articles were included because they present basic theories or state-of-the-art discussions. For example, there is extensive literature on vessel-generated waves, but only a few articles relate directly to barge tows in inland waterways. Articles describing similar effects in other types of waterways were often included because the physical and chemical interactions were transferable or provide a basis for specific study needs in the UMRS. A few articles were included because they were the only available reference on a topic. An example is Yousef et al. (1978) on outboard motor boats.

The general types of navigation effects considered here included those related to pool construction, maintenance and operation, and boat traffic. Two specific areas of concern, in terms of their environmental effects, were indirectly connected with this study but could easily support their own specific and exhaustive literature reviews. These included stream channelization and dredging. These effects were discussed as they specifically relate to the Upper Mississippi River System rather than on a general basis. Dredging and project construction were not included in the computer searches, but were added later using articles and reports available to the authors.

DATA BASES

The Illinois State Water Survey was responsible for compiling and summarizing the information relating to the physical and chemical effects of navigation, while the Illinois Natural History Survey was responsible for the biological information.

Two approaches were used in compiling the information. The first approach was to conduct computer and manual searches of several information data bases using various keyword combinations. Table 1 summarizes the data bases searched for physical and chemical navigation effects and Table 2 outlines the keyword combinations and strategies used for each. Table 3 summarizes the data bases searched for biological navigation effects and Table 4 outlines the biological terms and strategies. In addition to a computer search (COMPENDEX), a manual search for physical and chemical navigation effects was made on the Engineering

Table 1. Computer data bases used for assessing physical and chemical navigation effects.

Data Bases Searched	Items Retrieved	Items Considered Relevant after Review	Time Period Covered
COMPENDEX	28	11	1970-1980
NTIS (National Technical Information Service)	47	0	1970-1980
WRSIC (Water Resources Scientific Information Center)	693	100	1967-1980
Total	740	111	

Table 2. Physical and chemical navigation effects search terms and strategies.

Terms		Search Strategy
WRSIC SEARCH TERMS		
1. Barges Navigation Rivers Waterways	4. Waves 5. River regulation River training	1 and 2 1 and 3 1 and 5 3 and 4 6 and (1 or 2 or 3)
2. Sediment load Suspended sediment Suspended sediments	6. Illinois River Missouri River Ohio River Upper Mississippi River	
3. Bank erosion Channel erosion		
NTIS SEARCH TERMS		
1. Bank erosion Barges Navigation Sediment Training Waves	Missouri River Ohio River River Rivers Waterway Waterways	1 and 2 and 3
2. Illinois River Mississippi River	3. Effects	
COMPENDEX SEARCH TERMS		
1. Bank erosion Barges River training Sediment Suspended sediment Waves	Missouri River Ohio River River Rivers Waterway Waterways	1 and 2 and 3
2. Illinois River Mississippi River	3. Effects	

Table 3. Computer data bases used for assessing biological navigation effects.

Data Bases Searched	Items Retrieved	Items Considered Relevant after Review	Time Period Covered
Aquatic Science Abstracts	52	0	1975-1980
BIOSIS	576	45	1970-1980
BOOK	9	0	not applicable
DISS	13	0	1975-1980
Enviroline	32	0	1971-1980
NTIS	267	6	1970-1980
Scisearch	1	0	1974-1980
WRSIC	44	5	1967-1980
Total	946	56	

Table 4. Biological navigation effects search terms and strategy.

Terms		Search Strategy
1. Barge	Diversity	1 and 2 and 3
Barges	Endangered species	
Boat	Ephemeroptera	
Boats	Fish	
Construction	Fish fry	
Dam	Fish larvae	
Impoundment$*	Fishes	
Levee	Flies	
Locks	Fungi	
Naviga$	Insect	
Reservoir$	Insecta	
Wave	Invertebrate$	
Waves	Mayflies	
	Mayfly	
2. Freshwater	Microbial	
Limnology	Mollusca	
Mississippi River	Mussel$	
River	Mytilus	
Rivers	Muskrat	
Waterways	Odonata	
	Oligochaeta	
3. Algae	Periphyton	
Anisoptera	Plankton	
Anodonta	Plant	
Aquatic insects	Plants	
Bacteria	Sphaerids	
Beaver	Telemet	
Benthic	Threatened species	
Benthos	Trichoptera	
Biomass	Turbidity	
Chironomid	Vegetation	
Clams	Worm	
Damselfly	Zygoptera	

*The truncation feature ($) of each data base was used to search the various forms of the word (plural or single).

Index for the period 1950-1970. In addition, a citation index was searched for the authors of several important articles in each of the subject areas used In this review.

The search strategies in Tables 2 and 4 are best explained by an example. In Table 2, the first strategy in the WRSIC search identified any article with a keyword from Group 1 and a keyword from Group 2. The last strategy used in the WRSIC search identified articles in Groups 1,2, and 3 which dealt with one of the four rivers in Group 6.

The second approach used in compiling the available Information was to review previously published or compiled bibliographies and articles relating to navigation effects and the Upper Mississippi River. The articles and bibliographies listed below contributed substantially to the total available information.

Articles or reports:

Upper Mississippi River Basin Commission. Draft report on the Upper Mississippi River Main Stem Level B Study; June 1980; 132 p.

Ecology Consultants, Inc. Navigation and the Environment, Upper Mississippi River Main Stem Level B, Technical Paper D; 1979.

Great River Environmental Action Team. Draft fish and wildlife management work group appendix. Great II Upper Mississippi River (Guttenburg, Iowa to Saverton, Missouri); May 1980 draft.

U.S. Army Engineer Division, North Central. Summary report of fish and wildlife habitat changes resulting from the construction of a nine-foot channel in the: upper Mississippi River, Minnesota River, St. Croix River, Illinois Waterway. Chicago, IL: U.S. Army Engineer Division; 1978.

Institute for Water Resources. Analysis of Environmental Aspects of Waterways Navigation, Review Draft. Water Resources Support Center, Fort Belvoir, VA; 1980.

Bibliographies:

Helm, D.R. and T.L. Boland. Upper Mississippi River Natural Resources Bibliography. Fish Technical Section, Upper Mississippi River Conservation Committee; 1972.

Hazelton Environmental Corporation. Great II - Fish and Wildlife Management Work Group Annotated Bibliography, volumes I and II; 1979.

Environmental Effects Laboratory. Bibliography for navigation pools 24, 25, and 26, Upper Mississippi and Lower Illinois Rivers. Vicksburg, MS: U.S. Army Waterways Experiment Station; n.d.; 82 p.

Sparks, R.E. Bibliography of publications relating to Lock and Dam 26, Waterways Experiment Station, Turbidity and Navigation Effects, the Mississippi River, and the Illinois River. Photocopied memo to Pool 26 research team. Havana, IL; 1980.

Rasraussen, J.L., ed. A compendium of fishery information on the Upper Mississippi River. A Contribution of the Upper Mississippi River Conservation Committee. 2nd ed; 1979.

Single page reference descriptions were compiled for the articles identified by the above approaches. Each reference description included the bibliographic citation of the reference [following the format of the Council of Biological Editors (Council of Biology Editors 1978)]; a direct copy of the article's abstract and summary (if available) and a short description of the location and availability of the full reference. After reviewing these reference descriptions, the principal investigators identified those which warranted full retrieval.

NAVIGATION EFFECTS SUMMARY

Effects Related to Pool Construction, Operation, and Maintenance

The River and Harbor Act of 3 July 1930 authorized the construction and maintenance of a 9-foot-deep by 300-foot-wide channel for commerical navigation of the Upper Mississippi and Lower Illinois rivers. The channel geometry was achieved through the construction of locks and dams supplemented by dredging and bank stabilization (Solomon et al. 1975:7). Prior to this period, 4.5- and 6-foot navigation channel projects on the Upper Mississippi River system had been achieved through the construction of wing and closing dams and by dredging (Rasmussen 1979:3-4).

POOL CONSTRUCTION

Effects related to pool construction include those caused by the locks and dams on the Upper Mississippi River system, and wing and closing dams. Wing and closing dams as defined here include structures designed primarily to increase depth and flow in the main channel and include those structures described by Simons et al. (1976:25) as "dikes" and "jetties." Structures oriented parallel to the channel and generally used to stabilize already existing banks (revetments, rip rap berms, or retards) are discussed later under POOL MAINTENANCE AND OPERATION.

Lock and Dam Construction

Physical Effects. The locks and dams above St. Louis, Missouri on the Upper Mississippi River have been in operation since 1940. Their overall effect was to change the river from a free-flowing stream into a series of pools. While numerous local impacts such as increased turbidity and habitat destruction probably occurred during construction, these were considered temporary and beyond the scope of this summary. For a review of these effects, see Institute of Water Resources (1980).

A major effect of pool construction was a decrease in current velocities. Forbes and Richardson (1920:xi, xii) reported that the Illinois River's usual rate of flow for ordinary stages varied from 1.8 to 3.7 feet per second. As a result of higher dams associated with the nine-foot channel and reduced diversion from Lake Michigan, the current velocity is now only about 0.9 feet per second at ordinary stages. Solomon et al. (1975:67) indicated that on the Mississippi at low and intermediate river flows, pool levels are held above the natural level by the dams, resulting in decreased flow velocity. Carlander (1954: 21) also indicated the current in most of the Mississippi River from St. Paul, Minnesota to Alton, Illinois had been greatly reduced because of the dams. Stefan and Anderson (1980) investigated the effects of wind on currents and fluxes in a backwater lake and found significant changes in circulation caused by wind.

Such decreases in velocities usually result in lower suspended solids concentration in the main channel and increased sedimentation rates in off- channel areas. These generalizations, however, do not hold in all reaches or habitats of the Upper Mississippi River system or at all flow rates. Sparks et al. (1979) reviewed the literature relating to turbidity levels and suspended solids concentrations in the Upper Mississippi and Illinois Rivers. They noted that: (1) increasing silt loads were recognized as a major problem in the Upper Mississippi River system as early as 1930; (2) downstream increases in turbidity had been observed for both rivers; and, (3) turbidity usually increased with increasing water levels. They also noted substantial increases between pre- and post-impoundment turbidity levels in the Illinois River and that "the scant data available indicate that turbidity has increased in the Mississippi River, although this increase in not as great as in the Illinois River." (Sparks et al. 1979:143).

Sparks et al. (1979) also noted the difficulties in making pre- and post-impoundment comparisons of river turbidity levels that were caused by changes in agricultural and other land use practices during the same time period.

McHenry et al. (1976:1348) found that, as a result of lock and dam construction, sediments were accumulating at an average rate of 2.5 cm per year in selected areas between Pools 3 and 10 of the Mississippi River. Most of the sediment deposition occurs in the downstream portion of the pool, where the current is the slowest. McHenry et al. (1975) has estimated the life expectancy of Upper Mississippi River backwaters to be from 50-200 years if present sedimentation rates continue. Lee and Stall (1976, 1977) measured sedimentation rates in 15 backwater lakes along the Illinois River. They found average sedimentation rates to be 0.8 to 1.3 cm per year.

Eckblad et al. (1977:433) found that the sedimentation rate between 1964 and 1974 of Big Lake on Pool 9 of the Mississippi River was 1.7 cm/year and using two data sets estimated the "life span" of the lake to be 43 and 61 years (p. 441), respectively. Similar information is available for backwater lakes of the Illinois River (Stall and Melsted 1951, Jackson and Starrett 1959, Sparks et al. 1979, Bellrose et al. 1979). In addition, Bellrose et al. (1979) discussed the direct relationship between water depth and sedimentation rates. Based upon such information, the North Central Division of the U.S. Army Corps of Engineers (1978:page b of summary) stated that:

> The impoundments have increased the rate of accumulation of sand and silt in the river, because the pools, specifically the side channels, sloughs, lake and ponds, and marshes, act somewhat as sediment traps and decrease the ability of the river to transport sand and silt downstream. It is generally accepted that the pools are gradually filling with sediment, resulting in attendant losses of water surface, fish and wildlife habitat, and boating areas.

In the main channel and main channel border areas of the pools, longitudinal differences in sediment aggradation and degradation rates exist (Simons et al. 1976:68-70). Solomon et al. (1975:20) noted that at low or intermediate flows erosion occurs in upper reaches of Pools 24, 25, and 26, while deposition occurs in lower reaches. However, they also noted that this trend was reversed during high flows:

> In contrast, control gates are fully opened during high-volume flows and flow conditions approach those of the natural river. Deposition occurs in each upper pool area (eroded during low flow), and erosion occurs in each lower pool area (aggraded during low flow).
>
> These erosion-deposition cycles, attributable to the existence and operation of the locks and dams, recur yearly. Shallow river crossing areas in a pool accumulate a slightly larger amount of sediment during the deposition phase of the cycle than they lose during the erosion phase. Conversely, deep reaches of the pools undergo a net deepening over the cycle. Thus, shallow upstream ends of each pool are aggrading, and deeper downstream areas are degrading.

According to Chen and Simons (1979), long term effects of pool construction have been an increase in island development upstream of locks and dams in addition to the silting of backwater lakes and marshes.

The temperature regime of a stream can be greatly altered by impoundment. Ward and Stanford (1979:42) grouped thermal modifications into six groups: (1) increased diurnal constancy, (2) increased seasonal constancy, (3) summer depression, (4) summer elevation, (5) winter elevation, and (6) thermal pattern changes. However, no comparative pre- and post-impoundment data related to water temperature in the UMRS were found.

Initially, the construction of the high locks and dams resulted in dramatic increases of approximately 125,000 acres in the total river bed surface area of the Upper Mississippi River and in 6,100 acres for the Illinois Waterway (U.S. Corps of Engineers 1978:pages a, c, and g). Sedimentation since the initial inundation has resulted in a loss of approximately 3,500 acres in the LaGrange and Peoria pools of the Illinois Waterway (U.S. Corps of Engineers 1978:page g). A discussion of the habitat changes related to these gains and losses is included in the following section on biological effects.

Chemical Effects. Sparks et al. (1979:133) stated that "From a comparison of available pre- and post—construction dissolved oxygen data, it appears that the nine-foot navigation system has had no measurable effect on this water parameter." They also stated (p. 137) that, due to a lack of early data, it was impossible to evaluate the effects of impoundment on river nutrient quality.

Biological Effects. The aquatic and terrestrial habitat changes that resulted from the construction of locks and dams on the Mississippi and Illinois rivers were summarized by the U.S. Army Corps of Engineers (1978). Inundation resulted in the conversion of approximately 125,000 acres of terrestrial habitat to aquatic habitat in the Mississippi River and likewise approximately 6,100 acres in the Illinois Waterway. More detailed studies of habitat changes in Pools 5-10 were provided by the GREAT I Sediment and Erosion Control Work Group (1980). Habitat changes generally benefited aquatic populations but simultaneously restricted terrestrial populations.

Numerous changes in the flora and fauna of newly impounded reaches of streams have been reported (Spence and Hynes 1971a, 1971b). Unfortunately, most case histories of impoundments deal with flood control reservoirs on much smaller streams than the Mississippi River. However, some trends identified in these systems are similar to those observed on the UMRS. Generally, lentic species are selected for and lotic species are selected against and may be eliminated.

Plankton densities are usually inversely related to velocities in riverine systems (Kofoid 1903) and thus probably increased after impoundment, especially in backwater habitats. Waite (1980) noted a shift from lotic to lentic species of zooplankton in the Illinois River that may have been related to impoundment. Softer substrates associated with slower currents favor burrowing organisms, e.g., Chironomidae, Oligochaeta, and Ephemeridae, and may eliminate substrate surface dwellers. Sparks (1977) reviewed the effects of sedimentation and found that communities could be altered by being smothered, having habitats destroyed, and impairing prey finding ability. Isom (1969) and Starrett (1971) attributed the loss of 50% of the mussel species from two river basins partially to sedimentation created by dams. In contrast, fingernail clam populations in certain areas within the lower section of Pool 19, Mississippi River may be increasing due to the aggradation of silt deposits above the dam (Sparks 1980, personal communication).

Fremling (1974) stated that "as a result of broadening the river, increasing its surface area, corrugating it, and supplying nutrient to it, we probably have more fish per linear mile in the Upper Mississippi River, below Lake Pepin, than we did before the white man arrived." The following are specific Mississippi River fisheries impacts related to pool construction (U.S. Corps of Engineers 1978):

> Prior to contruction of navigation dams, the fast moving current of the main channel created habitat conditions that supported good populations of such species as sturgeon, blue sucker and paddlefish. Probably the most productive of aquatic habitats, channel borders with the associated regulatory works provided excellent habitat for walleye and channel catfish. Although side channels under pre-pool conditions provided good habitat for many species, the over-all quality was dependent upon flow conditions. Many river lakes and ponds, while providing good habitat for bullheads, bass, bluegill and crappie, were subject to drying up almost annually. The loss of a portion of these backwater fishes added to the rejuvenation of the fishery and often times increased the quality of the fishery. However, the Upper Mississippi River has always supported a high standing crop and great diversity of fish species.
>
> Habitat elements did change because of the navigation structures. Tailwater habitat created by the locks and dams is somewhat similar in character to natural river rapids, although tailwater habitat is different because of the deep scour holes below the locks

and dams. Available food source and fast, highly oxygenated water are among the factors that make tailwater areas excellent habitat for walleye, sauger, paddlefish and catfish.

The GREAT II Fish and Wildlife Management Work Group (1980) stated that:

> . . . Discounting all strays, there are 81 species that historically or presently characterize the Mississippi in the GREAT II reach. Out of these 81 species, two no longer oecur, and seven are considered rare. Impacts from construction and maintenance of the nine-foot navigation channel may have been detrimental to three of the nine absent or rare species. The blue catfish was collected historically as far north as Lynxville, Wisconsin, (Pool 9) but was not common above Keokuk (Pool 19) according to Coker (1919) who stated that dams blocked movement of this migratory fish. Since the blue catfish still occurs in the unpooled river downstream of the GREAT II stretch, it is obvious that the navigation dams are partly or wholly responsible for its disappearance from the pooled section of the river. Pflieger (1975) states the lake sturgeon was once abundant, but was overfished before 1900, drastically reducing populations that were further hurt by construction of the dams which blocked spawning migrations and increased siltation. The rock bass prefers gravel river bottoms and the reduction of gravelly areas due to the dams' slowing of river current and increasing siltation, is suspect in their decline. . .

The degree to which locks and dams affect fish migration patterns is dependent on the timing, magnitude and duration of floods which enable fish to circumvent these barriers. Hubley (1961:8) reported that the locks and dams were not barriers to channel catfish movements in the upper Mississippi River from Bay City, Wisconsin to Lansing, Iowa. Underhill and Eddy (1974) indicated that the American eel has declined drastically in the Upper Mississippi River system due to the navigation dams and possibly pollution, and that although paddlefish have declined, their decline is due more to pollution than to the navigation dams. Their decline may also have partially been caused by overharvesting (GREAT I, Fish and Wildlife Management Work Group 1979:255). Also, the U.S. Corps of Engineers (1978:5-21) summarized Underhill and Eddy (1974) as follows: "Movements of the white bass, walleye, and the freshwater drum have also been restricted by the dams, but such species have adapted by changing migration habits."

In addition to interrupting some fish migration patterns, the life cycles and distributions of some mussels, which have larval forms that are parasitic on fish, have probably been changed (U.S. Corps of Engineers 1978:5-22).

The U.S. Corps of Engineers (1978:5-25) also noted changes in aquatic plants, waterfowl, and mammals that were related to pool construction. They specifically noted that inundation probably reduced the low-flow drying periods of marshes which earlier helped "rejuvenate" the marsh soils. Many coontail-elodea (submergent plant) associations were replaced with pondweeds after inundation (Green 1960) and some Phragmites sp. stands in Pools 5 and 8 "are now gone because they must get dry now and then" (Green 1977). Yeager (1949:54-57) reported on the conversion of bottomland timber acreage to marsh after inundation. In general, aquatic furbearing animals increased in the Upper Mississippi River system after inundation but dryland furbearers decreased (Green 1960). In addition, waterfowl increased remarkably, but upland game birds decreased (Green 1960).

Wing and Closing Dams

Wing and closing dams have been used along the Upper Mississippi River since the late 1800's to divert flow from lateral areas to the main channel. Wing dams usually occur in main channel border areas singly or in combination, and closing dams extend completely or partially across the upstream openings of side channels or backwater areas. Both types of dams have been constructed of various materials; however, recently they have been constructed more of rocks than woodpilings and brush. These dams have been constructed in both the pooled and non-pooled sections of the Upper Mississippi River System. These dams vary in height, length and configuration depending on site specific requirements for diverting flow.

Physical Effects. The principal physical effect of wing dams is to concentrate flow in the main channel. As main channel areas are narrowed by wing dams, greater volumes of water are forced through smaller spaces and the potential for scouring becomes greater. Rasmussen (1979) reported that some unpooled sections of the river are 11 feet deeper than before construction of training dams. As greater volumes of water are carried in the main channel, velocity in other areas decreases. Reduced flows in the main channel border areas may result beneficially in locally decreased bank erosion but adversely in increased sedimentation rates in these areas and the resultant loss of water surface area (Funk and Robinson 1974, Lovejoy and Kennedy 1979). In connection with these effects, Rasmussen (1979:7) estimated that "at completion of the Corps' present project (i.e. reducing channel width to 1500 feet) the river will have been narrowed 40% and reduced in surface area by 22,242 acres since 1881." Similarly, Mueller (1977) stated that "since 1888, approximately 45 square miles or one-third of the surface area of the Middle Mississippi River has been converted to dry land."

Another effect of the U.S. Army Corps of Engineers wing dam construction programs has been to fix the position of the main channel in the river bed (Solomon et al. 1975:16). Noting this, Sparks (1978, in U.S. Army Corps of Engineers 1978:g) stated that: "If the present trends continue, the Upper Mississippi could gradually become a main channel bordered by terrestrial habitat, rather than shallow lakes, marshes, and backwaters."

Depending on their heights, configurations and angle to the shoreline, wing dams can result in either increased or decreased bank erosion in the vicinity of the dam or on opposite shorelines (Ecology Consultants, Inc. 1979:3, Rasmussen 1980).

Wing dams increase the available substrate-water surface area and increase substrate diversity in the river. The biological consequences of these effects will be discussed in the biological effects section. The GREAT II Fish and Wildlife Management Work Group (1980:124) has initiated a project to investigate the potential beneficial effects of notching wing dams.

The physical effects of closing dams are similar to those of wing dams except that they are exerted more in backwater areas where flows have decreased, and sedimentation rates have increased. Long-term decreases in backwater surface areas can result from these conditions. The magnitude of these impacts is directly related to the degree of flow loss in these areas and therefore also dependent on the height and length of the wing dam and its efficiency in blocking normal flow. Rasmussen (1980) and Kennedy (1980) have commented on the importance of wing dam heights (in relation to normal pool levels) in determining their biological impacts. Both emphasized that emergent wing dams are much more detrimental to aquatic habitats. In addition, Rasmussen (1980) noted that in some cases closing structures can actually extend the life of backwaters, presumably by preventing the input of sediment laden water into these areas, but that "closing structures at both the upstream and downstream ends of side channels can hinder the interchange of nutrients and biological organisms with the main river system, restrict recreational aecess and cause increased mortality during depressed oxygen periods."

These effects have encouraged several backwater rehabilitation projects on the Mississippi River (Fremling et al. 1979, Claflin 1976, Claflin 1979, Claflin and Rada 1979) and the development of a regression model to assess the causative factors related to the problem (Claflin and Rada 1979).

Chemical Effects. Although the chemical effects of wing and closing dams are similar they are more pronounced for closing dams which greatly reduce flow rates into side channel and backwater areas. This reduction in flow permits the aggradation of fine silt and detritus in these areas (GREAT II Fish and Wildlife Management Work Group 1980). Since the organic content of these substances is generally higher than that of coarser sediments, they exert a considerable amount of demand on the oxygen resources of the water flowing through these areas. Daytime oxygen production by macrophytes and algae in the areas can offset this oxygen demand, but in shallow backwaters with few macrophytes, water turbulence can resuspend the fine sediments, thus increasing turbidity and limiting oxygen production. Nighttime respiration of aquatic organisms can reduce oxygen concentrations to critical levels if enough flowing oxygenated water does not pass through the area. The recognition of these chemical effects of closing dams has at least partially resulted in cooperative efforts to rejuvenate some backwater areas (GREAT II Fish and Wildlife Management Work Group 1980:20, Fremling et al. 1979).

The buildup of fine sediments in some backwater areas has been accompanied by an accumulation of toxic materials which are adsorbed on the sediments (Mathis and Cummings 1973, Sparks 1977). Colbert et al. (1975:46-47) reported data on concentrations of metals, PCB's, and pesticides in the Illinois and Mississippi rivers, but relatively little is known about the bioavailability or long term biological consequences of such accumulation, even at local levels.

Biological Effects. The biological effects of wing and closing dams have been both detrimental and beneficial. The detrimental effects of wing and closing dams have been long-term in nature and related primarily to their influence on increased sedimentation rates in main channel border and backwater areas (Funk and Robinson 1974, Rasmussen 1979) and the resulting loss of aquatic habitat. Backwaters represent the most productive areas of the Upper Mississippi System. These areas produce tremendous quantities of macrophytes, plankton, and macro-invertebrates. They serve as reproductive and feeding areas for valuable fish and wildlife resources. The organic resources produced in backwaters are an important energy input that helps to drive the entire biological system of the entire Mississippi River. Thus, any impact on their well-being, such as training-dam induced sedimentation, is a serious threat to biological resources in the entire system. Not only are standing crops within backwaters limited by sedimentation, but the reproductive potential of backwater species is reduced due to reduced fitness of populations and physical interferences with reproduction (e.g., sediment covering spawning beds or smothering organisms (Sparks 1977)).

The beneficial effects of wing and closing dams have been to add to the substrate and benthic diversity of the Upper Mississippi River especially in those areas where flow rates are suitable for productive and diverse benthic communities. Not all of the wing and closing dams constructed to date provide this substrate diversity. A study of wing and closing dams along the Iowa border revealed that 32.6 percent of them had been covered over with sediments and that 3.8 percent had been removed by the U.S. Army Corps of Engineers (GREAT II Fish and Wildlife Management Work Group 1980:124).

The structures that have not been covered with sediment form a stable substrate with a high surface to volume ratio, provide important interstitial space, and serves as a catchment for detritus. Thus, these structures provide food and protection of organisms and exhibit high primary and secondary production

(Kallemeya and Novotny 1977). The high amount of stable surface area and occasionally increased light penetration due to the shallow heights of some wing dams provide ideal habitat for periphyton. The periphyton food source, deposited detritus, associated bacterial communities, and surface area provides a habitat that is typically high in secondary production. The macroinvertebrates present generally include all trophic types, i.e., shredders and collectors (filter feeders) to scrapers and predators (Cummins 1973).

The protection and food resources provided by these structures attract certain species of fish. However, the GREAT II Fish and Wildlife Management Work Group (1980:23) concluded:

> Despite the benefits some of these structures have for aquatic animals, overuse of such structures would cause channelization • which significantly impacts the fishery (Lund 1976, . . ., Sport Fishing Institute 1971, Schneeberger and Funk 1971).

The impacts of wing dams in decreasing side channel habitats in the unpooled reach of the Mississippi River between St. Louis, Missouri and Cairo, Illinois has been addressed by Boyd and Janecek (1981).

POOL MAINTENANCE AND OPERATION

The navigation effects discussed in this section include: water level regulation, bank stabilization, winter navigation, and dredging and channelization. Bank stabilization was considered here rather than in the POOL CONSTRUCTION section because the primary objective of bank stabilization activities is to maintain bank conditions in the pool and not to increase water levels. All of the topics in this section are ongoing activities and as such should be more amenable to the formulation of mitigation and enhancement measures than those topics discussed in POOL CONSTRUCTION.

Although the topics listed above are discussed here separately, their physical, chemical, and biological effects are so complexly integrated that it often becomes almost impossible to distinguish single cause and effect relationships among them. The degree of this complexity was indicated by Solomon et al.

(1975) who attempted to organize the impacts resulting from navigation operation and maintenance into a single flow chart (Figure 1). They grouped the maintenance and operation activities into categories that were different from the ones used here, but concluded that:

(1) Direct impacts are probably easiest to assess but may be short-lived and of minor consequence when compared to long-term, indirect impacts.

(2) Indirect impacts are probably the most meaningful in terms of impact assessment; but, unfortunately, they are often the most difficult to determine.

(3) Any discussion of the environmental impacts (of maintenance and operation) will be open-ended because of the myriad interactions involved.

While not necessarily pertaining to the impacts of pool operation and maintenance, the GREAT II Fish and Wildlife Management Work Group (1980:22) offered the following pertinent comments about these activities:

> Implementation of enhancement/rehabilitation projects are presently limited because of agencies' policy and law. For instance, present Corps authority to maintain the navigation channel does not include consideration of fish and wildlife as part of the 9-foot channel project purpose. Present Corps authority for backwater management is limited to actions which will increase the efficiency of the navigation channel. If authorized to include fish and wildlife as a purpose, new techniques could be implemented during operation and maintenance activities that would enhance fish and wildlife.

Water Level Regulation

Operation of the dams is required at low and moderate flows to maintain the nine-foot channel depth. As stages increase but before flood stages are reached, all control gates are opened, allowing uncontrolled river flow (Solomon et al. 1975:81). Most of the effects considered by Solomon et al. (1975:1-81) as being related to pool regulation (i.e., changes in water levels immediately after construction and altered flow characteristics) have been discussed already in the POOL CONSTRUCTION section of this report. This section deals primarily with effects due to the stabilization of low-flow water levels and to operation-

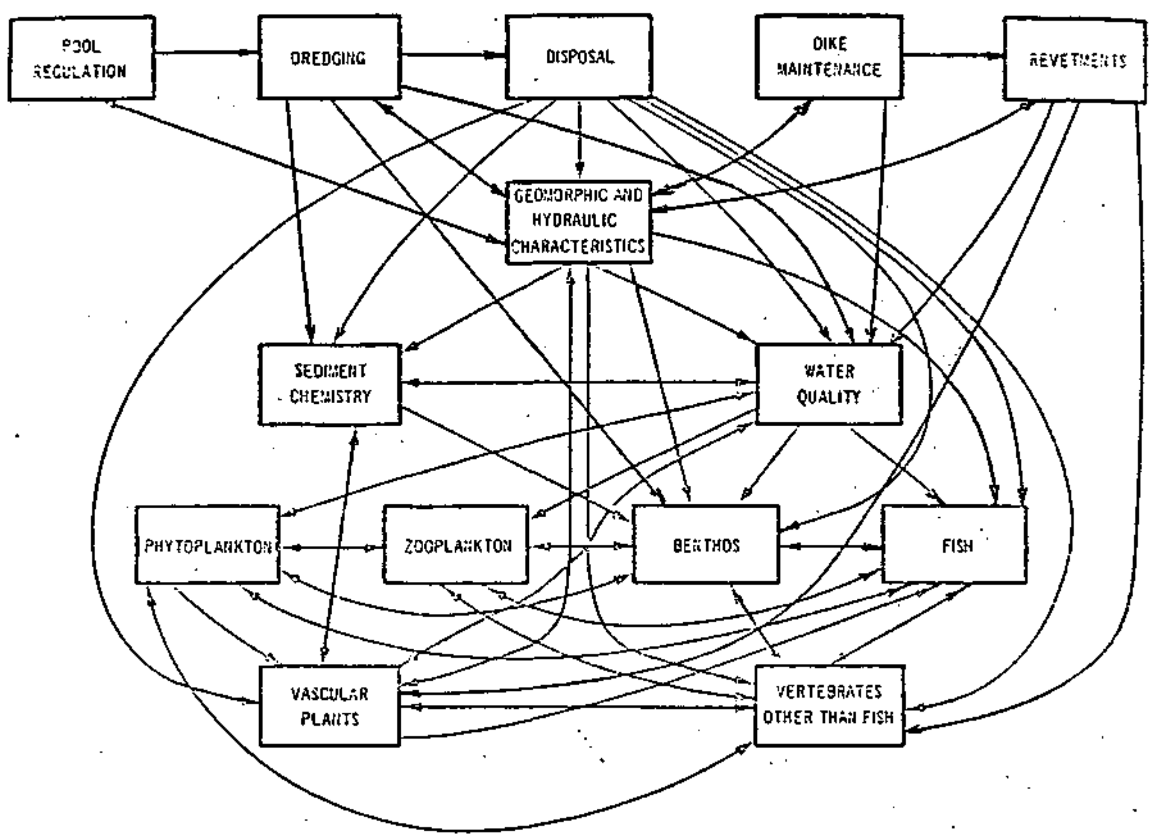

Figure 1. Impacts resulting from operation and maintenance activities (from Solomon et al. 1975:80). The original drawing was in color, but this black and white reproduction should indicate the complexity of the cause and effect relationships involved.

al drawdowns. Because of the relative lack of physical and chemical effect information available for these activities, all of the effects (physical, chemical, and biological) have been discussed together.

Stabilization of low-flow water levels. Low-flow water levels in the Upper Mississippi River System are more stable now than they were before construction of the locks and dams. As an example, Bellrose et al. (1977:C-M) documented this stabilization for Peoria Lake on the Illinois River. This stabilization was beneficial to submerged aquatic plant populations in the Upper Mississippi River System (Bellrose et al. 1977:C-34, Yeager 1949:54, Leopold 1939, Bellrose 1941:278).

On the other hand, the stable water levels probably shortened the low-flow drying periods of some marshes. These drying periods had earlier helped to "rejuvenate" the marsh soils (U.S. Army Corps of Engineers 1978:5-25). The lack of a drying period may now be preventing compaction of the soils of many of the existing shallow bottomland lakes of the Illinois River and sustaining the flocculent condition of their bottom sediments. The character of these sediments and their contribution to the poor quality of these habitats for fish life, was described by Havera et al. (1980:19-94).

Considerable water level fluctuations occur on a regular basis in the unpooled reaches of the UMRS. The fluctuations have been known to dewater certain side channels between St. Louis, Missouri and Cairo, Illinois (Mueller 1977, Boyd and Janecek 1981).

The operation of the locks and dams on the Illinois River influences dissolved oxygen concentrations (Butts et al. 1975). They typically increase dissolved oxygen concentrations of the river (which historically have limited aquatic life in the river) through reaeration as water passes over the dams. In addition, the Illinois State Water Survey has recently studied the potential benefits of altering control practices at the locks and dams to maximize their reaeration capacities.

Operational Drawdowns. Operational drawdowns of water levels in the Upper Mississippi River System have occurred periodically depending on the needs of the navigation system. The U.S. Corps of Engineers (1973) reported on the effects of drawdowns on flood heights. Sparks et al. (1979:119) noted that drawdowns in the pooled stretch of the Upper Mississippi River were conducted before 1970 to provide adequate depths for navigation in the lower river. GREAT II Fish and Wildlife Management Work Group (1980:22) noted that "pool level control is presently separately managed by Corps Districts (St. Paul, Rock Island, St. Louis) of the Upper Mississippi River" and that "because each district manages pool levels independently, those pools at bordering districts are prone to more extreme fluctuations."

The biological effects related to drawdowns that have been stressed in the literature concern both the upstream (from a dam) effects of decreasing water levels and the downstream effects of increasing water levels. Figure 2, for example, shows how water levels at the upper end (Lock and Dam 25 tailwater), the control point (Grafton) and the lower end (Lock and Dam 26 Pool) of Pool 26 varied throughout a period of 1980. At high discharge rates, upper pool water levels increased, while lower pool water levels decreased as more gates were opened in dams 25 and 26. Carlander (1954:23) stated that sudden and drastic lowerings of water often left fish stranded in pools isolated from the main channel. Greenbank (1946, in Keenlyne 1974:24) found that winter drawdowns led to oxygen depletion and fish destruction and that they seemed to have had a greater deleterious effect on game fish. Christenson and Smith (1965:46) reported that falling water levels during the winter were accompanied by a definite movement by carp, northern pike, erappies, spotted sucker and bowfin out of backwater areas in Pools 8 and 9. Bellrose et al. (1977:C-34 to C-39) discussed the effects of changes in water levels on plant communities in the Illinois River. Bellrose and Low (1943) discussed the effects of water level fluctuations on muskrats in the Illinois River. Havera et al. (1980) discussed the potential effects of water level increases along the Illinois Waterway that would be produced by increased Lake Michigan diversion. A wide variety of wildlife, fish and plant groups were considered.

Most of the effects of water level fluctuatons on aquatic populations have been studied below dams and in reservoirs on streams much smaller than the Mississippi River. Baxter (1977) and Baxter and Gluade (1980) reviewed the effects of impoundment drawdowns and pointed out that zones periodically exposed were

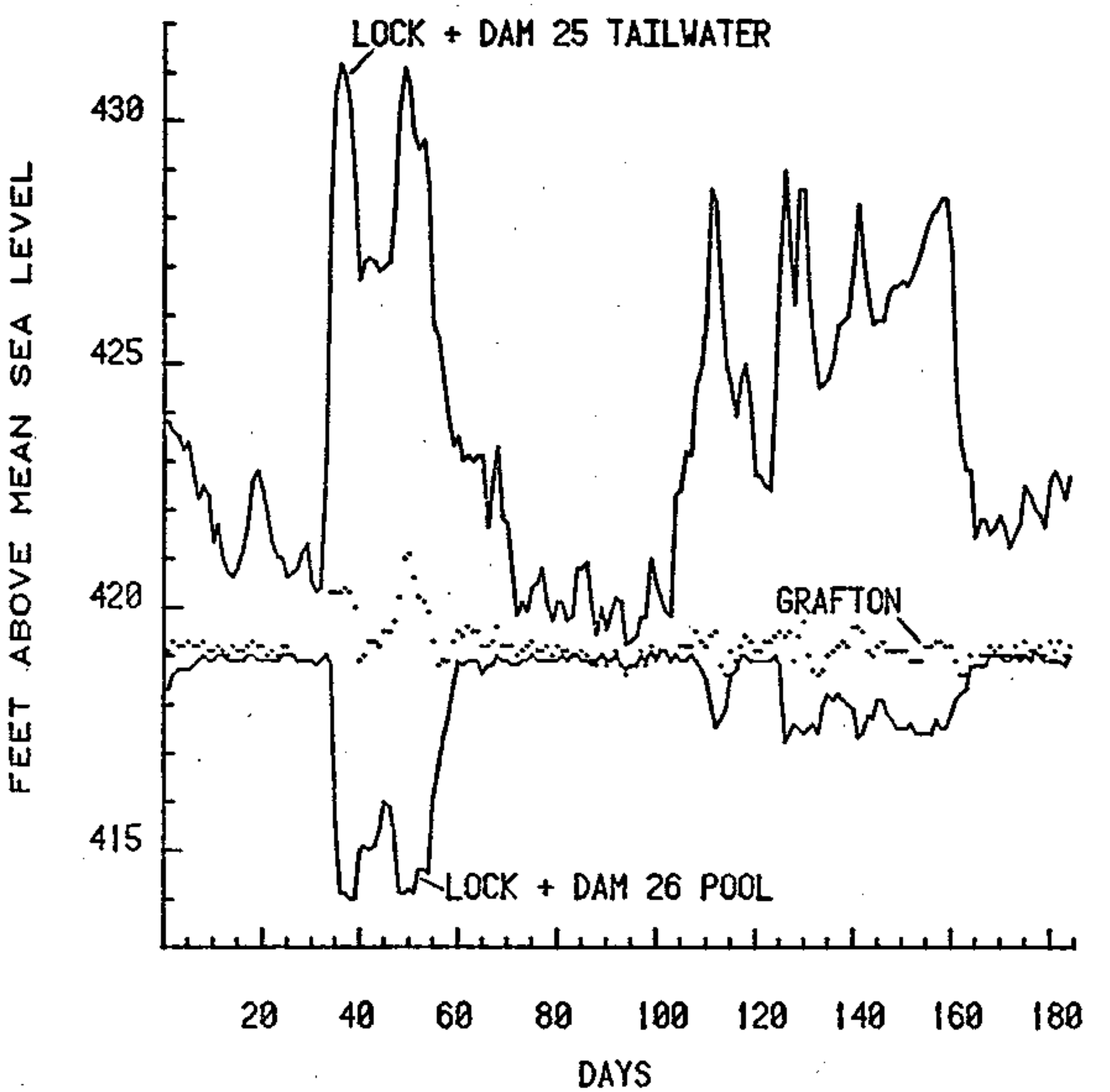

Figure 2. Water levels for three sites in Pool 26 from May 1 to October 31, 1980.

virtually barren. Trotzky and Gregory (1974) reported the diel flow fluctuations below dams eliminated many invertebrate species. Fisher and LaVoy (1972) found that areas periodically exposed below dams were lower in macroinvertebrate diversity, density, and biomass than areas not exposed to drawdown. They concluded that "normal" benthic communities were unable to become established as a result of water level fluctuations. Kennedy (1979) documented at least 50% reductions of benthic organisms in fluctation zones on the Lower Colorado River, and the non-existence of submergent vegetation in these zones.

GREAT II Fish and Wildlife Management Work. Group (1980) summarizes the potential effects of drawdowns on the Mississippi River as follows:

> During critical spawning, nesting, feeding, migration and other periods of life cycles, fish, wildlife and flora can be drastically effected by sudden fluctuating water levels. Natural rises in pool levels and manipulation of pool levels to maintain commercial tow passage can expose and destroy benthic and flora colonies which are primary food sources for fish, waterfowl and furbearers. Additional adverse impacts include island inundation during waterfowl nesting, furbearer nest exposure or inundation during critical times, vegetation coverage causing increased wave action and turbidity, exposed erodable shorelines and an inconsistent littoral zone.
>
> Despite these potential impacts, water level manipulation can be extremely beneficial if managed considering fish and wildlife purposes. This would entail comprehensive evaluation of fish, wildlife and aquatic vegetation seasonal stress periods. Management of water levels can be used to facilitate management of fish and wildlife resources by controlled vegetational growth, fish access to spawning areas, island isolation from disturbance (man, predator, etc.), access to waterfowl nesting, and maximization of littoral zone productivity. Equally important is the management potential that water level manipulations has to control undesirable biological productivity such as overvegetaton. The work group recommended manipulation of water levels in Pool 16 to improve habitat but weather conditions did not permit implementation of the program.

Bank Stabilization

Bank stabilization as defined here refers to the process of protecting already existing banks from erosion. Wing and closing dam construction were discussed in the POOL CONSTRUCTION section.

> Revetments are placed on eroding banks to aid in the maintenance of the navigation channel by preventing bank erosion and subsequent channel migration. Revetments are often associated with dikes, and the combined effect of both structures is to restrict the natural meandering of the main channel and to increase the current velocity, causing degradation of the channel bed. However, the effects of dikes and revetments are undoubtedly modified by pool regulation (Solomon et al. 1975:88).

Rasmussen (1979) suggested that the effects of revetments were domino-like and that revetments created the need for future revetments further downstream on the opposite shore.

Bank stabilization itself consists of (1) forming a desirable slope, (2) placing inert material such as rip rap, pilings, etc., and (3) planting vegetation to help retard the erosion process. These steps are used most commonly in conjunction with channelization methods and techniques (Nunnally and Keller 1979:9). Structural approaches to bank stabilization were also discussed by Hurst and Brebner (1969) and Richardson et al. (1975). The stabilizing effects of vegetation on stream banks were discussed by Seibert (1968) as well as by Nunnally and Keller (1979).

During construction of bank stabilization works, large volumes of rock are placed along shorelines that had produced turbidity and the shore habitat is completely restructured. Where plants and soil previously existed rock now dominates. Erosion-prone shores become stabilized and the erosion process in these localized areas is controlled if not completely stopped (UMRBC 1979). Solomon et al. (1975:88) summarized the biological effects of bank stabilization as follows:

> Construction of revetments can destroy existing nearshore and bank communities, but this impact is thought to be minor since revetments are usually placed on unstable banks. Placement of revetments will also cause localized temporary resuspenslon of

> sediment. Limited field observations by Johnson et al. (1974) have indicated that rock revetment may create a superior habitat as compared to natural shorelines by providing greater diversity for aquatic organisms through stabilization of the river's banks. Additional observations by Klein et al. (1975) and Terpening et al. (1975) indicated that revetted banks are colonized by pioneer plant species and may provide cover for reptiles, amphibians, and small mammals. Productivity and diversity of biotic communities associated with revetments (aquatic and terrestrial) need to be investigated and compared to nonrevetted areas.

While revetments may usually be placed on unstable banks, it should be understood that the construction of wing dams on stable banks at point A on the river may well trigger the instability of a bank at point B downstream.

In contrast, GREAT II Fish and Wildlife Management Work Group (1980:23) reported that:

> The Wisconsin Department of Natural Resources assessed fish utilization of sand, submergent wingdams and riprapped shorelines in the Upper Mississippi River by night electroshocking. Results of that study showed riprapped shoreline was the preferred habitat (Mississippi River Work Unit, 1978). A second study in 1979, winter catfish observations by SCUBA, showed catfish densities were highest along riprapped shorelines (250-650 fish/acre) and immediately downstream of submerged wing dam (1450 fish/acre). Very few fish were seen where rock substrate was absent.

Kennedy (1980) noted the apparent discrepancies between the situations described above and offered the following explanation:

> You need to explain the differences between riprap placement at LaCrosse, Wisconsin, versus Cape Girardeau, Missouri. The biologists along the upper river generally agree that riprap is beneficial because it adds diversity and aids the fishery, while biologists on the lower river see the riprap as an enemy to fishery biologists as it is reducing habitat diversity (too much is already riprapped).

Rasmussen (1980) noted that:

> While some revetment increases biotic and habitat diversity, we are approaching the point in the Middle Mississippi River where unrevetted banklines are becoming rare. It would appear to be

> reasonable, therefore, to assume that the organisms requiring eroded and otherwise unprotected banklines would also be reduced in number.
>
> Many organisms select eroded and undercut banklines as their desired habitat, or to meet specified life cycle needs. These include most Ictalurids native to the Upper Mississippi River (as spawning habitat), muskrats and river otters. Treefalls resulting from bankline erosion provide cover for many species of fish.

Winter Navigation

GREAT II Fish and Wildlife Management Work Group (1980:23) noted that:

> As navigation season begins to reach carrying capacity during non-winter months, the pressure for extension of navigation into the winter months will be increased. The extension of the navigation season into the environmentally sensitive winter period has the potential for many adverse environmental impacts. The adverse effects of physical impacts associated with navigation are intensified by winter conditions and by the increased physiological stress incurred by river organisms during periods of colder temperatures.

There is year-round navigation on the entire Illinois River and on the Mississippi south of its confluence with the Illinois at Grafton.

Potential physical effects related to winter navigation (GREAT II Fish and Wildlife Management Work Group 1980:24) are:

> . . . propeller damage, broken ice in the channel, barge noise and movement, wave action and water displacement, physical disruption of the river bottom, resuspension of sediments, and bubbler system aeration. Other physical impacts that may potentially occur are changes in frequency of ice jams, changes in frequency of spills, release of sediment-bound toxicants, and changes in water quality.

Information was obtained for this report relating to ice breakage, additional production of ice, damage to structures, and ice jams.

Effect on Ice Breakage and Production. The most obvious physical effect of winter navigation Is the breakage of ice in the channel. The U.S. Army Corps of Engineers (1973:16) describes the mechanism:

> "Although a virgin ice cover appears to be a formidable barrier, its uniformity offers advantages to navigation. As the tow moves forward, the ice bends downward, cracks and passes beneath the tow. The barges cut a uniform track only slightly wider than the tow width with little outward cracking. It has been estimated that 70 percent of the broken ice returns to the track, while the remainder becomes lodged beneath the shelf ice."

Although the path cut by a barge through the ice is relatively narrow, additional tow traffic can cause lateral ice breakage on the sides of the previously cleared channel:

> "Another consequence of the passage of a towboat in a previously cleared channel is the potential for breakage of the adjacent ice sheet by the divergent waves generated in the vicinity of the bow... It was also clear during that investigation that higher speeds were more conducive to side breakage than were lower speeds. The consequence of the breakage, of course, is the existence of additional brash of thickness greater than that which would be generated in breaking the ice which forms in a previously cleared channel." Ashton 1974:19)

However, Ashton (1974:35) later states, "The additional production of ice resulting from repeated clearing was found to be but a small part of the total production of ice in the river," implying that the effect of additional ice production is not significant.

Damage to Structures. Bridges, dikes, and other structures in the river could be subject to damage due to winter navigation. Although ice is known to cause significant shore erosion, navigation is not expected to increase the damage:

> "There is a possibility that part of the force required to break ice in the main navigation channel and access channels would be transmitted to bridge piers and other structures in the river. Such a force could cause damage to these facilities. Based on the trip of the Renee G, there would be little lateral cracking of the ice cover, indicating no major force transmission to the shores by the passage of the tow in the channel. Therefore, damage to shore property is not expected to result from winter navigation." (U.S. Army Corps of Engineers 1973:18,19).

Ice Jams. There is also some fear that the breakage and transport of ice in the channel may contribute to the production of ice jams, which can in turn halt navigation and cause flooding. Ashton (1974:34) concluded that this is not so, and that winter navigation may in fact reduce the incidence of jamming:

> "It is concluded that operation of an MIC (mechanical ice cutter) and the associated traffic will not result in increasing the hazards of ice jamming. The continual cutting of the ice cover may reduce the Incidence of jamming by weakening the cover and reducing its potential to act as an obstacle to ice arriving from upstream. Since the severe ice jams on the Mississippi River generally result from a large ice supply associated with a rise in discharge or from the discharge of ice from a tributary it is considered unlikely that navigation will cause ice jams."

Ashton (1974) and the Corps of Engineers (1973) were concerned with winter navigation problems rather than impacts of winter navigation on the river system. With the exception of potential damage to structures, they concluded that the effect of winter navigation on the river is small.

The Midwest Research Institute (1978) addressed numerous potential problems that could result from winter navigation. Table 5 summarizes the potential studies and their priorities that were recommended to provide information relevant to physical and biological concerns related to winter navigation.

Cawley (1978) collected biological data from Pool 12 in an effort to provide baseline information for predictions of winter navigation impacts. He indicated that the major areas of potential impacts were in bends and river crossings, sites of ice gorge development during ice breaking activity. Ecology Consultants, Inc. (1979) provided an annotated bibliography on information regarding winter navigation on the Mississippi River, but noted the lack of research specific to winter navigation or winter biological conditions. Poe et al. (1980) conducted a study from January to April 1979 to evaluate the effects on fishery resources of ship-induced, under-ice surge and drawdown waves during a period of ice cover. Drift nets were used to sample biota and organic detritus. Under solid ice cover drift rates for all sampled components were significantly higher during vessel passage than without vessel passage, and Poe

Table 5. Potential physical and biological studies to resolve concerns of year-round navigation (taken from MRI 1978).

	Priority
A. Physical Concerns	
1. Forecasting ice jams	1
2. Rate of broken ice thickening	2
3. Characteristics of unstable ice jamming	2
4. Roughness of ice undersurface	2
5. Growth of ice jams	2
6. Fate of displaced ice	1
7. Water quality changes	1
8. Frequency of spills	1
9. Effects on bank erosion	3
B. Biological Concerns	
1. Benthic organisms	1
a. Effects of scour	
b. Effects of sediment redistribution	
2. Fisheries	
a. Physical damage from propellors	1
b. Probability of deleterious spills	1
c. Reduction in dissolved oxygen	3
d. Effects of increased turbidity	2
e. Isolation of backwaters due to ice jams and subsequent reductions in dissolved oxygen	1
3. Wildlife and plants	
a. Effects of open channels on deer migrations	3
b. Fluctuating water on semiaquatic mammals	2
c. Northern shift of residency for some birds	3
d. Overwintering reptiles and amphibians	1
e. Primary production	3

1 = high priority; 3 = low priority

et al. (1980:28) concluded that the increase in the composition, density, and biomass of these components of the drift were significant as follows:

> If the vessel traffic is very frequent, these areas may not be replenished or recolonized and cause a subsequent reduction in the diversity and density of macroinvertebrate and fish populations in these areas. In addition, the transport of bottom sediments during vessel passage, which has been documented in the St. Marys River. . . may lead to increased instability of the sediments which can also reduce macroinvertebrate and fish communities. . .

Effects of winter navigation could include scouring of productive benthic areas, increased chances of exposure of organisms to accidental spills, and physical damage to aquatic organisms that would be lethargic and in stressed conditions due to low temperatures. These effects, however, have not been adequately documented, which caused GREAT II Fish and Wildlife Management Work Group (1980:24) to conclude:

> Since the extent and degree of physical impacts resulting from winter navigation, the short and long term effects of these physical impacts on riverine organisms and the winter biology of Mississippi River organisms are almost completely unknown, environmental investigations are needed to assess environmental impacts which may result from extension of the navigation season.

Finally, the U.S. Corps of Engineers, Rock Island District (1980) noted that "additional knowledge and baseline data concerning the environmental impacts of winter navigation are needed," and recommended an environmental study (minimum of 5 years at $200,000/year) to investigate the Mississippi River during fall and winter months.

Dredging and Spoil Disposal

The effects of dredging and dredge spoil disposal have been the subject of a number of previous studies and reviews (Saucier et al. 1978, Held 1978, Allen and Hardy 1980, Anderson et al. 1981). Morton (1977) provided an excellent literature review of the physical, chemical and biological effects of dredging in . estuaries. Additional related studies have been published in the area of stream channelization (Little 1973, Schneeberger and Funk 1971, Corning et al. 1975).

Conflicts related to dredging on the Upper Mississippi River System have been specifically addressed at length during the GREAT studies (GREAT I 1980, Comptroller General of the U.S. 1977).

The channel width on the Upper Mississippi River System is currently maintained at 400-500 feet in river bends and at 300 feet in straight reaches. The maximum depth dredged is about 11 feet unless a greater depth is required at a particular location. Depending on hydraulic (flow discharge and sediment load) characteristics, a given reach of the river will support a specific channel size and width. Dredging without consideration of the charactersitics will be ineffective, since dredged areas will refill quickly as the channel attempts to establish a cross-section which is in balance with the hydraulic conditions. Typical reaches requiring dredging are: (1) below major tributary junctions where sediment load exceeds transport capacity, (2) at crossings where the natural cross section is shallow and wide, and (3) in bends where the flow tends to follow the outside of the bend causing point bar shoaling. Because of the fluid mechanics of sediment transport, even optimum control of upland erosion would not eliminate dredging requirements (GREAT II 1980:40).

Kennedy (1980) noted: ,r

> There have been considerable changes in dredging since 1975. The common practice before 1975 was over-depth dredging to 13-ft. at almost all locations. Since the start of the GREAT River studies, in general, river widths have been made slightly smaller in some areas and the normal dredging depth in the GREAT-I and CREAT-II areas is 11-ft. unless justified by a site specific review. The reduced depth dredging program also seems to be working in many of the areas in which it is tried (Dredging Requirement Work Group 1979).

Considering the interaction of regulatory structures, river hydraulics, channel geometry, and barge tow characteristics, the dredging requirements work group of GREAT II made reduction of required dredging volumes its primary objective (GREAT II Dredging Requirements Work Group 1980:II-7). Similarly, the Rock Island District established the "Committee for the Assessment of Regulatory Structures" to evaluate the efficiency of these structures in maintaining the desired channel dimensions. Reduction of dredging volume by repair or construction of regulatory structures is the goal of this committee (GREAT II 1980 :125-127).

Physical Effects. Morton (1977:3) organized the physical effects of dredging into three areas: temporary increases in turbidity (suspended solids) at both dredge and disposal sites, changes in bottom topography with resulting changes in water circulation patterns, and changes in the mechanical properties of the sediments at the dredge and disposal sites. In addition he stated that:

> The relative significance of these effects on a given estuarine system is a function of the ratio of the dredged area to the total bottom area and contained water volume. . . Other important factors influencing the physical impact of dredging and spoil disposal are type and volume of sediments to be dredged, frequency of dredging, climatic conditions during and after dredging, the dredging and disposal methods used, and the size and draft of the dredging vessel (Slotta et al. 1973; Mauerer et al. 1974).

Concerns about dredging and disposal of dredged material contributed to the formulation of the Dredged Material Research Program (DMRP) which the Corps of Engineers carried out from 1973 to 1978. In the Rivers and Harbors Act of 1970, Congress authorized a comprehensive research program on dredged material problems (Saucier et al. 1978:21,23). Boyd et al. (1972) identified the problems with dredge spoil disposal and developed the program requested by Congress in 1970. The Upper Mississippi River System maintenance dredging amounts to only 12.5 million cubic years per year of a nationwide annual average dredging requirement of about 300 million cubic yards. The entire Mississippi River . navigation system including the Ohio, Missouri, and Arkansas Rivers requires about 63 million cubic yards to be dredged each year (Boyd et al. 1972:37). Thus, dredging in the Upper Mississippi River System is only 20% of the total Mississippi River System dredging requirements and only 4% of the nationwide dredging requirements. Consequently the DMRP (Saucier et al. 1978) focused most of the research on estuary and harbor dredging and spoil disposal problems.

The primary physical impacts of dredging are the increase in channel cross sectional area and the associated changes in velocity and flow distribution. Other physical impacts result from spoil disposal. DMRP summarizes its results in two statements:

> To those concerned with national or regional planning and policy formulation, there are two extremely important fundamental conclusions that can be drawn from the DMRP. The first is that there is no single disposal alternative that presumptively is suitable for a region or a group of projects. Correspondingly, there is no single disposal alternative that presumptively results in impacts of such nature that it can be categorically dismissed from consideration. Put in different terms, there is no inherent effect or characteristic of an alternative that rules it out of consideration from a technical standpoint prior to specific on-site evaluation. This holds true for open-water disposal, confined upland disposal, habitat development, or any other alternative.
>
> The second basic conclusion is that environmental considerations are acting more strongly than possibly any force to necessitate long-range regional planning as a lasting, effective solution to disposal problems. No longer can disposal alternatives be planned independently for each dredging operation for multiple projects in a given area. While each project may require a different specific solution, the interrelationships must be evaluated with a holistic perspective and thought given to when particular disposal alternatives may have to be replaced with others as conditions change. Regional disposal management plans not only offer greater opportunities for environmental protection ultimately at reduced project cost, but also meet with greater public acceptance once they are agreed upon (Saucier et al. 1978:6).

The summary continues with the statement:

> Considering first the specific findings with regard to the effects of open-water disposal, the physical effects-—the logical and easily predicted physical effects-—are with few exceptions more important than chemical or biological effects. Physical effects include the smothering of a clam bed, the disruption of a flow pattern, a change in salinity, or a similar effect. These possible consequences of disposal operations are persistent, often irreversible, and compounding. However, they are infrequent and can be avoided with the judicious application of evaluative procedures available under guidance for the Section 404 (P.L.92-500) and 103 (P.L. 92-532) programs. More intense evaluations of physical impacts traditionally have relied on physical hydraulic

> models, but the DMRP developed mathematical models that can also be used for certain needed predictions. Specifically, a partially verified and tested math model is now available to predict the short-term fate or dispersion of barge and hopper dredge dumped material as well as pipeline dredged material in ocean, estuarine, lake, and river environments. An unverified sediment transport model for the long-term and ultimate fate of these deposits is now available (Saucier et al. 1978:7).

Chemical Effects. Morton (1977:28) summarized the chemical effects of dredging and spoil disposal as follows:

> The most critical, yet least understood, chemical effect of dredging and spoil disposal is the release of contaminants from polluted dredge spoils. This release may occur immediately as the deep, reduced sediments are mixed with water overlying the dredge and disposal sites or may occur gradually over a long period, after the spoil is in place at the disposal site. Greater understanding of this problem is needed to determine whether less environmental damage is produced by confined disposal sites than by unconfined, open-water disposal. Because the presence or absence of oxygen has such an important effect on the processes controlling the flux of contaminants across the sediment-water interface, researchers should also conduct more studies to determine how dredging and spoil disposal affect dissolved oxygen concentration in the vicinities of the dredging and disposal sites.

Patrick et al. (1977) reported on the physicochemical factors that influence the solubility and bioavailability of toxic heavy metals in contaminated dredged sediment.

It should also be noted that while the physical and chemical effects of dredging and spoil disposal have been reported for numerous locations, they are apparently highly site-specific. Regarding this, GREAT II Fish and Wildlife Management Group (1980:18) noted:

> Experiments performed at the U.S. Waterways Experiment Station (WES) as part of the Corps of Engineers Dredged Materials Research Program concluded that concentration of sediment suspended during dredging are generally non-toxic and of short duration (Hirsch, et al., 1978). However, more study is needed to be sure that this generalization is correct for all aquatic environments and geographic locations.

The following statement on physical-chemical impacts is from the DMRP summary report:

> Turning to inland and coastal areas, the DMRP achieved definitive results that soundly substantiate that most widely held fears over the short-term release of contaminants to disposal site waters are unfounded. As long as the geochemical environment is not basically changed, most contaminants are not released from the sediment particles to the water. However, in contrast, upland disposal often does result in a change in the geochemical environment that can lead to contaminant release. Some nutrients such as ammonium and manganese and iron are released in open-water disposal, but in most cases enough mixing is present to rapidly dilute these to harmless concentrations. Situations where toxic effects could occur would most likely be where pipeline dredges are discharging large volumes of material into very shallow estuarine waters.
>
> The difficult problem of the effects of turbidity or suspended sediment particles on both water quality and aquatic organisms was addressed with significant results. It was found that, except in unusually environmentally sensistive areas such as coral reefs, turbidity is primarily a matter of aesthetic impact rather than biological impact. It is, of course, often advisable to schedule dredging and disposal operations to avoid disrupting spawning activities and fish migrations. However, studies showed that most adult organisms can tolerate turbidity levels and durations far in excess of what dredging and disposal operations produce. These studies, conducted in the laboratory and verified in the field, involved a variety of marine, estuarine, and freshwater organisms.
>
> With regard to benthic or bottom-dwelling organisms, their resiliency, once beyond the larval stage, was demonstrated. Disposal sites can be and are rapidly recolonized by the establishment of new populations, by migration of organisms from adjacent unaffected areas, and by survival of the organisms buried. Colonization by opportunistic species can occur within weeks and by the orginal species within months. When the type of dredged material disposed at a site is of the same grain-size distribution as the natural bottom (e.g., sand deposited on sand or silt on silt), survival of existing organisms is maximized. Conversely, a mismatch of sediment type can be quite detrimental. The condition that could be most injurious to benthic organisms is when the disposal operations, primarily hydraulic pipeline operations, produce a fluid mud or "fluff" layer that is a difficult and alien environment for many organisms (Saucier et al. 1978:7,8).

These paragraphs clearly show the interaction of the physical, chemical, and biological elements in the riverine ecosystem. There is hope for reduced ecological impacts from dredge spoil disposal plans that are interdisciplinary and comprehensive.

One final quotation from DMRP concerns the possible chemical changes possible in upland spoil disposal.

> With time, the soil physicochemical environment in a confined disposal site can become appreciably different from that of sediments before dredging or sediments deposited in open water. The upland drained situation can lead to an oxidizing acidic environment that was shown in laboratory studies to be conducive to the leaching of contaminants, particularly heavy metals. Whether or not the leachate will contaminate groundwater will depend on the absorptive capacity of the natural soil, which is normally quite high. A far more serious and more probable impact can occur when saline sediments are placed in a freshwater upland environment. Salt will leach from most dredged material and whether or not it will contaminate groundwater must be carefully evaluated on a case-by-case basis (Saucier et al. 1978:11).

In 1978, the St. Paul District, Corps of Engineers (Anderson et al. (1981), monitored five dredging operations at various locations on the Upper Mississippi River, including three hydraulic dredging operations and two mechanical (clamshell) dredging operations. All five studies were conducted in areas with relatively coarse sediments (less than 10 percent silts and clays). They noted:

> In the four turbidity and suspended solids studies, no changes or only minor changes in water quality were found to result from either the hydraulic or clamshell dredging activity. The study that monitored the effluents from a confined on-land disposal area indicated slight elevations in turbidity and suspended solids but noted that these levels had returned to ambient within 100 feet downstream of the disposal area.
>
> In the study which also monitored chemical and microbiological parameters, no significant increases below the hydraulic cutterhead were evidenced for any of the physical, chemical, or microbiological parameters investigated. The effluent from the confined on-land disposal area contained concentrations of some parameters (especially iron, manganese, and the physical parameters) that exceeded the predredging and upstream control values. However, only iron and manganese were found to be significantly higher downstream of the disposal pipe than in upstream control values. Daily fluctuations in concentrations for most of the parameters were fairly substantial and tended to mask any impacts caused by dredging.

> Overall, with the methods used for disposal of the dredged material at the five sites studied, no major degradation of water quality was evidenced for either the mechanical (clamshell) or hydraulic dredging and disposal operations.

Biological Effects. The biological effects connected with dredging and spoil disposal include habitat destruction (short and long term), physical damage and burial of benthic organisms, exposure to toxic contaminants in the dredged material, and dissolved oxygen stress caused by (1) oxygen demand created by the resuspended sediments and (2) lower photosynthetic rates due to increased turbidity (Morton 1977, Hirsch et al. 1978, Allen and Hardy 1980).

The most destructive of these effects to date on the Mississippi River has been habitat destruction due to spoil disposal, and the secondary movement of dredged material into backwater areas, which has in turn reduced flow rates and oxygenation and increased sedimentation in these areas. GREAT II Fish and Wildlife Management Work Group (1980:18, 20) identified several of these areas. GREAT II Fish and Wildlife Management Work Group (1980) also included a description of the most recent efforts undertaken with the Corps of Engineers to prevent indiscriminant spoil disposal.

The effects of spoil-related toxic contamination to aquatic organisms has been studied at length but still presents major problems as noted in Morton (1977: 28):

> . . . understanding of how various organisms are affected by different doses of a contaminant is limited because of the complexity of the processes controlling the remobilization and uptake of the various contaminants and because of the variability in response between species and between different life stages of the same species. A critical problem requiring further study is the uptake and accumulation of contaminants released from polluted sediments by marsh vegetation, phytoplankton, zooplankton, benthic animals, and fish. Also necessary is a further investigation of the pathways by which contaminants enter the food chain and the steps or processes that affect the rate of concentration in the tissues.

While turbidity produced by dredging and spoil disposal is one of the most obvious physical effects, Morton (1977:28) states that the biological consequences are relatively small:

> A less important physical impact is the reduction in light penetration caused by the surface turbidity plumes that occur during dredging and disposal. Turbidity plumes usually disappear, however, within a few hours after dredging and disposal have been completed.

Gustafson (1972) reported that turbidity caused by dredging could have a number. of beneficial effects by increasing the rate of bacterial breakdown of sewage, adsorbing metals, and by sheltering larval marine life from predators.

Once again, the duration of turbidity plumes due to dredging and spoil disposal is probably site specific, and any generalizations about the systemwide biological consequences of these turbidity plumes would be premature.

Clearing and Snagging

As defined here clearing and snagging refers to the selective removal of trees, rocks, and other debris from main channel or main channel border areas (see Little 1973:195). Clearing and snagging on the Upper Mississippi River has been conducted since 1820 (Rasmussen 1979:3) but a schedule of recent clearing and snagging operations on the Upper Mississippi River has not been found. It is apparently done on a "when and where necessary" basis. Funk and Robinson (1974:14) did report that on the Missouri River snag removal was poorly coordinated before about 1885, but systematic and intensive from 1885 to 1900. Generally, less attention was paid to clearing and snagging after this period as more effort was put into construction of revetments and wing dams, and later to lock and dam construction and maintenance dredging.

In spite of a broad base of information related to stream channelization and the effects of major channelizations projects on local fish and wildlife communities (Little 1973; Schneberger and Funk 1971; Corning et al. 1975; Marzolf 1978), information on the specific effects of snagging and clearing is generally lacking.

In terms of physical effects, Little (1973:330) noted that only a modest improvement in the conveyance capacity of most streams can be achieved by clearing and snagging. He also noted that the operation is usually done by a bulldozer (or perhaps other heavy equipment) on shore (pg. 330) and that the potential biological effects from clearing and snagging are dependent on the operating agencies definition and scope of the clearing and snagging operation:

> Clearing and snagging is not a definitive operation because to some agencies or groups it means simply removal of trees and debris from the channel area which are weak, dead or undercut and probably will fall into the channel in the near future. To other agencies or groups, clearing and snagging encompasses activities such as removal of gravel bars, shoals, and riffles from the stream proper as well as deforestation of the floodway. Clearing and snagging of the former type is far more compatible with maintenance of a productive fisheries and wildlife resource and, in no way approaches the magnitude of biological disruption associated with channelization of streams.

Marzolf (1978:iii) also noted the lack of direct quantitative evidence about the biological effects of clearing and snagging but considered generally the potential effects of this activity on primary production (alteration of plankton production, substrate type and habitat for rooted macrophytes), the decomposition and processing of organic matter, macroinvertebrates (through removal of coarse particulate organic matter, changes in sediments and direct physical effects), and fish (through loss of cover, and disturbances in territories, orientation and spawning areas).

Effects Related to Boat Traffic

The physical, chemical and biological effects of boat traffic on a waterway can be best thought of as occurring through one of several chains of effects. For example, one hypothetical chain could be described as: boat traffic generates waves which cause bank erosion, which increase the sediment load of the river, which affects water quality (turbidity) and photosynthesis.

All of the effect chains connected with boat traffic do not necessarily have to be this long, nor do they have to terminate in a biological effect. Another hypothetical chain, for example, might be: boat traffic causes turbulence in the main channel which increases turbidity temporarily. The effect chain ends if no other physical, chemical, or biological consequences result from the temporarily increased turbidity. Effect chains can branch, as when one physical effect has more than one chemical or biological effect. Both the length and branching of each effect chain can vary due to site-specific environmental parameters such as depth and width of the main channel, prevailing wind action, or current velocity.

Every chain, however, begins with a physical effect and therefore the following section has been organized by physical effects as follows:

EFFECTS RELATED TO BOAT GENERATED SURFACE WAVES

- Wave Effects
- Drawdown Effects

EFFECTS RELATED TO PRESSURE AND VELOCITY CHANGES

Here the term "waves" refers to the diverging, or bow, and transverse waves associated with the movement of a vessel floating on any water body. The term "drawdown" refers to the change in water surface elevation associated with the increased velocity caused by displacement of water by the moving vessel and the open channel flow conditions of continuity and energy. Either wave height or drawdown may increase in shallow water and result in larger amplitude effects in side channels or backwater lakes.

EFFECTS RELATED TO BOAT GENERATED SURFACE WAVES

Wave Effects

Physical Effects. Many early studies on the effects of boat-generated waves were published by the Institute of Naval Architects. These investigators were primarily concerned with the effects of wave generation on the speed of the vessels. They were interested in reducing drag forces due to wave generation (for example see Froude 1881). Their efforts produced more efficient ships but they did not recognize the possibility of damage or hazards resulting from boat-generated waves.

Later investigators attempted to quantify the characteristics of waves produced by ships, describing their size, shape, speed and water depth. Hay (1968) concluded that for a given ship, with a given speed and distance from the sailing line, peak wave height increases with decreasing water depth. In shallow water the wave height increases as a result of the increased resistance and squat of the vessel. Therefore, waves produced in a channel closer to banks, beaches, docks and shoreline have greater energy.

Sorenson (1967, 1973) studied waves produced by different types of vessels in harbors. He compared cabin cruisers, a Coast Guard cutter, barges, tankers and other large boats, and determined that the highest ship-generated waves are generally from smaller vessels that operate at high speeds rather than larger and slower tanker and cargo ships.

Johnson (1963, .1969) investigated the effects of ocean ships traveling at high speeds through the Columbia River from Portland to the Pacific Ocean. He compared wave heights approaching the public beaches, and performed mathematical and experimental model studies on ocean ships in confined channels and wave-wash effects (Johnson 1958).

Bank erosion from boat generated waves may be serious. In 1969, a report prepared by the U.S. Army Corps of Engineers for the Secretary of the Army stated that 8% of the 7 million miles of streambank in our nation had been damaged due to the erosion process (U.S. Congress 1969:III). Though only some of this erosion can be attributed to the effects of boat traffic, boat traffic is one of the contributing factors.

In general, an equilibrium state exists between the soil particles which comprise the bank and the forces exerted by the flow of the river. When the force exerted by Che flow to the bank is greater than the resistance of soil particles, erosion results. However, it is extremely difficult to pinpoint one specific cause of erosion at any given location. Other factors influencing the erosion process are discharge stage, amount of suspended sediment, and man's intervention (U.S. Congress 1969).

A bank's resistance to erosion is dependent upon soil composition and condition, particularly its water content. This is true for banks composed of silt, clay and sandy materials. As the percentage of binding material within the soil increases, erodability decreases. Soil moisture acts as a lubricant; as the moisture content increases due to either wave action, precipitation, or fluctuations in river levels, resistance to erosion decreases. At the point of saturation large chunks of soil may erode, simply due to their own weight (U.S. Congress 1969). This is called shear failure. In summary, bank erosion can result either from an induced disequilibrium in the bank-soil river-energy relationships, or due to a change in the moisture content of the soil especially for sandy-silty and clayey materials.

When a wave generated by a boat impinges on the shoreline, it effects a transfer of energy from the ship to the shore. Sorenson (1973) produced an equation for the energy per surface area of a wave produced by a ship. Energy values increased linearly with an increase in wave length, wave velocity, crest length, and exponentially with wave height. Wave energy spectra were described for wind waves by Bhowmik (1976, 1978). Das (1969) determined wave energy characteristics for vessels in restricted waterways from model studies. Since the energy contained on the wave surface is directly proportional to the square of the wave height, the variable of primary interest in dealing with the effects of waves on shorelines is, therefore, wave height (Karaki and van Hoften 1974:20).

As the wave approaches the river bank, the water depth decreases causing a decrease in wave celerity, or speed of propagation. The wave crest then rises until the wave eventually breaks. When waves break, the energy is partially converted into turbulence which suspends fine material near the shore (Bhowmik 1976:7, Karaki and van Hoften 1974:22). However, if the waves do not break, they run up the bank and impinge on it, depending on the bank slope, as shown by Bhowmik and Schicht (1979) to be a factor in the rate of erosion due to waves. This alternate motion of a wave running up the shore and washing back will continue to cause erosion until an equilibrium bank slope is reached (Karaki and van Hoften 1974:22).

A factor that must be considered is the distance a wave must travel. In the wide portions of a river, wave action resulting from boat traffic may make a minor contribution to bank erosion; but in narrower channel sections, waves lose very little energy before reaching the shoreline and can cause substantial shoreline damage. Hurst and Brebner (1969:55) developed a general set of criteria to account for the proportion of erosion attributable to navigation on specified sections of the St. Lawrence and St. Glair rivers. The criteria are as follows:

1. If the center of the navigation channel is equal to or less than 2,000 feet from the bank, 50% or more of the bank erosion is due to navigation.
2. If the. center of the navigation channel is greater than 2,000 feet and less than 3,000 feet from the bank, less than 50% of the bank erosion is due to navigation.
3. If the center of the navigation channel is greater than 3,000 feet from the bank, erosion is essentially due to natural causes.

These criteria do not necessarily hold true for other river systems, but do offer a basis for further research on these systems.

As sediment enters the river from the erosion process, the river must make adjustments to accomodate this additional sediment load. For example, a wide channel is necessary for the efficient transport of a large bed load. If the bed load is to increase, so must the width. Additional energy is needed to transport the increased load. Since, initially, the energy is not available, aggradation will occur which increases flooding, destroys meanders, and straightens the channel, thus providing the additional energy needed for transport (U.S. Congress 1969).

Erosion, and additional amounts of sediment due to erosion, have the capability to inflict the following damage:

1. Increase water treatment cost
2. Lower the quantity and quality of shellfish
3. Hamper recreational use of reservoirs and backwater lakes
4. Necessitate extensive dredging to maintain adequate harbor and channel depths
5. Create unsightly conditions by undermining woody and non-woody vegetation, also creating submerged hazards to vessels
6. Destruction of property and public land
7. Elimination of sensitive ecosystems

There is, however, a beneficial aspect to bank erosion. If a stream attempts to increase its channel width because of additional sediment load, and in the process creates a width which is more than adequate, the resulting channel has a greater capacity which reduces the frequency and degree of flooding.

Camfield et al. (1979) reviewed the role of vessel wakes on bank erosion for the U.S. Coast Guard. Wind-generated waves were also discussed. They conclude that there is a lack of information on waves and velocities in boat wakes and on the erodibility of soils in river banks.

In the upper Mississippi River basin region, streambank erosion due to navigation does contribute to the overall sediment content of the river, but not to the extent of other erosional processes such as erosion due to agriculture, sheet and gully erosion, and annual runoff. According to the Great River Environmental Action Team, streambank erosion contributes 26% of the sediment (Great II Sediment and Erosion Control Work Group 1980:27). Streambank erosion is caused by wind waves and floods as well as vessel waves.

Chemical Effects. Sediment ranks as the nation's greatest water pollutant and plays a major role in determining water quality by transporting or storing various chemical pollutants, and affecting turbidity and dissolved oxygen concentrations (Livesey 1970). Any impact of navigation on sedimentation thus implies a corresponding water quality change.

Deposited as well as suspended sediment particles provide a large surface area, thus allowing soluble chemical pollutants such as lead, mercury, cadmium, nickel, and arsenic to adhere to the particle surface through an ion exchange (Task Committee, ASCE 1971). Sediment particles are not dispersed or transported as quickly as dissolved pollutants; therefore, the attachment of pollutant chemicals to sediment can both help and hinder water quality management (Livesey 1970). With this reduction in transport rates, concentrations of chemical pollutants may be stored in the stream bed awaiting a water chemistry change, resuspension, or other disturbance to be released into solution. This build-up in bed material can occur even though the suspended concentration of these chemicals is within allowable water quality limits (Task Committee, ASCE 1971). Similarly, the pollutants adhering to sediment particles could be deposited and buried in bed material, thus being removed entirely from the working ecosystem (Livesey 1970).

Turbidity, the measurement of the scattering and absorption of light by suspended particles in water, has an effect on water quality. The amount of turbidity determines the depth of the euphotic zone and therefore influences dissolved oxygen concentration by affecting photosynthesis. However, when turbidity increases temporarily due to resuspension of settled particles, a nutrient exchange from sediment to water may have a stimulatory effect (Task Committee, ASCE 1971).

The stimulatory effect of such nutrients as phosphorus and nitrogen increases the growth potential of aquatic plants which, upon decay, exert a reduction on the dissolved oxygen content. The dissolved oxygen content of water can be reduced both directly and indirectly by the amount of fine-grained organically-rich sediment present. The natural oxidation process on suspended or resuspended organically-rich material exerts a high oxygen demand which may result in an oxygen sag within the system (Schubel 1978). Again, constant resuspension not only decreases dissolved oxygen, but also increases turbidity which will decrease the depth of the euphotic zone resulting in lowered oxygen production by aquatic plants.

Though sediment is our nation's largest water pollutant by volume, both positive and negative effects on water quality exist (Great II 1980d). The sediment concentration and turbidity level above which sediment or turbidity should be considered pollutants have not been defined. Therefore, more information needs to be obtained to better understand the full impact of sediment and turbidity on the quality of water (Task Committee, ASCE 1971).

The effects of recreational motor-boat activity on water quality was studied in a report from the Florida Technological University (Yousef et al. 1978). Turbidity, total phosphorus, total dissolved oxygen, total organic carbon and chlorophyll-a, were all found to be increased by mixing by motor boat traffic. These changes were all dependent on water depth, motor power, operational time and type of sediment on the bottom of the lake. The mixing depth varies directly with the horsepower of the motor; for example, a 50 HP motor can cause resuspension of 0.05 mm sediment particles at a depth of 10 feet.

Jackivicz and Kuzminski (1973) estimated that in 1970 there were 7.2 million outboard motors in use and over 98% were of the two-stroke cycle type. Some of compounds discharged into the water by two-cycle outboard motors are non-volatile oil, volatile oil, lead, phenols, and raw fuel. The above authors report that up to 55% of the original fuel can be discharged into the water. The average value is between 10-20%.

Biological Effects. Ecology Consultants, Inc. (1979:5) stated that "while wake-caused wave action serves to increase sediment and turbidity, the impacts of these increases on aquatic biota is not known." Undoubtedly these effects on the Upper Mississippi River system are site-specific depending on the physical dimensions of the channel, habitat type, substrate slope and composition, and present flora and fauna. Sparks (1975) discussed the possible biological impacts of wave wash and resuspension of sediments caused by boat traffic in the Illinois River. In summary he noted:

> Wave wash from towboats and large pleasurecraft may increase bank erosion, which adds to the turbidity of the river and which can reduce the low levees used for managing water levels in conservation areas. Levees and pumping operations are essential for keeping turbid river water out of desirable areas, for exposing mud flats in order to grow duck food plants, and for restoring degraded areas by drying and compaction of flocculent bottom muds. Movement of towboats in the main channel can cause changes in the direction and magnitude of current in side channels, and may result in disruption of spawning activities of fish and disorientation of juvenile fish. Towboats resuspend sediment in the main channel. If this sediment moves into backwaters and bottomland lakes when these areas are connected to the river, then turbidity and sedimentation will increase in these areas. Sediment has direct and indirect effects which have tended to shift the composition of fish populations in bottomland lakes from game fish to catfish and rough fish. Since 1955, even the food organisms for the rough fish and catfish appear to have been affected by low oxygen levels. Illinois River sediment apparently exerts an oxygen demand which lowers dissolved oxygen concentration in the lakes and backwaters, which historically have been the nurseries for the tremendous sport and commercial fisheries of the Illinois River.

The U.S. Corps of Engineers (1980) commented that:

> . . . this discussion fails to consider the relative effects of wave action generated by tow boats and natural wind-generated wave action. In a severe spring squall, the wave action generated over a continuous period of a few minutes or hours may be greater in magnitude and effect than that generated by many tow boat passages. The same is true for turbidity increases. While tow boats suspend sediments, the amount of tow-caused resuspension compared to storms and high river flows may be small. Regardless of the relationship, these factors should be evaluated to present an objective assessment of tow boat effects.

Wave action can have considerable impact on some of the most productive river areas, i.e., backwaters and littoral zones. These areas serve as nurseries for larval fish and produce high numbers of macroinvertebrates and plankton. Moreover, the greatest intensity and frequency of wave action due to heavy boat traffic by tows, fishermen and pleasure boats during the warmer months (late spring, summer, and early fall) occurs during the most productive seasons for animals. Wave action may affect the fauna and flora in a variety of ways. Larval and small fish and benthos may experience stress from excessive wave action and the shock wave may actually knock them off plants and substrates causing physical damage and exposing them to predation. Invertebrates may be more likely to be entrained into drift along steep shorelines exposed to currents sufficient enough to sustain drift. Macrophytes may be uprooted by wave action and the wave action may make it difficult for future plant generations to remain in a given area. Sediment movement and resuspension may have an adverse effect by changing the habitat to the extent it is no longer optimum or even marginally aceptable by some species. Turbidity induced by wave action restricts the periphyton communities, and limits the euphotic zone thus limiting primary production of phytoplankton. Settling of resuspended sediment fouls gills of fish and invertebrates, smothers eggs of animals, and restricts primary production areas of submerged vascular plants (Sparks 1975).

While the authors of this report believe these impacts do occur in the UMRS, their magnitude is dependent on several navigation, stream morphology and flow factors. The magnitude and system-wide distribution of these impacts on the UMRS (beyond the fact that they are probably higher on the Illinois than the Mississippi River) are virtually unknown.

The disappearance of much of the aquatic macrophytes along the Illinois River has resulted in the loss of their wave-dampening properties. The presence of submergent and emergent vegetation is an important factor in reducing the energy content of waves and therefore bank erosion.

In the early 1900's Kofoid (1903) described the Illinois as a relatively clear stream. Since that time, river activity and land use has changed so dramatically that waters of the Upper Mississippi River System are turbid year around. Johnson (1976) and Karaki and van Hoften (1974) observed increases in turbidity associated with tow traffic. However, Moss (1977) found only a weak correlation between boat traffic and turbidity in a British stream. He suggested that nutrient loading was the primary cause of turbidity. Boat traffic is a significant cause of turbidity in the Upper Mississippi River System but it must be remembered that there are many other sources.

Ellis (1936) and Peltier and Welch (1969) stated that turbidity alters aquatic habitats in several ways: (1) screening out light; (2) changing heat radiation; and, (3) contributing to sedimentation. Such factors as changes in temperature and light regimes can drastically alter ecosystems and create wholesale changes in community structure and function.

Ellis (1937) suggested that the greatest limiting factor to aquatic life in the Missouri River was turbidity. Problems in reproduction, spawning, respiration, photosynthesis, and finding food can result from turbidity (Mills et al. 1967, GREAT II 1980). Wange (1974) found that turbidity interfered with algae growth and Buck (1956) found that clear ponds produced 13 times more plankton than turbid ponds. Mills et al. (1967) suggested that turbidity, among other things, may have contributed to the disappearance of fingernail clams and macrophytes from portions of the Illinois River. Moss (1977) and Peltier and Welch (1969) suggested that macrophyte growth rates were reduced because of turbidity. Buck (1956) found clear ponds to produce five times more fish than turbid ponds. He also suggested that turbidity altered fish community structure, selecting for carp and catfish and retarding the growth of largemouth bass.

The Academy of Natural Sciences of Philadelphia (1980) assessed the effects of tow traffic on the biological components of the Ohio River. They calculated that an increase in tow traffic from 8 to 12 and 20 tows/day would have insignificant effects on wave wash since wave heights were predicted to be less than 4 inches (ANSP 1980:2). They did not however address impacts of littoral phytoplanktonic production in fine-grained sediment areas if the fine material was continually winnowed from wave-caressed river banks (ANSP 1980:9). Their assessments were based on predicted physical impacts from previously developed equations, rather than from actual field measurements.

Drawdown Effects

Drawdown due to vessel passage may result in periodic exposure of shoreline and backwater substrates. Exposure generally lasts less than several minutes. The magnitude of tow drawdown is related to vessel displacement, velocity, direction of travel, and mid-ship cross-sectional area (Hurst and Brebner 1969), e.g., a large loaded vessel moving swiftly downstream causes the greatest drawdown. Small, empty, or slow-moving vessels cause only slight drawdowns while pleasure craft generally cause none at all. It must be stressed that the vessel cross sectional submerged area to river area ratio is important and in large river areas vessel-caused drawdown is seldom observed. Gelencser (1977) conducted additional studies on the St. Lawrence Seaway which support these results.

One of the major impacts on aquatic populations resulting from drawdown is the flushing action. Large volumes of water containing plankton, larval fish, and some invertebrates (especially surface dwellers such as waterstriders and whirligig beetles) can be drawn from sloughs and backwaters during drawdown. This serves to diminish backwater populations but may be an important energy input to main-channel food chains. Claflin (1976) presented data that demonstrated the effects of tow passage on the exchange of sediment between the Mississippi River and Raft Channel.

Another impact of drawdown is the periodic exposure of substrates. This may expose a variety of organisms such as oligochaetes, midges, odonates, mussels, invertebrates eggs, fish spawn, and may temporarily strand organisms. Single short duration exposure (up to several minutes) may not be critical but prolonged periods of pool drawdown and frequent short duration exposure may cause organisms to perish, thus limiting the diversity and density of drawdown zones. Some organisms can tolerate a wide spectrum of environmental conditions and may continue to thrive under drawdown conditions, while others may be less tolerant and be effectively eliminated. Biological drawdown impacts were assumed to be less significant than those of velocity and pressure changes in a 60-foot band centered on the tow sailing line in the Ohio River (ANSP 1980:1-2).

Sparks (1975:20) concluded that drawdowns of water resulting from passage of towboats can expose portions of the bottom and bottom-dwelling organisms on the Illinois River. Once again, the magnitude and distribution of this impact on the UMRS has not been well documented.

EFFECTS RELATED TO PRESSURE AND VELOCITY CHANGES

Boats generate a complex association of velocity and pressure changes within a navigation channel. These changes generally take two forms: acceleration of flow and turbulence. Both aspects cause resuspension of sediments in the river.

The amount of sediment resuspended Is dependent on many factors, reviewed below.

The increased velocity and turbulence produced by a barge tow will increase resuspension of sediments dramatically. Liou and Herbich (1976) developed a numerical model of this velocity increase using the momentum theory of the propeller. They simulated the velocity distribution downstream of the propeller and obtained the shear velocity and shear stress. From this, knowing data about a particular ship, the velocity distribution and the grain size of particles which will be moved can be obtained. Thus we can mathematically determine how much a particular barge will affect resuspension of sediments. Besides resuspending sediments, this increased velocity can transport sediment to side channels and backwater areas.

Karaki and van Hoften (1974:2-4) describe the flow changes caused by a barge:

> "Beneath the surface, a complex turbulent flow pattern is generated. (There is an increase in velocity of water beneath the boat relative to the mean velocity in the river.) The acceleration of flow depends on the proximity of the bottom of the barge to the river bed and is due to pressure differences created by the water surface profile along the sides of the barges. The interaction of the two flow patterns create a region of marked turbulence and increased velocities along the sides. The propellors of the tug also add turbulence to the already disturbed flow caused by barges. Depending on the proximity of the boat to the streambed and the sizes of bed material, a certain amount of bed sediment is either moved on the bed or suspended in the flow. The material in suspension will remain until the turbulence decays sufficiently for the material to settle out."
>
> "With either a shallow draft or a deep channel, even though turbulence is generated around the towboats, the effect of disturbances on the riverbed is small. With deeper draft and less clearance between the keel and riverbed, which Is the more normal situation with towboats on the river, a flow pattern with a large separation region at the sides and accelerated flow beneath the boat results."

In observing barge-induced velocity changes in a side-channel of the Illinois River, Johnson wrote:

> "The passage of a single upstream tow increased current velocities in the side channel at the surface from 0.25 m/sec before the tow passed to 0.41 m/sec after the tow passed. Currents measured at mid-depth in the side channel increased from 0.20 to 0.31 m/sec after the tow had passed." (Johnson 1976:84).

Johnson (1976:126) observed the effects of speed and type of traffic.

> "It appeared that faster moving tows had a greater effect on resuspending sediments than did slower moving tows. Also, multiple tow traffic produced additive effects and maintained previously elevated concentrations caused by prior traffic."

Barge effects can vary in different rivers and even in different sections of the same river, as Karaki and van Hoften noted (1974:26-27).

> "Large towboats cause greater resuspension of sediments in the channel than smaller pleasure crafts due to their size and proximity to the river bed.' The Illinois River is more susceptible to these effects than the Upper Mississippi River because of the finer bed material and generally shallower depths. Increasing river traffic will increase resuspension and thus turbidity at a rate proportional to the frequency of towboat passage."

The GREAT I Water Quality Work Group (1978) studied the effects of the first barge tow of the season on water quality in Lake Pepin:

> Fine sediments, contaminated with metals, nutrients, and PCB's were resuspended during passage of the initial barge tow before ice had completely disappeared from the lake. Release or dissolution of contaminants from resuspended sediment to the water column was not evident. Elevations in several parameters, particularly suspended solids, and a decrease in pH were observed immediately after initial barge tow passage, but concentrations generally returned to background within six hours. Water quality Impacts from subsequent barge tow passages were not discernable.

The effects of barge traffic events on main channel and main channel border velocities, pressures and water quality were studied on the Illinois River reach of Pool 26 and the Mississippi River in Pool 9 between August and October 1980 (Environmental Science and Engineering 1981):

> The results of the analysis of the backwater velocity components indicate that near-bottom velocities were substantially affected by tow passage. Upstream tows frequently doubled or tripled the ambient backwater velocities for 2 or 3 minutes. Downstream tows readily reversed the river flow for approximately 2 minutes. The resulting upstream veolcities frequently equaled or exceeded ambient downstream river speed. The backwater velocity changes produced by passing tows were generally between 0.5 and 1.0 ft/sec. Offshore components of the Induced velocity frequently exceeded 0.2 ft/sec.
>
> Although tow traffic significantly changes the river velocity for a short period, the impacts on the sediments and river ecology may not be as great. Tow traffic, however, does contribute to increased resuspension of sediments. Fine sand (0.1 ram) can be resuspended as the velocity exceeds 0.3 ft/sec. Consequently, whenever the tow-induced currents in combination with the ambient river velocity exceed 0.3 ft/sec, unnatural resuspension of sediments will occur. Once the sediments are in suspension, they will remain in suspension because the ambient river velocity is usually above the settling velocity for this size sediment. This occurrence, however, must be evaluated with knowledge that the natural river velocity frequently exceeds 0.8 ft/sec. Consequently, sediment resuspension and transport are continuous natural processes, and the added sediment resuspension potential created by river traffic may not produce significant impacts on the ecology of the river. The major effect of river traffic on suspended sediments will be to eliminate period of relatively low turbidity that might occur during low river flow.
>
> The pressure and water quality measurements indicated that the effects of tow passage on pressure, DO, conductivity, pil, temperature and transraissivity adjacent to the navigation channel were nearly undetectable. However, measurements were not made directly under the tow where impacts would be the greatest. Also, the study was designed to detect short-term changes caused by individual tow passages, and any long-term effects of river traffic on water quality could not be determined from the data.

In addition to creating turbulent flow patterns and increasing current velocities by their very act of passage, barges and tows also create such changes in water velocity and pressure through the waves they generate. One study which relates wave characteristics to changes in water velocity at the bottom of a channel reports that this velocity increases with an increase in wave height or wave period, and decreases with an increase in water depth. The maximum velocity for any wave occurs in the breaking region; thus, sediment movement would be maximum in this region (Herbich and Brahme 1977).

An extensive study of velocity pressures, and waves generated by boat traffic is presently being concluded (Berger Associates, Ltd., et al. 1980). Existing equations are selected and used to predict the effects of coramerlcal navigation on sedimentation, erosion, and water quality. An extensive bibliography which emphasizes European experience and analysis is included. Specific equations are recommended for calculating wave height and propeller jet velocity.

Fuehrer and Romisch (1977) give detailed equations for drawdown and backflow velocity in European canals due to barge tows. They also present information on propeller jet expansion behind a tow boat. Ballin et al. (1977) present similar data for European canals and for a moveable-bed model study of propeller jet effects on canal beds. The model results are difficult to scale up to prototype conditions but indicate clearly the area and pattern of bed material movement due to tow boat propeller jets in navigation canals.

Environmental Science and Engineering (1981:3-10, 3-16) compared actual data from Mississippi and Illinois River barge traffic events to calculated results from equations used on the Ohio River (Berger Associates, Ltd. 1980, U.S. Army Corps of Engineers, Huntington District 1980):

> In 82 percent of the cases, the model underestimated the measured velocity. For the data collected near shore (Pool 26, 40 feet from shore), the model underestimated the velocity by a factor of 2. The offshore velocities were underestimated by an average of 30 percent. This amount of error, however, is not unreasonable considering the number of parameters that influence the velocity field. Also, the measured parameters, such as the velocity, tow speed, distance from shore, etc., all have margins of error that could contribute to some of the scattering in the data points. . .
>
> . . . since the model consistently underestimated the velocities, a correction equation was developed so that the model would better fit the data collected on the Upper Mississippi River system. . . The correction equation did not reduce the scatter in the data, but it did eliminate the bias toward predicting values that were too low. The final model results provide realistic estimates of backwater velocities that can be expected from passing tows.
>
> Even though the model provides good estimated for backwater velocities, there are assumptions and simplifications in the model development that limit the model's ability to describe the velocity generated by passing tows. The model is one-dimensional, which

> means it only considers flow parallel to the river channel. The measurements indicated that passing tows frequently produce offshore velocities greater than 0.2 ft/sec. These velocities are not large, but they are approximately equal to the ambient river speed measured on Pool 26. The unnatural offshore component may be important in transporting sediments, eggs, or larvae into or out of the navigation channel. Also, the model uses a depth-integrated velocity technique which does not consider variations of velocity with depth. Since the velocity measurements on Pool 26 indicated the velocity near the surface may be 1.5 to 2.0 time greater than the velocity measured 1 foot from the bottom, the generated velocities from passing tows are undoubtedly greater at distances further from the bottom. Since the final model was calibrated with data collected 1 foot from the bottom on Pool 9 and Pool 26, it will still underestimate velocity changes at mid-depth or near the surface.

Tow generated turbidity plumes in the Illinois and Mississippi Rivers caused by velocity changes and turbulence were photographed and tracked by Link and Williamson (1976). Sparks (1975:6) showed that turbidity in the main channel at mile 25.9 on the Illinois River required approximately 2.5 hours to fall back to background levels after the passage of tows.

Similar results were obtained by experiments conducted by the Illinois Environmental Protection Agency (Barganz 1976a, Barganz 1976b) who also demonstrated increases in river iron concentrations due to barge events. These results prompted the following statements by Dr. Richard H. Briceland, Director, Illinois Environmental Protection Agency (1976):

> As I have indicated above, wideranging, intensive efforts are now being made to clean up discharges to the Illinois River. Yet the Corps of Engineers seems to have discounted these efforts, as it relies heavily on the conclusion that existing barge traffic has had no appreciable impact on the admittedly marginal water quality which has characterized the Illinois River since commercial navigation facilities were first provided in the 1930s. This line of reasoning ignores the likelihood that as other causes of water quality degradation are corrected, the impacts of barge traffic may well become the single most important limiting factor on achievement of present water quality goals.
>
> In its Final Environmental Statement dated July, 1976, the Corps estimates that by 1985, the number of tows on the Illinois will increase to an average of one every 90 to 120 minutes. It also projects that, by 2035, the lower Illinois (below Peoria) will be sub-

jected to just over one tow per hour. Given what recently-available data suggest to be the recovery time following tow passage, these projections raise serious questions about whether water quality degradation related to resuspension of bottom sediments will even be reduced to what are now considered acceptable levels.

Sparks et al. (1978) studied the effects of lock closures and traffic reduction on the turbidity of the Upper Illinois River. Recent statistical analysis of their data has shown that both tributary discharges and boat traffic contribute to the background levels of turbidity in the Upper Illinois River (Sparks et al. 1980). The return of tow traffic to normal levels increased total suspended solids an average of 19 mg/l, representing a contribution of approximately 30-40% to the average total suspended solids concentrations at all sites in October 1978.

Direct biological effects of velocity and pressure changes caused by boat traffic were estimated by the Academy of Natural Sciences of Philadelphia (ANSP 1980). Their predictions of turbidity plumes generated by turbulence and velocity changes were limited to a 60-foot wide band centered around the line of traffic and assumed no overlap of turbidity events occurred (ANSP 1980:6). They predicted that an increase in traffic from 8 to 12 or 20 tows/day could reduce carbon fixation (the light-dependent reaction of photosynthesis) by 6-17%. ANSP (1980:29) also stated that the most serious effects of increased traffic on Ohio River fish would be through entrainment of larvae and juveniles in propellers. It should be noted that most of their predictions of biological effects were based on modeled physical effects. No attempts were made to predict effects in off-channel habitats.

Mueller (1980) studied the effects of recreational traffic on the nesting behavior of longear sunfish and found the degree of behavioral disturbance depended on proximity of the nest to the line of traffic, the substrate type, the speed of the boat, and the degree of protective cover available.

INFORMATION GAPS

The purpose of this section is to point out specific types of currently unavailable information that we consider necessary in order to comprehensively predict the present and future physical, chemical, and biological impacts of navigation on the Upper Mississippi River System. After a General Section, the organization of the section matches that of the NAVIGATION EFFECTS SUMMARY rather than being an indication of priorities. The second report for this phase of the Navigation Effects Study will expand on these information gaps, prioritize them, and describe research efforts or monitoring programs that could provide the necessary information.

General

The few short-term studies that have addressed cause and effect relationships related to navigation have stressed singular causes and effects. Many of the either potential or demonstrated impacts of navigation can result from more than one activitiy. For instance, increased sedimentation rates have been attributed to lock and dam construction, wing and closing dam construction, dredging and spoil disposal, and may additionally be influenced by boat traffic. In cases like this, the relative contribution of each activity to the overall impact needs to be quantified.

Similarly, most short-term studies have not addressed the relative contributions of the navigation system to impacts that are also caused by other river uses or even natural processes.

Almost all of the short-term studies that have addressed specific navigation effects have additionally been site-specific. Even short-term studies must be designed to make use of whatever systemic Information is available. This includes tributaries as well as main steal areas, and even tributaries that do not support barge traffic. Smith (1971) for instance listed recent changes in Illinois stream fish populations and pointed out how some species have been decimated due to lower summer water levels which have been caused by channelization and the shorter time required for water to reach larger rivers.

Not enough information was obtained on the effects of traffic waste discharges or the development of fleeting areas along the Upper Mississippi River system to even warrant specific discussion of these activities in the NAVIGATION EFFECTS SUMMARY. These impacts may require site-specific assessments within the system..

The long-term potential impacts (beneficial oc detrimental) of navigation on water quality, habitats, and populations will not be able to be put on a comparable scale to the economic impacts of the system until acceptable methods are developed and used to determine both their present and future value. This is particularly critical information since it could influence economic cost-benefit analyses of navigation system projects.

A distributional atlas of all major aquatic and semi-aquatic species and habitats in the Upper Mississippi River system needs to be compiled as a reference source. This could probably be compiled with current information and updated every 10 years.

Information Gaps Related to Pool Construction, Operation, and Maintenance

Effects related to pool construction, operation, and maintenance are generally more long-term in nature than those related to boat traffic. As a result their study requires more than just short-term sampling programs. Long-term monitoring programs are necessary to assess long-term changes in sedimentation, water quality, and habitat quantity and quality.

Pool level regulation under the right circumstances appears to be an excellent opportunity for the navigation system to function as a tool for fish and wildlife managers. However, before water level control procedures can be recommended, far more information from pilot regulation projects is necessary.

System-wide contour maps and sedimentation rates for off-channel areas are necessary. Contour maps should be updated frequently, as often as every 2 years. Sediment budgets for selected representative pools need to be conducted at regular intervals of approximately 5 years.

Maps showing present wing and closing dams, revetments and all other shoreline protection areas needs to be updated regularly.

A survey of all unprotected banks needs to be conducted. This should include distances from main channel, bank composition and slope.

No action to stimulate winter navigation on the main-stem of the Upper Mississippi River can be recommended until more intensive studies, including short and long term pilot projects, have been completed and the impacts fully assessed.

Site-specific long-term monitoring of selected dredged and spoil disposal sites should be conducted, perhaps with tracers, to determine long-term trends in spoil movement and/or corresponding habitat loss.

Information Gaps Related to Boat Traffic

Perhaps the most important information gaps related to barge traffic is the absence of the system-wide contribution boat traffic has to the movement of sediment into backwater areas. First, methdology needs to be developed to measure both short- and long-term movements of boat generated resuspended sediments into backwater areas. Then these methodologies need to be applied at more selected sites on the Upper Mississippi River system and the measured rates compared to those caused by other sources (i.e., natural runoff, dredging).

System-wide bank erosion caused by both commercial and recreational traffic needs to be measured and the relative importance of these sources quantified.

Relatively little biological information is available on the effects of boat traffic. All of the following areas will require studies to measure present impacts and predict future impacts:

- wave effects on aquatic vascular plants, terrestrial shoreline communities, nearshore benthic and epibenthic organisms;
- drawdown effects on the same groups;
- effects of main channel and main channel border velocity and pressure changes on plankton, benthos, and fish at all life stages;

- effects of release of pollutants such as gasoline, oil or sewage wastes from boats (commercial and recreational) on aquatic organisms;
- behavioral effects of boat traffic on Upper Mississippi River system aquatic animals;
- effects of entrainment of aquatic organisms by propellers.

Matrix Display of Information on Physical and Chemical Effects of Navigation (numbers refer to citation order in annotated bibliography)

Navigation Activities	Waves	Water Velocity and Pressure	Sediment Deposition	Sediment Resuspension	Shore/bank Erosion	Side Channels and Backwater Lakes	Water Quality
High locks and dams		24, 39, 46, 74, 126, 148	12, 25, 39, 77, 103, 123, 126, 132, 138, 148, 150	39, 123, 126, 132, 148	148	12, 25, 77, 103, 126, 132, 138, 148, 150	21, 39, 74, 132, 148, 150, 154
Wing and closing dams		59, 116, 118, 123	51, 59, 98, 101, 109, 116, 130, 150	116	39, 51, 98, 116, 118, 145	19, 25, 27, 29, 30, 39, 48, 101, 109, 116, 117, 130, 150	32, 48, 59, 101, 130
Bank stabilization		126	39, 98	98, 126	16, 39, 73, 98, 111, 116, 118, 122, 126, 145	98, 126	
Water level regulation		126, 148	12, 126, 148	126, 132, 148	17, 148	19, 59, 109, 126, 148, 150	21, 132, 148
Dredging		34, 39, 96, 107, 116, 119, 120, 123, 126, 148	2,3,18,33,39 53,57,58,107 119,148	2, 3, 18, 39, 53,57,58,107, 119,148		34, 58, 96, 116, 119, 120, 126, 148	2, 3, 18, 33, 39, 59, 64, 71, 107,112,119,148
Winter navigation	4, 59, 115	4, 59, 115	105	59, 105, 115	4, 105, 146	105	59, 105
Clearing and snagging		51, 96, 116			111	25	100
Boat traffic (general)	1,14,15,37, 49,54,59,65 80,81,82,85 127,128,156	1, 5, 14, 39, 44 50, 52, 54, 59, 78, 85, 94, 95, 156	14	5,6,14,53,54,55 56,57,59,60,78 85,94,95,108, 129,133,134,156,157	14, 22, 37, 55, 60, 73, 80, 151	39, 44, 78	1,5,6,14,39,44, 54,56,59,61,76,78 85,97,108,121,133 134,141,156,157
Wave action induced by navigation		15, 49, 70, 81, 82, 85, 127, 128	151	14,15,70,85, 129,145,148, 151,156	1,5,14,15,17,22,37, 39,60,65,73,80,85, 128,129,151	39, 65, 129	39, 129, 145
Water velocity and pressure induced by navigation		1,5,14,28,39,44, 50,52,73,78,85, 94,95		5,6,14,44,50, 56,78,85,94,95 108,148,156	50, 52, 73, 129	1, 28, 39, 44, 52, 73, 78, 129	1,39,44,54,56,59, 61,78,85,97,108, 121,129,141,156

Matrix Display of Information on Biological Effects of Navigation
(numbers refer to citation order In annotated bibliography)

Navigation Activities	Habitats		Populations							
	Aquatic	Terrestrial	Aquatic Plants	Terrestrial Plants	Plankton	Benthos	Fish	Birds	Aquatic Furbearers	Other Wildlife
High locks and dams	54, 55, 59, 116, 150	54, 55, 59 150	54, 59, 62, 63, 150	54, 59, 150, 155	54, 59, 152	54, 59, 75, 139	31, 47, 54, 59, 72, 114, 144, 150	54, 59, 62, 150	11, 54, 59, 62	54, 59, 150
Wing and closing dams	19, 51, 54, 59, 88, 116, 117					54, 59, 84	54, 59, 99, 12[illegible] 137			
Bank stabilization	54, 59, 89, 116	89, 142				142	54, 59	142	142	142
Water level regulation	8, 9, 13, 19, 59, 66, 109, 150	13, 66	10, 13, 66, 87, 93, 150, 155	66, 150, 155		45, 87, 143	24, 26, 66, 86	66	11, 66	66
Dredging	2, 71, 107		2, 71, 107		2, 71, 107	2, 71, 107	2, 71, 107			
Winter navigation						59, 105	59, 105		105	105
Clearing and snagging	34, 51, 96, 100	34, 51, 96, 100				96, 100	96, 100			
Boat traffic (general)	129		106, 129		1, 129	1, 106, 129	1, 129			
Wave action induced by navigation	28, 129		129		1, 129	1, 129	129			
Water velocity and pressure induced by navigation	1, 105, 134					1	1			

ANNOTATED BIBLIOGRAPHY

Annotations for the following citations have been taken if possible from abstracts, conclusions, or summaries within each reference. If these were not available, we annotated the citation by stressing information that seemed most pertinent to our objective of identifying navigation effects. In some cases, annotations were taken from previously compiled annotated bibliographies. In these cases, the source bibliography is identified.

1. Academy of Natural Sciences of Philadelphia. Analysis of the effect of tow traffic on the biological components of the Ohio River. Huntington: U.S. Army Corps of Engineer District; 1980. 47 p.

The interpretation of biological impacts on the Ohio River caused by increased tow traffic has been based on physical data provided by Louis Berger and Associates, Inc. (1980). It is our judgment, based on these data, that most physical impacts as generated by upstream loaded tows are not significant. Consequently, estimates of biological impacts are conservatively defined and are based on "worst-case" conditions. This decision was in part necessary because of the lack of baseline information on Ohio River referenced biological groups and by the general nature of these impact studies.

It is expected that barge traffic will increase from 1976 levels of 8 upbound, loaded tows/day to 12 and 20 upbound, loaded tows/day in 1990 and 2040, respectively. Approximately 10% of these will, in later years, be in excess of 4500 hp. Of the ten test transects located on the Ohio River, only one will experience turbidity related impacts 2 kg/m^3 after passage of a maximum hp tow (upbound, loaded) during normal flow conditions. Duration of turbidity levels above ambient would persist for less than 35 min and generally for less than 15 min (with only 5 exceptions being recorded out of 30 test situations).

Other impacts from wave wash and back flow velocities are considered even less significant as wave' heights are normally less than 4 in and backwater flow velocities are usually well under 1 ft/see. According to Louis Berger and Associates, Inc. (1980) it would take 50 tows to deliver as much energy to the river banks as a 4-h storm with wind velocities of 40.0 ft/sec. However propeller jet flow velocity may cause direct physical damage to benthic organisms and propeller entrainment may kill pelagic or drifting animals. These points will be addressed with respect to particular life groups.

Impacts which have not been adequately predicted but which may require additional consideration include spillage of toxic materials and shore-zone mooring. To some extent, shore-zone mooring after locks and dam renovation will be reduced. However, mooring areas and emergency cells should be located in low-impact areas, as navigation use impacts are particularly critical during fish spawning periods.

Five gcoups of organisms will be discussed in the following sections. They are: phytoplankton, non-insect invertebrates, insects, and fish.

2. Allen, K.O.; Hardy, J.W. Impacts of navigational dredging on fish and wildlife: a literature review. Vicksburg, MS: U.S. Fish and Wildlife Service, Biological Services Program; 1980. 81 pp.

Literature about the impacts of navigational dredging on fish, other aquatic biota, and wildlife is reviewed. Also included are types of dredging equipment, characteristics of dredged material, evaluation of dredged material pollution potential, and habitat development and enhancement opportunities arising from dredged material disposal. The review con-

tains a brief discussion of the state of knowledge and refers the reader to pertinent literature for additional information. The discussions about impacts and habitat development are divided into "Coastal Waters" (including disposal in estuarine, continental shelf, and deep ocean waters) and "Rivers." A limited discussion of the "Great Lakes" is included as an Appendix.

3. Anderson, D.D.; Whiting, R.J.; Jackson, B. An assessment of water quality impacts of maintenance dredging on the Upper Mississippi River in 1978. St. Paul, MN: U.S. Army Corps of Engineers; 1981. 125 pp. + appendices.

In 1978, the St. Paul District, Corps of Engineers, monitored five dredging operations at various locations on the Upper Mississippi River, including three hydraulic dredging operations and two mechanical (clamshell) dredging operations. All five studies were conducted in areas with relatively coarse sediments (less than 10 percent silts and clays).

In the four turbidity and suspended solids studies, no changes or only minor changes in water quality were found to result from either the hydraulic or clamshell dredging activity. The study that monitored the effluents from a confined on-land disposal area indicated slight elevations in turbidity and suspended solids but noted that these levels had returned to ambient within 1000 feet downstream of the disposal area.

In the study which also monitored chemical and microbiological parameters, no significant increaes below the hydraulic Cutterhead were evidenced for any of the physical, chemical, or microbiological parameters investigated. The effluent from the confined on-land disposal area contained concentrations of some parameters (especially iron, manganese, and the physical parameters) that exceeded the pre-dredging and upstream control values. However, only iron and manganese were found to be significantly higher downstream of the disposal pipe than in upstream control values. Daily fluctuations in concentrations for most of the parameters were fairly substantial and tended to mask any impacts caused by dredging.

Overall, with the methods used for disposal of the dredged material at the five sites studied, no major degradation of water quality was evidenced for either the mechanical (clamshell) or hydraulic dredging and disposal operations.

4. Ashton, G.D. Evaluation of ice management problems associated with operation of a mechanical ice-cutter on the Mississippi River. Hanover, N.H.:U.S. Army Corps of Engineers Cold Regions Research and Engineering Lab. Prepared for Department of Transportation, U.S. Coast Guard; October, 1974.

Ice management problems associated with operation of a mechanical ice cutter for use in icebreaking us an aid to winter navigation were examined. The study concentrated on effects occurring after the cutting operation. Included In the evaluation were assessments of refreezing rates, movement and disposition of the slabs produced by the cutting, and examination of effects related to ice jams. The evaluation was specific to the upper Mississippi River; in particular Pool 19 above Lock and Dam 19 at Keokuk, Iowa. It was found that most ice production during a winter occurs

during a small fraction of the period of ice cover; hence, removal after these short periods may allow navigation to proceed for significant wintertime periods. A relation was found between cut slab dimensions and critical velocity to move them that will enable estimates to be made of accumulation. Breakage of adjacent ice by vessel waves was found to impose a possible restraint on vessel speed but not a serious one.

5. Ballin, C.-W.; Brandenburg, G.; Felkel, K.; Hager, M.; Masson, M; Muller, E.; Obius; Schale, E.; Wetzel, V. Rapport. Proceedings of the 24th International Congress, Leningrad; 1977.

A considerable amount of knowledge has been acquired over the past years by virtue of systematic investigations as regards the behavior of inland vessels in restricted waters, besides the occurrence of the reciprocal effect between ship and waterway. In this connection, model tests have been carried out whenever possible. Where the reduced size model proved ineffective, recourse was had to the one of natural size, i-e., to the experiment in nature itself. Particular emphasis is had on the Main-Danube Canal, the Rhine, the Main and the Danube, in addition to results obtained from measurements on sea vessels in the North-East Sea Canal and in coastal waters. The experiments with inland vessels extended to their behavior during travel and their dependence on the form of convoy and their means of propulsion, to waterways of varying dimensions and to the draught, as well as to the causes of wave and current formation, to a tendency to the lowering of the water level, the lowered squat of the vessel and to the effects occurring on the bottom and on the slopes of the waterway. A Check on traveling behavior in curves and in the meeting of different types of vessels and convoy formations was secured by recourse to radar phase pictures. The results in their incidence have exercised an impact on the reckoning methods in the matter of fairway breadths and led to appropriate definitions being reached where waterway extensions are involved. The water level's deformation was determined by stereographic photographs of coutour maps represented by longitudinal and transversal cross-sections: less satisfactory values have been observed in the case of the usual self-propelled goods craft as against pushed convoys and pushed lighters. Current measurements, especially those near the bottom, provide a clear picture of the hydrodynamic conditions in the vessel's vicinity and of the resultant consequences to be deduced as regards the occurrence of stress to bottoms and slopes. The measurements applicable to a vessel's lowered squat yielded criteria of the traveling speed in the case of differing water depths and depths, as well as of draught conditions obtaining in respect of different types of vessels and convoys. Tests made on the Upper Rhine have provided confirmation of the deformations caused by vessels to mobile water bottoms. In this connection, sole deformations depend on the distance separating the vessel's means of propulsion, the water's bottom, and the direction of the effects at the same location. In the light of observations in nature and on models, particular requirements are engaging attention here, special regard being had to the effect exercised by high-powered push-craft. The behavior of sea vessels and the reciprocal action affecting slopes and bottoms, as well as the influence exercised by cross-shoots, widened fairways and docks have been subjected to model tests on the canal linking the North Sea with the Baltic The behavior during travel of seagoing vessels in estuaries provide indications, especially where the move-

ment of large vessles La narrow fairways is concerned. The answer to the questions of requisite fairway measurements for large tankers has been secured by measurements in nature in the Jade's navigable channel.

As regards the safety problem of high slopes, notable practical experience has been gathered on the Baltic-North Sea Canal. Provision for the safety of embankments against the effects of ships' waves is a necessity; tests are being undertaken on new types of revetments.

6. Barganz, R. Memo regarding Illinois River - barge traffic influence on water quality. Illinois Environmental Protection Agency; 1976a.

This memo contains a brief summary and field survey results of barge traffic effects on the Illinois River near Seneea in Grundy County.

7. Barganz, R. Memo regarding Illinois River survey - barge traffic influence on water quality. Illinois Environmental Protection Agency; 1976b.

This memo contains a summary report with conclusions about a field survey of barge traffie effects on the Illinois River near Seneca.

8. Baxter, R.M. Environmental effects of dams and impoundments. Ann. Rev. Eco. Sept. 8:225-283; 1977.

Although reservoirs have sometimes been referred to as "embryo lakes" (106), they are probably better regarded as a distinct type of freshwater ecosystem differing from both streams and lakes. Many are characterized by a highly developed shoreline, a longitudinal profile with its maximum depth near the downstream end, a complicated flow pattern often involving discharge from the hypolimnion, and a pattern of seasonal variation in water . level involving a long period of flooding and a short period of exposure. Because reservoirs are frequently built on streams carrying a heavy sediment load, the deposition and distribution of this material within the reservoir are often more important in reservoirs than they are in natural lakes. Therefore constraints on the nature of the developing biological community are imposed when a new reservoir is constructed. Large impoundments now exist under a variety of climatic and geographical conditions. Since not all the hydraulic head of the world's rivers has yet been utilized, it seems likely that more remain to be built. Certainly the rate of construction of smaller reservoirs shows no sign of diminishing (107). Will there be further ecological surprises?

The development of reservoirs in the temperate regions has been more gradual. Experience with smaller reservoirs has consequently been applicable, within limits, to larger ones. Moreover, the generally lower rate of biological processes at higher latitudes has made their effects less dramatic, and perhaps has allowed more time to arrest and reverse undesirable effects before they become irreversible, as for example, the drying up of the Peace-Athabasca Delta. It seems unlikely that subsequent impoundments in the temperate regions will give rise to any large-scale surprises. On the more detailed scale likely to be of importance to man, much remains to be learned. How the flooding of a certain area will influence the runs of

salmon up it, are likely Co be matters of intense concern to the people whose livelihood depends on these resources. Such questions can only be answered by a careful and thoughtful Lavestigation of all possible aspects of the ecology of the region.

9. Baxter, R.M.; Gluade, P. Environmental effects of dams and impoundments in Canada: experience and prospects. Can. Bull. Fish Aquat. Sci. 205:1-34; 1980.

Although dams and reservoirs have contributed immeasurably to the well--being of Canadians they may have side effects which may be detrimental to the environment and to human welfare. In this Bulletin, the authors survey the environmental consequences that have ensued from dam construction and the impoundment of water in Canada in the past, and attempt to alert environmentalists and engineers to the types of problems that may be associated with such activities in the future. Some of these effects are immediate, direct, and obvious, such as the loss of resources by flooding, interference with the passage of fish, and environmental damage and pollution as a result of construction activities. Others may manifest themselves only over a period of time, such as changes in water chemistry and modifications of the new shoreline. This last is likely to be of particular importance in reservoirs on permafrost. Large impoundments may influence the climate in their vicinities and sometimes induce earthquakes. Still other consequences follow from the mode of operation of the reservoir. Low-level discharge through turbines may radically alter the temperature regime in the stream below. The induction of an unnatural seasonal pattern of water level flucuation may lead to the formation of a virtually barren drawdown, sometimes at great distances. Many of thse effects act in various and sometimes opposing ways on the living organisms in the reservoir and the stream so that the ultimate biological consequences often cannot be confidently predicted. It is sometimes difficult to reconcile the interests of those who stand to benefit from a given project and the interests of others who are likely to suffer a loss from it. This conflict is particularly acute when the project affects communities of native peoples following a traditional way of life. Such fragile societies are likely to be gravely disrupted unless particular care is taken.

10. Bellrose, F.C. Duck food plants of the Illinois river valley. Illinois Natural History Survey Bulletin 21:237-280; 1941.

The major waterfowl habitat in Illinois extends along the Illinois River for 140 miles, coinciding with the distribution of bottomland lakes. The water levels of the river and the connecting bottomland lakes customarily fluctuate greatly with the season. Recently navigation dams have stabilized water levels in many lakes. At other lakes, natural and artificial levees stabilize and control water levels. With respect to water levels, the bottomland lakes lying adjacent to the Illinois River may be grouped into three classes: stable, semistable and fluctuating. Abundance of aquatic plants in various lakes of the Illinois River valley was determined by plotting the vegetation beds on base maps and measuring the areas by means of a planimeter. Flood which occur between June and September may be destructive to aquatic plants. A reduction in the abundance of sago pondweed, American lotus, duck potato and river bulrush is often directly traceable to high water.

11. Bellrose, F.C., Jr.; Low, J.B. The influence of flood and low water levels on the survival of muskrats. J. Mammalogy 24(2):173-188; 1943.

    There can be Ittle doubt that a rL.se of five to seven feet of water during flood stage disrupted and reduced muskrat populations in certain areas of the Illinois River valley in October 1941. Exceptionally favorable environmental conditions, prior to high water early in October, had resulted in higher, better situated populations than usual.

    Muskrats were not without adaptibility to meet the crises of flood water. They attempted to repair and build their lodges higher and when the chambers become flooded they sought refuge on the tons.

    Cognizance has been taken of the effect high water may have on fairly high muskrat populations. While such occurrence are the exception rather than the rule, it is also true Chat the effect may be extensive, thereby perhaps seriously depleting the muskrat population over a wide area. Depletion from such unnatural elimatic causes may thus necessitate reduced muskrat trapping to insure against further depletion in the marshes.

    While muskrats may be harassed and decimated within a short time during flood conditions, those living under low water conditions may escape without serious loss in summer but may be seriously affected during Cold, winter weather.

12. Bellrose, F.C.; Paveglio, F.L. , Jr.; Steffeck, D.W. Waterfowl population and the changing environment of the Illinois River valley. Illinois Natural History Survey Bulletin 32:1-53; 1979.

    Fluctuating river levels adversely affect the development of aquatic and marsh vegetation on those bottomland lakes connected with the river at all stages. In the early years of the study, the more the lakes were separated from the river, the more extensive were their aquatic and marsh plant beds.

    During the earlier years of the study, aquatic and marsh plants disappeared from those lakes connected with the river at all water stages (and thus subject to water-level fluctuations). During the later years of the study, aquatic plants disappeared and the area of marsh plants greatly declined in all lakes, even in those enjoying a degree of separation from the elver and minimal water-level fluctuations. Increases in water turbidity and bottom softness, stemming form sedimentation, appear to he responsible-

    Sedimentation is rapidly filling in the bottomland lakes of the Illinois Valley, reducing their size, degrading water quality, and minimising the diversity of bottom depths. The fine silts and clays deposited on the bottoms when river water invade bottomland lakes are readily resuspended by wave action and the activity of rough fish. The consequent turbidity reduces the euphotic zone to such a shallow depth that aquatic plants can

no longer survive. Marsh plants have difficulty maintaining footings as bottom soils become softer.

13. Bellrose, F.C.; Sparks, R.E., Paveglio, F.L. , Jr.; Steffeck, D.W.; Thomas, R.C.; Weaver, R,A,; Moll, D. Fish and wildlife habitat changes resulting from the construction of a nine-foot navigation channel in the Illinois waterway from La Grange Lock and Dam upstream to Lockport Lock and Dam. Chicago, IL: U.S. Army Corps of Engineers District; 1977.

The subject of this report is the Illnois Waterway Federal nine-foot navigation channel project and its beneficial and adverse effects on fish and wildlife habitat. The construction of this navigation system was undertaken in the 1930's. It has allowed passage of commercial barge and recreational boat traffic from the Mississippi River navigation system to the Great Lakes navigation system.

This report only considers the portion of the Illinois Waterway contained within the Chicago District from La Grange lock and dam near Beardstown, Illinois, upstream to Chicago, Illinois. However, because the portion of the Illinois Waterway above Lockport lock and dam, at Lockport, Ilinois, was constructed by non-Federal interests from 1900 to 1922, and is heavily developed for urban and industrial use, this report concentrates on the portion of the Illinois Waterway from La Grange to Lockport locks and dams.

14. Berger Associates, Ltd.; Louis Berger and Associates, Inc; Academy of Natural Sciences, Environmental and physical impact studies for Gallipolis Locks and Dam, Ohio River; Phase I replacement study, Volume II: navigation impacts; 1980.

Volume I describes existing conditions. Volume II reviews and selects formula best suited for use In determining boat-generated waves, displacement velocities, and propellor jet velocities in restricted waterways. The use of these equations to estimate the boundary forces and likelihood of suspension or resuspension of sediment is described. Bank erosion by boat-generated waves is discussed. The report concludes with a summary of commerical navigation effects on various parts of the environment including air and noise pollution as well as water quality.

15. Bhowmik, N.G. Development of criteria for shore protection against wind-generated waves for lakes and ponds in Illinois. Univ. Illinois Water Resources Center Report No. 107, Illinois State Water Survey, Urbana; 1976.

A methodology was developed for estimating the height of wind waves *in* any lake for a given wind condition. Maximum wind speeds for five elimatologlcal stations in and around Illinois for the period of 1950-1972 were analyzed and a table was prepared showing the maximum wind speed for various durations and return periods. Statistical analysis of wind wave data collected from Carlyle Lake indicated that Rayleigh distribution fitted the wave height distribution reasonably well and that the nondimenslonal energy spectra followed $(f/f_m)^{-5}$ rule in the equilibrium range of frequencies. Boat-generating wave heights fitted Rayleigh distribution to some extent and a relationship was developed relating boat speed, maximum wave height, distance between the boat and the wave gage, and the draft of the boat.

From a consideration of various forces and physical properties of riprap particles and water, a relationship was developed to estimate the stable weight of riprap particles. Recoramentations as to the proper selection of gradation, range of sizes, thickness of riprap particles and their size distribution, and gradation and thickness of filter materials were also incorporated. A design procedure was developed and one specific design problem was solved showing in detail all the steps involved in an actual design problem.

16. Bhowmik, N.G. Lake shore protection against wind-generated waves. Water Resources Bulletin 14:1064-1079; 1978.

A method is reported for estimating the height of wind waves in any lake for a given wind condition. Maximum wind speeds from five climatological stations in and around Illinois for the period of 1950-1972 were analyzed and the maximum wind speed for various durations and return periods were presented. Statistical analysis of wind wave data collected from Carlyle Lake indicated that Rayleigh distribution fitted the wave height reasonably well and that the nondimensional energy spectra followed the $(f/fm)^{-5}$ rule in the equilibrium range of frequencies. From a consideration of various forces and physical properties of riprap particles and water, a relationship was developed to estimate the stable weight of riprap particles. A practical design criteria is proposed to stabilize lake shores against wind waves.

17. Bhowmik, N.G. ; Schicht, R. I. Bank erosion of the Illinois River. Contract Report to the U.S. Army Corps of Engineers, Chicago, District, Illinois State Water Survey; 1979; 243 p.

The present investigation of bank erosion along the Illinois River was initiated to study the impacts of increased diversion from Lake Michigan. A boat trip was taken to document and select some representative bank erosion areas of the Illinois River. Based on present and anticipated flow conditions, measured and estimated hydraulic parameters, bank stability analyses at each study reach were made following different accepted procedures. Stability analyses indicate that as far as the flow hydaulics are concerned, bank erosion along the Illinois River will not be affeeted by the proposed increase in diversion. In all probability, the main cause of the bank erosion of the Illinois River is the wave action caused by the wind and the waterway traffic. A future monitoring program is proposed to document and monitor areas of bank erosion along the river at a few selected locations during the actual diversion.

18. Boyd, M.B.: Saucier, R.T.; Keeley, J.W. ; Montgomery, R.L.; Brown, R.D. ; Mathis, D.B.; Guice, C.J. Disposal of dredge spoil. Problem Identification and Assessment and Research Program Development. Vicksburg, MS: Army Engineer Waterways Experiment Stations; Nov. 1972.

The navigable waterways of the United States have, through the years, played a vital role in the nation's economic growth. Their importance is reflected in the continuing major advance in total waterborne commerce which, in 1970, exceeded 1.5 billion tons. The Corps of Engineers, in fulfilling its mission in the development and maintenance of these waters, is responsible for the dredging of large volumes of sediment each year. Annual quantities are currently averaging about 300,000,000 cu. yd. in maintenance dredging operations and about 80,000,000 cu. yd. in new work dredging operations with the total annual cost now exceeding $150,000,000. In recent years, as sediments in many waterways and harbors have become polluted, concern has developed that dredging and disposal of this material may adversely affect water quality or aquatic organisms. A number of localized studies have been made to investigate the environmental impact of specific disposal practices and to explore alternative disposal methods. However, these studies have not provided sufficient definitive information on the environmental impact of Current disposal practices nor have they fully investigated alternative disposal methods. As a result, the Corps of Engineers was authorized by Congress in the 1970 River and Harbor Act to initiate a comprehensive nationwide study to provide more definitive information on the environmental impact of dredging and dredge spoil disposal operations and to develop new or improved dredge spoil disposal practices. The study was divided into four phases: (1) problem identification and assessment, (2) development of research program, (3) accomplishment of needed research, and (4) field evaluation of new or improved disposal practices. Phases 1 and 2 were assigned to the U.S. Army Engineer Waterways Experiment Station for conduct during FY72. This report presents the results of the problem assessment phase of the study and outlines the recommended research program.

19. Boyd, W.; Janecek, J. Future of the Middle Mississippi River. Paper presented at 37th Annual Meeting of the Upper Mississippi River Conservation Committee. St. Louis, MO; 1931.

This is a summary of a paper presented to the UMRCC in 1981. Several relationships between navigation system construction and operation procedures and the ecosystem of the Middle Mississippi River are discussed.

20. Buck, D.H. Effects of turbidity on fish and fishing. North American Wildlife Conference Trans. 21:249-261; 1956.

Fishery workers have known for many years that turbidity caused by erosion silt has a harmful effect on fish life - hence, fishing. Numerous studies have dealt with phases of this problem, but none of recent date have been concerned with a direct measure of how erosion silt affects fish growth and reproduction, basic food production, and fishing success. Our study on ponds and reservoirs in Oklahoma was designed. to eategorize and measure these influences.

For two years we collected data from farm ponds and large reservoirs, and during the second year we also had the use of a series of small hatchery ponds. The farm ponds - 39 in all, with a wide range of natural turbidi-

ties - were rotenoned and then restocked (with largemouth bass and bluegills or largemouth bass and redear sunfish) at the start of the study, in 1954. In the hatchery experiments, turbidities were created artificially. On the two large reservoirs - one muddy, one clear - natural, uncontrolled fish populations were studied and public fishing success was sampled.

21. Butts, T.A.; Evans, R.L.; Lin, S. Water quality features of the Upper Illinois Waterway. Ill. State Water Survey Report of Investigation 79; 1975. 60 p.

The dissolved oxygen resources of the Upper Illinois Waterway are depressed because of a combination of oxygen demand sources including carbonaceous and nitrogenous BOD, benthic biological extraction, and sediments. Because of these demands, maintenance of 6.0 mg/l DO in the stream system is difficult, and achievement of a minimum DO requirement of 5.0 mg/1 requires the nitrogenous and carbonaceous demand to be substantially reduced. Water quality data obtained from field surveys are summarized together with hydraulic and hydrologic data to determine wastewater treatment needs. Collection of the waterway algal types reveals that diatoms are the dominant group comprising about 85 percent of the total densities. However, algal concentrations do not impair use of the waterway for recreation. Fecal coliform bacteria densities decrease with downstream movement at a rate of 0.77 per day in the upper pools and 0.42 per day in the lower pools. About 9 percent of the total coliform bacteria population are fecal coliforms. Only 3 of 19 stations sampled met the bacterial quality standards required by the Illinois Pollution Control Board.

22. Camfield, F.E.; Ray, R.E.L.; Eckert, J.W. The possible impact of vessel wakes on bank erosion. U.S. Army Corps of Engineers, Coastal Engineering Research Center; 1979.

The physical characteristics of waterway banks including grain size, strength, moisture content, and porosity of the soil or rock are discussed. The natural processes which cause bank erosion are: stream velocity, wind-generated waves, ice, debris, and floods. Vessels moving on the waterway generate waves and propeller jets which may strike the bank and cause bank • erosion. Effects of speed blockage, and return flow are discussed. Critical areas are identified as moving or landing locations and channel bends.

23. Cawley, E.T. Biological impacts study of winter navigation, Pool 12, Upper Mississippi River. Dubuque, IA: Loras College, Environmental Research Center; 1978. 14 pp.

The effects of winter navigation on the biotic environment of Pool 12 in the Mississippi River were studied at ten stations during February and March, 1978. Water quality, plankton, benthic fauna and mammal movement over the ice were investigated during conditions of ice cover and spring thaw.

Water quality was very good under the ice. Low plankton concentrations and typical benthic fauna were sampled. While there was very limited mammal movement across the channel, there was abundant activity in the back sloughs and side channel areas.

The major area of potential impact is in the bends and river crossings which are sites of ice gorge development during ice braking activity. Since navigation had ceased before the start of the study, no comparison data was available.

Further study should concentrate on the ice gorge areas. The studies should investigate the direct effect of ice damage on the benthic community, the modification of flow, and the effect of increased siltation from tow boat activity. Commercial fishermen should be surveyed for their observations, and mammal activity during ice breaking should be evaluated.

24. Carlander, H.B. History of fish and fishing in the upper Mississippi River. Upper Mississippi River Conservation Committee; 1954; 96 p.

This report summarizes historical studies and reports of fish populations on the Upper Mississippi River previous to 1954. Most of the reports were scattered throughout the literature, and while considered useful for this work, were too general to be of much use in intensive analysis.

25. Chen, Y.H.; Simons, D.B. Geomorphic study of upper Mississippi River. Journal Waterway, Port, Coastal, and Ocean Division, ASCE 105(WW3):313-328; 1979. Proc. Paper No. 14778.

In order to estimate the effects of removal of snags hazardous to navigation and construction of dikes, revetment, and locks and dams in the river geomorphology, the past and present geomorphic features of the upper Mississippi River were studied. The geomorphic features studied include: riverbed surface area, surface widths, water depth, side channels, and riverbed elevations. The study results indicate that natural and man-induced activities in the last 150 years have produced subtle changes in the river geomorphology. The low dike fields narrowed the river, created new islands and chutes, and enlarged old islands. Locks and dams have widened the river and increased the number of islands in the pools. It was concluded that 50 years from now the river scene of the Upper Mississippi River will be essentially as it is today if no major man-made changes or natural events occur.

26. Christenson, L.M.; Smith, L.L. Characteristics of fish populations in upper Mississippi River backwater areas. U.S. Dept. Interior, Fish and Wildlife Service, Bureau of Sport Fish and Wildlife Circular 212:1-53; 1965.

Standing crops of fish and their fluctuations from year to year, age and size class structure of the populations, and growth rates of the common species present in three backwater areas of the upper Mississippi River were determined during the period 1947-52 under the auspices of the Upper Mississippi River Conservation Committee.

Standing crops as estimated from six collections following rotenone treatment of blocked-off areas ranged from 39 to 605 and averaged 248 pounds per acre.

Growth rates of most species were greater than most of those described in other waters of the north central States and in downstream areas of the Mississippi River.

Limited data on environmental factors are presented. Differences in standing crop and species composition could not be related to changes in the water level.

27. Claflin, T.O. Lake Onalaska rehabilitation feasibility assessment report on navigation pool no. 7, upper Mississippi River. Wisconsin Dept. Nat. Res; 1976a.

Because of the Mississippi River's vast watershed there appears to be virtually no methods available to alleviate the inflow of materials into the lake, the report said. However, the closure of three of the channels into the lake from the main channel would reduce the sediment inflow into the lake during periods of high flow as well as normal flow periods. This would reduce the amount of sediment that could be trapped and maintained by the lake. Unfortunately this would only be a temporary measure since the transitional areas would become saturated with sediment materials in a few years. Approximately 80% of the total sediment load is carried by the Mississippi River during flood periods. With this consideration, the report recommended that, if water flow were to be controlled, that control gates across the primary feeder channels be installed. Keeping these control gates closed during periods of high flow could divert a major portion of the high sediment load.

Chemically killing the plants is an ineffective means of long-term control, simply because the plants still contribute to the nutrient load of the lake. In essence, the poisoned plants act as a fertilizer for the next year's growth.

The lake, with its inherent trapping efficiency, will continue to progress toward a higher eutrophic state unless the hydraulic conditions of the system are radically changed. In addition, at the present time most of the conventional methods of bringing about such change is expensive, and to a certain degree, environmentally unsound.

Annotation from: Hazelton Environmental Sciences Corp., 1979.

28. Claflin, T.O. Statement of Dr. Thomas 0. Claflin, Director, River Studies Center, University of Wisconsin - La Crosse before the Water Resources Subcommittee on Public Works; 1976b.

I have attached a table containing data from a field study done during the first week of July, 1975, by the River Studies Center in Navigation Pool 8. It should be noted, that at the time of data collections, the river at LaCrosse, Wisconsin, was only two feet below flood stage due to extensive rainfall in Minnesota and Wisconsin. To briefly summarize those data, one can conclude the following: A. In the main channel (1) Five minutes after passage, the turbidity increased from 23 to 107 turbidity units, an increase of 328%. (2) Two hours after passage, the percent increase was still 52%. B. In a bay 800 meters downstream from the measuring point (1)

One hour after passage a 290% increase was noted. (2) Two hours after passage, the turbidity remained 133% higher than ambient. These data demonstrate that even during high water, (I might add, higher than many annual flood stages) the effects of tows are noticeable and significant. These data were collected at the mouth of and in Raft Channel, an imporant feeder channel for the vast downstream marsh areas on the Minnesota side of the River. I would also add that this does not necessarily represent the worst case conditions.

Field observation on current velocities recorded in two channels leading form the main channel up-bound to Lake Onalaska before, during, and after tow passage reveal that: Discharges through the channel are temporarily reduced by 30-40% just prior to and during passage. After the tow passes the opening, the discharge through the channel increases by 30%. Accompanying this increase is an increase in turbidity due to prop wash. The duration of the increase in discharge is dependent upon the size of the tow. However, an extrapolation of our data reveals that an additional 2,700 pounds of sediment enter the lake from each tow passage.

29. Claflin, T.0. Lake Onalaska rehabilitation feasibility study. LaCrosse, WI: River Studies Center; 1979; 43 p.

30. Claflin, T.0; Rada, R.G. A study of effects of diverting water into upper Burnt Pocket, navigation pool no. 8, Illinois, and a field test of the progression simulation model previously developed on navigation pool no. 8. A progress report. Rock Island, IL:U.S. Army Corps of Engineers, Rock Island Dist; 1979; 73 p.

31. Coker, R.E. Fresh-water mussels and mussel industries of the United States. Bull. U.S. Bur. Fish. Washington, Vol. XXXVI. 1919. p. 13-39.

This article discusses fresh-water mussels and the industry in the United States prior to 1919. It includes economic values and harvesting methods.

32. Colbert, B.K.; Scott, J.E.; Johnson, J.H.; Solomon, R.C. Environmental inventory and assessment of navigation pools 24, 25 and 26, Upper Mississippi and Lower Illinois Rivers; an aquatic analysis. Vicksburg, MS: Army Engineer Waterways Experiment Station; 1975; 368 p.

The purpose of this report was to establish a data base for the physical, chemical, and biological components of the aquatic system in Pools 24, 25 and 26 on the Upper Mississippi and Lower Illinois Rivers. Four major habitats were sampled--49 sites at 13 transects on the Upper Mississippi River and 21 sites at 6 transects on the Lower Illinois River. Habitats sampled were the main channel, side channel, river border areas, and areas downstream of dikes. Water and sediment samples were collected for physical and chemical characterization. In situ measurements were made for dissolved oxygen, temperature, total alkalinity, pH, turbidity units, and settleable solids. Laboratory analyses were made of phenols, heavy metals selected nutrients, and chlorinated hydrocarbons. Benthic organisms, drift organisms, phytoplankton, and zooplankton were collected during both sampling periods. Fish were collected from the Illinois River only. The data collected were subjected to various statistical analyses to test for dif-

ferences between dates and among habitats and between rivers. The environmental impacts of operation and maintenance activities on the aquatic system are discussed.

33. Comptroller General of the United States. Dredging America's waterways and harbors--more information needed on environmental and economic issues. Report to Congress; 28 June 1977.

The effects that dredging and disposing of dredged material will have on the environment have come into sharper focus within the last decade; and, the Corps of Engineers has been required by legislation, litigation, and regulations to modify its practices. In response, the Corps has undertaken a research program, and changed its dredging practices at certain locations, but at much higher costs. To date their research has been incomplete. In fact, the long-term effects of contaminated dredged material on the environment have not been determined.

Additional information should be included in the Corps' budget justifications submitted to the Congress on the costs and environmental effect of alternative disposal practices for those projects which the Environmental Protection Agency questions or objects to.

34. Corning, R.V.; Raleight, R.F.; Schuder, G.D.; Wood, A., editors. Symposium on stream channel modification proceedings; 1975 August 15-17; Harrisonburg, VA; 172 p.

This is a series of papers on strem channel modification. Hirsch prepared the keynote address "Stream Channel Modification - An Overview." Session titles are: Policies and objectives of agencies that modify stream channels (3 papers); Biological considerations of stream channel modification (5 papers); Stream modification alternatives and methods of mitgation or enhancement (3 papers); Panel discussion; Citizen's forum.

35. Council of Biology Editors Style Manual Committee. Council of Biology Editors style manual: a guide for authors, editors, and publishers in the biological sciences. 4th ed. Council of Biology Editors; 1978.

This report is a manual for writing biological papers. It was used as a guide for this report.

36. Cummins, K.W. Trophic relations of aquatic insects. Ann. Rev.Entomol. 18:183-206; 1973.

Freshwater ecosystems of the temperate zone might ben generalized as having a reasonably constant biomass of macrobenthic animals, dominated by aquatic insects (plus mollusks, annelids, and crustaceans), which is turning over at a rate controlled primarily by temperature, seasonal temperature adjustments being much less pronounced in running water in which a very significant amount of feeding and growth occurs in the fall and winter. The temperature control of biomass turnover is mediated primarily through the positive correlation between temperature and feeding rate and temperatue and respiration; thus, the ratio of feeding, or respiration, to growth is fairly constant. The aquatic insects are supplied with consistent and

abundant food supplies of similar caloric and protein content. Their assimilative efficiency is independent of temperature over wide ranges and fairly constant over the broad range of food quality normally ingested (predators may have a higher efficiency than herbivore-detritivores, 70). Food resources are partitioned on the basis of particle size and whether active (prey), stationary (periphyton, vascular plants, deposited detritus), or in suspension (plankton and fine particle detritus in standing waters, particulate drift in streams and rivers). Within any general food compartment, specific utilization is determined by temporal and microspatial isolation of potential competitors - size (age) groups of a large number of species that are all trophic generalists within the particle size ranges that they are capable of ingesting. Although the data on aquatic insects are not extensive enough to determine the validity of all aspects of these generalizations, the information at hand supports the contention that most aquatic insects are best termed polyphagous or generalists and that availability, most frequently delineated by food particle size and texture, is the key to trophic relationships among aquatic insects.

37. Das, M.M.. 1969. Relative effect of waves generated by large ships and small boats in restricted waterways. Hydraulic Enegineering Laboratory, College of Engineering, Univ. California, Berkeley; 1969; 112 p.

The peak wave energy in. a system of waves resulting from the passage of a ship is of importance in such problems as bank erosion, the motion of moored vessels, forces on fixed and floating docks, etc. With respect to the bank erosion problem, the question often asked is whether the single passage of a large ship during a day, for example, is more damaging than numerous passage of small pleasure craft during the day. With this in mind this study was conducted to determine the relative importance of the peak energy resulting from the passage of a cargo ship and a pleasure cruiser. The characteristics of the waves generated by these vessels moving at various speeds in deep and shallow water were determined from model studies. A numerical example is given in which prototype values of peak wave energy were predicted from the model data, and then ratios of the peak energies computed. The importance of ship speed is evident in these comparisons.

38. Eckblad, J.W.; Peterson, N.L; Ostlie, K.; Temte, A. The morphometry, benthos and sedimentation rates of a floodplain lake in Pool 9 of the Upper Mississippi River. Amer. Midl. Nat. 97:433-443; 1977.

Big Lake is a shallow (mean depth = 0.89 m in 1973) 256-ha backwater lake on the floodplain of the Mississippi River in NE Iowa. During the summers of 1973 and 1974 Sphaerium and Hexagenia made up 81% of the benthic macroinvertebrate abundance and 92% of the benthic biomass; both taxa had greatly reduced abundance and biomass within stands of emergent Sagittaria along the lake margin. During July 1974 the Sagittaria net productivity was about 19 g/m^2/day. Between 1896 and 1973 about 76 cm of sediment had accumulated in Big Lake, and the recent sedimentation rate (1964-1974) was about 1.7 cm/year. The calculated annual reduction in lake volume of about 37,400 m^3/year suggests that the physical and biological components of this productive aquatic habitat will be greatly modified during the next few decades.

39. Ecology Consultants, Inc. Navigation and the environment. Twin Cities, MN: Upper Mississippi River Basin Commission; 1979. 152 pp.

This review of navigation effects on the environment contains a text summary of potential effects on Upper Mississippi River biology (direct and indirect effects), two matrices showing navigation (action) vs. effects (impacts) and effects (impacts) vs. receptors (impacted entities), and an annotated bibliography of 264 citations.

40. Ecology Consultants, Inc. Potential environmental impacts of Mississippi River year-round navigation on commercial fishing, vol. II. Rock Island, IL: U.S. Army Corps of Engineers; 1979. 128 pp.

An intensive literature search was conducted to identify and acquire information pertaining to winter navigation on the Mississippi River. Impacts on rivers under winter conditions, ice jams, water quality, and the biology of benthic organisms, fish, birds, and mammals under winter conditions were topics searched in accessing computer data bases. The following data bases were searched on-line: Aquatic Science and Fisheries Abstracts; BIOSIS; Compendex; Dissertation Abstracts; NTIS; Pollution Abstracts and Water Resources Research Abstracts (WRSIC).

In addition, Federal and state agencies, university and college resource centers were contacted. These are documented in Volume I, Appendix D.

Papers have been indexed under three general categories: (1) Subject (broad headings); (2) Geographic Area (State, River or area in which the work was carried out); (3) Systematic (species of major concern in the study).

41. Ellis, M.M. Erosion silt as a factor in aquatic environments. Ecology 17:29-42; 1936.

Erosion silt alters aquatic environments, chiefly by screening out light, changing heat radiation, by blanketing the stream bottom, and by retaining organic material and other substances which create unfavorable conditions on the bottom. The present erosion silt loads of our inland streams have reduced the millionth intensity depth for light penetration from 15,000 mm to 34,000 ram or more, to 1,000 mm or less, the summer average for the Mississippi River (1934) above Alton, Illinois being less than 500 mm. Erosion silt in river water acts chiefly as an opaque screen to all wave lengths of visible light, but in very muddy waters a small differential was found favoring the transmission of scarlet-orange light. Erosion silt alters the rate of temperature change in river waters. This is particularly significant in deep river lakes where thermal stratification of the water produces a stratification of the silt load, a warm muddy river, the hyperlimnorrheum flowing over a clear, cold lake, the hypolimnion, during the summer months. Excepting the very quiet portions, erosion silt is quite uniformly distributed throughout the waters of rivers even in very deep holes, and in those river lakes in which there is no thermal stratification. Erosion silt does not materially alter the salt complex or the amount of electrolytes in river waters. Experimental studies demonstrated that layers of fine silt from one-fourth of an inch to one inch thick produced a very high mortality among freshwater mussels living in gravel or sand beds, and in water which was otherwise favorable. The amount of organic material carried to bottom with erosion silt ranged from 8 to 12 percent of the dry weight of the mud on the bottom of Lake Pepin and Lake Keokuk.

42. Ellis, M.M. Detection and measurement of stream pollution. U.S. Bur. Fish Bull. 22, vol. 48:365-437; 1937.

This article contains methods for measuring stream pollution but also contains water quality data for certain stations in the Upper Mississippi River System.

43. Environmental Effects Laboratory. Bibliography for navigation pools 24, 25, and 26, Upper Mississippi and Lower Illinois Rivers. Vicksburg, MS: U.S. Army Waterways Experiment Station; n.d. 82 p.

This is a bibliography of citations on environmental topics related to navigation pools 24, 25, and 26 obtained from the U.S. Army Waterways Experiment Station.

44. Environmental Science and Engineering. Navigation impact study, Illinois River, Pool 26, August 1980; Mississippi River, Pool 9, October 1980; Phase III, Task 9. Grafton, IL: Illinois Natural History Survey; 1981.

To fully assess potential biological and water quality impacts of increased navigation, it is important to document the physical effects resulting from river traffic. To document these effects, water velocity, pressure, and water quality measurements were conducted at two sites on the Upper Mississippi River system. Measurements were made on the Illinois River, Pool 26, near Grafton, Illinois, in August 1980 and on the Mississippi River, Pool 9, near Lansing, Iowa, in October 1980. Ambient river conditions and conditions during tow passage were measured to document the physical effects of river traffic.

The results of the analysis of the backwater velocity components indicate that near-bottom velocities were substantially affected by tow passage. Upstream tows frequently doubled or tripled the ambient backwater velocities for 2 or 3 minutes. Downstream tows readily reversed the river flow for approximately 2 minutes. The resulting upstream velocities frequently equaled or exceeded ambient downstream river speed. The backwater velocity changes produced by passing tows were generally between 0.5 and 1.0 ft/sec. Offshore components of the induced velocity frequently exceeded 0.2 ft/sec.

Although tow traffic significantly changes the river velocity for a short period, the impacts on the sediments and river ecology may not be as great. Tow traffic, however, does contribute to increased resuspension of sediments. Fine sand (0.1 mm) can be resuspended as the velocity exceeds 0.8 ft/sec. Consequently, whenever the tow-induced currents in combination with the ambient river velocity exceed 0.8 ft/sec, unnatural resuspension of sediments will occur. Once the sediments are in suspension, they will

remain in suspension because the ambient river velocity is usually above the settling velocity for this size sediment. This occurrence, however, must be evaluated with knowledge that the natural river velocity frequently exceeds 0.8 ft/sec. Consequently, sediment resuspension and transport are continuous natural processes, and the added sediment resuspension potential created by river traffic may not produce significant impacts on the ecology of the river. The major effect of river traffic on suspended sediments will be to eliminate periods of relatively low turbidity that might occur during low river flow.

The reversal of river flow and offshore velocity components generated by tow passage will also have an impact on the river system. The unnatural offshore and onshore velocities will tend to transport sediments, detritus, larvae, and eggs alternately toward and away from the navigation channel. Any detrimental effects of this transport, however, is undetermined. The flow reversals may have a disorienting effect on certain species such as mussels that align with the current. However, the periods of reversal are so brief (approximately 2 minutes) that the impacts are probably minimal. The current reversals and surges may also damage food gathering nets of certain net spinning Trichoptera. The extent or net impact of such damage cannot be assessed from available data.

The pressure and water quality measurements indicated that the effects of tow passage on pressure, DO, conductivity, pH, temperature, and tranmissivity adjacent to the navigation channel were nearly undetectable. However, measurements were not made directly under the tow where impacts would be the greatest. Also, the study was designed to detect short-term changes by individual tow passages, and any long-term effects of river traffic on water quality could not be determined from the data.

45. Fisher, S.G.; LaVoy, A. Differences in littoral fauna due to fluctuating water levels below a hydroelectric dam. J. Fish. Res. Bd. Can. 29:1472-1476.

Water level fluctuations below a hydroelectric dam on the Connecticut River produce a freshwater "intertidal" zone. Along a transect in this zone from high to low water mark benthic invertebrates increased markedly in density and taxonomic diversity. Community composition shifted from chironomid-oligochaeta predominance on the most exposed sites to mollusc predominance on the least exposed sites.

46. Forbes, S.A.; Richardson, R.E. The fishes of Illinois. 2nd ed. Urbana, IL: Illinois Natural History Survey; 1920; 357 p.

It is the purpose of the present volume to furnish to those interested in Illinois fishes a reliable guide to a knowledge of the species, a careful account of their local and general distribution and of the reltions to their environment, a correct idea of the function and relative importance of the different species in the general system of aquatic life, and fairly full summary of their habits and utilities so far as these are now known. To this end the species have, with very few exceptions, been described anew

from the specimens of our collection, with due use, however, of descriptions already extant; analytical keys have been made, adapted, or selected, with special reference to the Illinois species; and our data of geographical and local distribution and of ecological situation and relationship have been analyzed, to a considerable extent, by statistical methods.

47. Fremling, C.R. The impact of man on the ecology of the Mississippi River. Encounters: A Journal of Regional Interaction 2:23-25; 1974.

This article includes (1) a discussion of major aquatic organisms in the Mississippi River and (2) changes in the Mississippi River that have occurred due to increased use of the river for navigation, commercial fishing, and sewage treatment.

48. Fremling, C.R; Nielsen, D.N.; McConville, D.R.; Vose, R.N.; Faber, R.A.; Dieterman, L.J. The feasibility and environmental effects of opening side channels in five areas of the Mississippi River (west Newton Chute, Fountain City Bay, Sam Gordy's Slough, Kruger Slough, and Island 42). Twin Cites, MN: report submitted to the U.S. Fish and Wildlife Service; 1979; vol. 1 and 2.

In 1975, Winona State University and Saint Mary's College were awarded the present contract by the U.S. Fish and Wildlife Service as part of the GREAT program, to determine the feasibility and environmental effects of opening side-channels in three areas of the Mississippi River. The three areas encompassed: (1) West Newton Chute, Murphy's Cut and Half Moon Lake, (2) Fountain City Bay and adjacent marshes, and (3) Sam Gordy's Slough. A multi-disciplinary rsearch team was assembled that provided the broad range of experience, expertise, and equipment necessary to gain insights into Mississippi River habitat degradation. The basic research plan was to conduct pre-operational studies in all areas to obtain baseline data. Subsequent to making side-channel openings, studies would be made to determine the impact of the openings.

This study has been unusual in that several complex recommendations were made, remedial actions were taken, and habitat improvements were observed - all within a 4-year contract period.

In the long run, however, the greatest value of this study may be the resultant volumes of priceless baseline data, and an increased understanding of backwater environments.

49. Froude, R.E. On the leading phenomena of the wave-making resistance of ships. Transactions Institution of Naval Architects 22:220-233; 1881.

The experiments described in this paper were on a series of models, all having identical entrance and run, but different amounts of parallel middle body. The remarkable feature of the results was that the introduction of the parallel middle body not only increased the skin friction in virtue of the added area of skin, but affected the wave-making resistance also in virtue of the changed position of the after-body in reference to the wave system left by the bow; so that if the parallel middle body were gradually elongated, the wave-making resistance would alternately decrease and in-

crease as the after-body was brought into favorable or unfavorable juxtaposition with the successive features of the wave system.

"This discovery," as says the paper, was "a most material addition to our conceptions of the manner of operation of wave-making resistance." The theory, as thus completed, may be briefly sketched as follows. The passage of the features of the ship through the fluid involves local excesses and defects of pressure due to "stream line" action, which tend to cause corresponding local rises and depressions of surface, thus forming undulations
defects of pressure due to "stream line" action, which tend to cause corresponding local rises and depressions of surface, thus forming undulations
resembling waves or portions of waves. When the speed of the ship approximates to that appropriate to the lengths of these waves, large waves are formed, and proportionaly great wave-making resistance is encountered; there tends, therefore, to be a rapid increase of resistance as a certain speed is approached, a phenomenon which is of course the more definitely marked the more nearly uniform are the wavelengths of the several portions of waves which the features of the ship tend to form.

50. Fuehrer, M; Romisch, K. Effects of modern ship traffic on inland- and ocean-waterways and their structures. Proceedings of the 24th International Navigation Congress, Leningrad; 1977.

Through model investigations and mathematical equations, addressed the problem of:

(1) The distribution of the displacement current of a ship during her navigation in canals and channels of limited wideth and depth (part 1),
(2) The squat of ships in canals and channels of limited width and depth (part 2), and
(3) The damages of waterways and hydraulic structures caused by the attack of a propeller jet.

Includes a calculation of local displacement current, squat, and critical speed of a ship, as well as a discussion of the jet velocity of propeller backwash and the stability of the bottom and slope.

51. Funk, J.L.; Robinson, J.W. Changes in the channel of the lower Missouri River and effects on fish and wildlife. Missouri Dept. Conservation Aquatic Series No. 11:1-52; 1974.

Radical changes have been impressed upon the surging brown Missouri River in the years since Lewis and Clark threaded their boat up a sprawling river studded with islands and sunken timber. Mean have been altering the channel of the Missouri River since the first explorers and fur traders chopped away obstructing snags and tree tops to ease the passage of their keelboats, mackinaws, bullboats, and canoes. "Improvement: of the channel has been a Federal government activity since 1884, first under the Missouri River Commission and, since 1902, under the U.S. Army Corps of Engineers.

This publication was sritten to document the extent of the changes made in the channel of the Missouri River in the past 90 years, to illustrate the

loss of fish and wildlife habitat, and to evaluate these losses in present-day terras.

The Corps of Engineers, Kansas City District, published (undated) a set of maps entitled "75 Years, Comparison of Conditions, Missouri River, Rulo, Nebraska to Mouth, 1879-1954." The publication consisted of an index and 14 maps, each depecting a section of river in the reach referred to in the title. On the individual maps the channel, landmarks, and cultural developments based on surveys made between September 16, 1878 and September 6, 1879 were depicted in red. Superimposed on this in blue were the channel, landmarks and cultural development as they existed in 1954. The set of maps apparently was published to show the Corps' accomplishments in improving the navigability of the river. They also show very graphically what this improvement has cost in lost fish and wildlife habitat.

52. Gelencser, G.J. Drawdown surge and slope protection, experimental results. Proceedings of the 24th International Navigation Congress, Leningrad; 1977.

The principal objective of this paper is to describe, define, and characterize the drawdown surge created by passing ships in a restricted canal. With the use of the prototype measurements the representing physical equation of the drawdown surge will be defined in function of various factors such as are the ship's length, beam, draft, velocity, the canal's cross-section, and the passing distance. This equations will be compared to the model results and verified in data available of other experiments.

The peculiar divergences appearing in the drawdown curve's registered shape will be analyzed, classified, and qualitatively reasoned. As a secondary objective the protection methods considered will be mentioned but not detailed and the type of the protection selected for the model study justified.

53. GREAT I, Main report. GREAT I Upper Mississippi River; Sept. 1979.

The GREAT I final report consists of nine volumes as identified on the outline in each of the report documents. The nine volumes include four documents that provide distinct types of information about our work or our products; Each document is directed at a different audience.

The Main Report (Volume 1) is the most comprehensive description of our efforts and results and provides sufficient information for most analyses of the GREAT I program and proposals. It provides background on the Upper Mississippi River and the GREAT I Study. It also describes the study process; presents the findings, conclusions, and recommendations of the GREAT I Team; and provides a guide for implementation of the recommended actions.

54. GREAT I, Fish and Wildlife Work Group. GREAT 1 Upper Mississippi River. Sept. 1979; 605 p.

This report has been prepared by the Great River Environmenal Action Team (GREAT I) Fish and Wildlife Work Group. The report was not formally approved by the Fish and Wildlife Work Group but represents the contribu-

tions of all work group members. The GREAT I Team is the group to which this report is submitted. Therefore, the GREAT I Team has not reviewed or approved the report at this date. Further, the views and recommendations expressed within this report do not necessarily represent those of the agencies participating in the GREAT I.

The FWMWG and SCOWG came to the following specific conclusions:

The Fish and Wildlife Management Work Group successfully fulfilled nearly all of its responsibilities within the GREAT.

Partial closing dams, which are specficially designed to enhance fish and wildlife, can be used successfully to reduce sediment influex to the backwaters while maintaining adequate water flow resulting in good habitat maintenance.

Well designed, gated culverts constructed through the dikes of the locks and dams can greatly enhance the fish and wildlife habitat quality and diversity of the backwater areas for several miles downstream of a dike.

Small side channel openings can be very beneficial to backwater habitat diversity and quality if they are well designed to avoid additional sediment transport into the backwater.

Rehabilitation of major backwater areas is possible if the problems are. well investigated and recommended remedial measures are well designed.

State and/or Federal regulations may preclude the implementation of any major backwater rehabilitation on the Upper Mississippi River.

The regressions simulation model (Claflin et al. 1977) is a useable and reasonably accurate predictive model, capable of predicting the benthos and rooted aquatic macrophyte response to physical changes proposed for backwaters in the GREAT I study area. The model should be used in backwater project planning.

The concept of "logical predictive capability" is generally sound when applied to the fish and wildlife resources of the Mississippi backwaters.

The vegetative inventory (Meyer et al. 1977) is a valid and useable base for establishing a fish and wildlife habitat inventory of the Upper Mississippi, with the exception of some aspects of fish and wildlife habitat requirements.

There is a need for a submergent vegetation inventory in order to establish fish and wildlife habitat definition on the river.

The vegetative inventory needs to be redone periodically, possibly every 10 years, in order to continue as a valid base for a habitat inventory of the river.

The On-Site Inspection Team process has increased cooperation between the Corps of Engineers and the natural resources agencies, resulted in more environmentally sound dredged material placement, and should be continued.

Increased use of land treatment programs in the upland agricultural areas could substantially reduce fine sediment deposition in the backwaters downstream of Lake Pepin.

There is a need for establishing what fish and/or wildlife species specific areas of the river are to be managed for.

The Side Channel Work Group was partially successful in fulfilling its responsibilities within the GREAT.

Side Channel openings can enhance boat access to the river for many years.

Side channel openings accomplished for improved boat access may be detrimental to fish and wildlife resources.

55. GREAT I, Sedimentation and Erosion Work Group. GREAT I, Sediment and Erosion Work Group Appendix. 1979; 107 pp.+.

This report was prepared by the Sediment and Erosion Work Group of the Great River Environmental Action Team (GREAT I). The conclusions and recommendations presented reflect the work performed by this work group only, within its specific area of expertise. Recommendations from this report will be considered in relation to other objectives for overall resource management and may be included in the final GREAT I report as considered appropriate by the GREAT I Team.

The work groups has shown that:

The life expextancy of the backwater areas is limited if present rates of sedimentation are allowed to continue. Already, approximately one-quarter of the open water area present when the lock and dam system was completed has become marshland.

From 1895 to the present, approximately one-third of the capacity of Lake Pepin has been lost to sediment. Some areas of the lake which were once 8 to 12 feet deep are now 2 to 4 feet deep. A unique recreation and environmental resource is dying.

The primary source of the fine sediments which are clogging the backwaters and filling Lake Pepin is erosion from farmlands. The principal source area is relatively small - approximately 9 million areas out of a total of 51 million acres in the total drainage area.

The primary source of the sand which fills the main channel is streambank erosion from tributaries. The majority of this sand comes from key sand producing tributaries. These tributaries have been identified. The greatest contributor of sand is the Chippewa River in Wisconsin. Accumulating sand sediments ultimately must be dredged to maintain the 9-foot channel. Disposal of this dredged material must be done in an environmentally sensitive manner to minimize further habitat destruction.

Erosion control alternatives available under existing programs and technology could reduce upland erosion by one third in the fine sediment source areas. Such a program would cost an estimated $243 million initially and $44 million to maintain. Because existing treatment measures are able to reduce erosion only by one-third, new, more intensive erosion control practices need to be identified.

Preliminary feasibility studies indicate that streambank stabilization measures may reduce coarse sedimentation at some locations.

56. GREAT I, Water Quality Work Group. GREAT I Water Quality Work Group Appendix. 1979. 79 p.

This report was prepared by the Water Quality Work Group of the Great River Environmental Action Team (GREAT I). The conclusions and recommendations contained in this report reflect the work performed by this work group only, within its specific area of expertise. Recommendations from this report will be considered in relation to other objectives for overall resource management and may be included in the final GREAT I report as considered appropriate by the GREAT I Team.

Since 1976, the major thrust of work group research activity has focused on the water quality impacts of dredging, disposal, and navigation. Specific activities in this regard have included:

A pilot study on the effects of hydraulic dredging and disposal on water quality of the Upper Mississippi River at Grey Cloud Island (1976).

A study of the effects of the first tow of the navigation season on Lake Pepin water quality (1977).

A study of the effects of mechanical dredging and disposal on Boulanger Bend water quality (1977).

A literature review of the effects of navigation on water quality (1978).

Development of dredged material disposal management alternatives (1977--1978).

57. GREAT II. Main report. GREAT II Upper Mississippi River, Guttenburg, Iowa to Saverton, Missouri. 1980. 113 pp.

The following list displays the broad planning objectives of the GREAT II Team. More specific planning objectives were developed individually by each of the GREAT II functional work groups. The specific planning objectives may be found in the respective work group appendix.

To identify present and future problems in river navigation. To identify the needs created by these problems. To identify alternative ways to meet these needs.

To determine the means, and to make recommendations, for preserving and protecting the cultural resources of the GREAT II reach of the URM.

To identify and develop ways to use dredged material as a valuable resource for productive uses.

To reduce the quantity of dredged material in the short-term (site-specific each dredging occurrence) and still maintain a safe navigable channel. To reduce the quantity of dredged material in the long-term by determining channel depths and widths to minimize dredging quantitites, and still maintain a safe navigable channel and, to make more use of regulatory structures to prevent channel shoaling.

To determine the means and to make recommendations for preserving, protecting and enhancing the fish and wildlife resources of the UMR.

To strive to comply with State and local regulations concerning dredging and dredged material disposal, and to perform those studies necessary to develop unified floodplain management along the GREAT II reach of the UMR.

To assure necessary equipment to maintain the total river resources on the UMR in an environmentally sound manner.

To develop procedures for assuring an appropriate level of public participation.

To eliminate adverse effects to recreation resulting from channel maintenance activities. To enhance recreational benefits of the river corridor from channel maintenance activities. To enhance recreational use of the river corridor consistent with maintaining the quality of the corridor's . natural resources by adequate distribution of related recreational opportunities, to maintain the integrity of the recreation viewshed, and to distribute information on study findings.

To determine the source(s) of sediment causing dredging and sedimentation; to determine the quantity of sediment entering the river corridor from these sources, and to propose land treatment and land management alternatives to alleviate the sedimentation.

To make resource management recommendations that will insure the protection and/or enhancement of fish and wildlife resources and their enjoyment and utilization by the public in off-channel (side channel, backwater) areas, this being in the context of an artificially controlled, riverine ecosystem operated and maintained for commercial navigation.

To promote the improvement and/or maintenance of water quality in the GREAT II area.

Although a specific objective was not developed in regard to commercial and industrial development, GREAT II recognized the need for research in this area. As no work group was specifically responsible for this element, limited research was conducted and recommendations made were for further study only.

58. GREAT II Dredged Material Work Group. GREAT II Dredged Material Work Group Appendix. 1980.

The Dredging Requirement Work Group (DRWG) has two objectives. The short-term objective is to reduce the quantity of dredged material (site specific each dredging occurrence), and still maintain a safe navigable channel. The long-term objective is to reduce quantities of dredged material by determining channel depths and widths that minimize dredging quantities, yet maintain an adequate navigation channel, and to make more efficient use of regulatory structures to prevent channel shoaling.

To accomplish the objectives of reduced dredging, the Dredging Requirement Work Group scheduled a variety of coordination activities throughout the study period's duration. Formal work group meetings were held on a regular basis to consolidate views and direct the overall team effort. Items addressed at these meetings included the identification, review, and discussion of dredge requirement problems; developing associated recommendations and impact assessments; and the review and discussion of the Dredging Requirements Work Group Appendix.

The problem identification and recommendations of other work groups were also addressed at these monthly, meetings. Coordination meetings were held as required to discuss and review input from individual group members to the Dredge Requirements Work Group Appendix. Meetings involving all or a portion of the work group were held as necessary to resolve problems encountered between regularly scheduled quarterly meetings.

59. GREAT II, Fish and Wildlife Management Work Group. Great II Fish and Wildlife Management Work Group Appendix. 1980. 300 pp+.

The FWMWG was composed primarily of field level biologists from the States of Iowa, Illinois, Missouri and Wisconsin, and the U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service. The FWMWG pursued its objectives by contracting for research and studies with universities and private consultants and by conducting pilot projects and studies themselves. In addition, the FWMWG chairman (U.S. Fish and Wildlife Service) chaired the In-Site Inspection Team which dealth with each year's dredged material disposal problems on a site-by-site basis.

The objective of the FWMWG was: "To determine the means and to make recommendations for preserving, protecting, and enhancing the fish and wildlife resources of the Upper Mississippi River."

The subobjectives were as follows:

Recommend the implementation of practices and programs which reduce upland erosion and its associated impacts on fish and wildlife resources. Recommend measures to identify critical areas needing restoration.

Recommend and encourage the implementation of navigation project operation and maintenance programs and practices which preserve, restore or enhance fish and wildlife resources. Recommend the implementation of interagency fish and wildlife committee to coordinate programs and practices.

Identify voids in our present knowledge of the distribution and abundance of fish and wildlife resources of the UMR. Conduct and recommend studies to fill voids in our knowledge of fish and wildlife distribution.

Identify and discuss alteration methods and measures which will improve habitat in off-channel areas.

Identify the extent of the area and habitat, if possible, which has been usurped by industrial, agricultural or municipal development. Recommend the implementation of a land use plan to assure an orderly use of the river by all interests. Recommend restoration of areas lost to encroachment. Recommend actions to reduce impacts of encroachment.

Identify measures and practices to reduce water quality impacts on fish and wildlife resources.

Identify detrimental effects of recreational and commercial traffic on fish and wildlife resources. Recommend measures to minimize impacts on fish and wildlife resrouces.

Distribute information on contracted items.

After the Work Group's objectives were formulated, they identified problems affecting fish and wildlife. Details of these specific problems are found in the FWMWG Appendix.

As part of the problem solving and planning process, the general base conditions of the fish and wildlife resource were documented. This essentially states how many species and what habitat types are found in the GREAT II area. In addition, pool specific base conditions were developed for the fish and wildlife resource. Future conditions of the resource were also projected to determine possible gains or losses of the resource.

60. GREAT II, Sedimentation and Erosion Control Work Group. GREAT II Sediment and Erosion Work Group Appendix. 1980; 83 p.

The primary objective of the Sediment and Erosion Work Group was to determine the source and quantity of sediment entering the Mississippi River corridor and propose land treatment and land management alternatives. The study identifies problems, proposes recommendations and evaluates impacts for both the long and short term.

The study includes the identification and evaluation of potential action items which should be initiated or accelerated during the next 10 to 15-year period. Emphasis was given to those measures which should be implemented in the short term.

61. GREAT II, Water Quality Work Group. GREAT II Water Quality Work Group Appendix. 1980; 216 p.

The Water Quality Work Group, GREAT II, consisted of members representing the Rock Island District, Corps of Engineers, the U.S. Fish and Wildlife

Service, U.S. Environmental Protection Agency (Regions V and VII), Wisconsin Department of Natural Resources, Iowa Division of Environmental Quality and the Missouri Department of Natural Resources. This group was responsible for identifying water quality problems on the Mississippi River, formulating appropriate studies to better define or solve the most important of these problems, and finally to make recommendations to the Plan Formulation Work Group supportive of water quality interests.

Thirty-five problems were identified by the work group and the public. Seventeen of the identified problems were addressed (due to the broad nature of some problem statements, many of these problems were only partially addressed) by work group activities. Four other problems were too low on the priority list for funding of studies. The remaining 14 problems were considered more appropriate to other work groups within GREAT II, to studies being conducted by GREAT I, or were beyond the scope of the GREAT process.

The major accomplishments of the work groups were: studies on water quality effects of dredge disposal site return flows, and on desorption of pollutants from sediments. These studies were contracted to the University of Iowa, Institute of Hydraulic Studies. The final reports of these contracts not only explain study results but develop predictive water quality models to be used by the Rock Island District Corps of Engineers in estimating impacts of dredging, a requirement of the 404 permit process.

62. Green, W.E. Ecological changes on the upper Mississippi River fish and wildlife refuge since inception of the 9-foot channel. Revised. U.S. Dept. Interior Fish and Wildlife Service; 1960; 14 p.

Not seen. Referenced in U.S. Corps of Engineers (1978).

63. Green, W.E. Fish and Wildlife Service, Retired. Winona:MN: Personal communication 1976a; 1977 (in U.S. Army Corps of Engineers 1978:5-26).

64. Gustafson, J.F. Beneficial effects of dredging turbidity. World Dredging and Marine Construction 8:44-45, 47-48, 50-52, 72; 1972.

Evidence detailing the beneficial roles of clay particles and the sediments they form, which arise from dredging, is presented. Bacteria attack attached sewage substances much more readily when they are attached to clay than when they are dispersed within the water, as long as the clays remain suspended. The much larger concentrations of the metals attached to the sediments vs. those concentrations suspended in the water are illustrated. The difference speaks to the adsorptive capacity of the sediments and proves their important role in the removal of these undesirable chemicals from the water. The dredging industry is urged to conduct experiments consisting of the determination of metal pollution concentrations in the water before and after bay sediments are resuspended. Turbid waters also offer shelter and protection to larval and immature marein life utilizing bay waters as nrsery grounds. Results from preliminary study of the ability of clams to remova metals and pesticides from the sediments were inconclusive.

65. Hay, D. Ship waves in navigable waterways. Proc. 11th Conference on Coastal Engineering, London, England; 1968:1472-1487.

Model tests were conducted at the University of California, Berkeley, on six ship models to determine the heights of the waves produced by ships. Measurements were made at various distances from the sailing line with the models moving at various speeds in various water depths. The results of the tests are presented in graphical form, as prototype values.

66. Havera, S.P.; Bellrose, F.C.; Archer, H.K.; Paveglio, F., Jr.; Steffeck, D.W.; Lubinski, K.S.; Sparks, R.E.; Brigham, W.U.; Coutant, L.; Waite, S.; McCormick, D. Projected effects of increased diversion of Lake Michigan water on the environment of the Illinois River Valley. Havana, IL: Ill. Nat. Hist. Surv. unpublished report; 1980.

The Water Resources Act of 1976 authorized the Secretary of the Army, acting through the Chief of the Engineers, to implement a five-year demonstration program to increase the average annual Lake Michigan diversion at Chicago from the present limit of 3,200 cfs up to 10,000 cfs. The act also directed the Corps of Engineers to conduct a study and a demonstration to determine the effects of the increased diversion on the levels of the Great Lakes, on the water quality of the Illinois Waterway, on the susceptibility of the Illinois Waterway to additional flooding, and to investigate any other adverse or beneficial impacts which may result.

The objective of this study was to document and evaluate the present quality and quantity of the fish and wildlife resources of the Illinois Waterway including a portion of Pool 26 of the Mississippi River in enough detail to (1) predict the probable impacts on aquatic and terrestrial communities of increased Lake Michigan diversion at an annual average rate of 6,600 cfs and 10,000 cfs, and (2) establish current baseline biological conditions of the Waterway for future comparisons.

67. Hazelton Environmental Corporation. Great II - Fish and Wildlife Management Work Group Annotated Bibliography, vol. I and II; 1979.

This bibliography is a compilation of published and unpublished data relating to the fish and wildlife of the Upper Mississippi River from its headwaters to its confluence with the Ohio River. Entries to the bibliography were received in three manners: (1) through computerized bibliographical retrieval systems; (2) through written and/or telephone contact with agencies, universities and individual authors, where the agency, university or author sent Hazelton ES appropriate entries through the mail; and (3) through personal visits to agencies and universities, where Hazelton ES personnel directly retrieved appropriate entries.

The bibliography is subdivided into two sections: (1) an alphabetical listing of all entries authored by individuals; and (2) an alphabetical listing of all entries authored by state and federal agencies, organizations, companies, universities and colleges, and/or other groups (also including those entries listed as anonymous).

68. Held, J.W. Environmental impacts of dredging and disposal on the Upper Mississippi River at Crosby Slough. Misc. Paper D-78-2. U.S. Army Corps of Engineers Waterways Experiment Station, NTIS No. AD-A061847. 1978.

This study was designed to investigate the environmental effects of disposal of material from maintenance dredging on the aquatic habitat around Island 117, Pool 8, Upper Mississippi River. Dredging impacts of disposal of dredged material in the past have included the conversion of productive aquatic and semiaquatic habitat to sandy shoals and islands, as well as the impairment of backwater circulation.

69. Helm, D.R.; Boland, T.L. Upper Mississippi River natural resource bibliography. Fish Technical Section, Upper Mississippi River Conservation Committee; 1972.

This report is a bibliography intended for the use of fish and wildlife managers along the Upper Mississippi River.

70. Herbich, J.B.; Brahme; S.B. Estimation and analysis of horizontal bottom velocities due to waves. College of Engineering, Report No. 202, Texas A & M Univ., College Station, Texas; 1977.

Maximum bottom velocities caused by waves were calculated using digital computers. Four wave theories, Airy, Stokes third order, Cnoidal and Solitary, were applied in the computation. Results of the study were tabulated and presented graphically to highlight the importance of various parameters affecting the maximum bottom velocity.

71. Hirsch, N.D.; DiSalvo, C.H.; Paddicord, R. Effects of dredging and disposal on aquatic organisms. U.S. Army Corps of Engineers Waterways Experiment Station Tech. Rpt. DS-78-5; 1978.

This report synthesizes data from the U.S. Army Corps of Engineers' Dredged Material Research Program, Task 1D. Task 1D consisted of six research projects (work units) that investigated the direct and indirect effects of dredging and disposal of dredged material on aquatic organisms.

Determination of potential environmental effects of dredging and disposal, in spite of research conducted to date, is still in preliminary stages due to the multiplicity of variables involved.

Direct effects of dredging and disposal are restricted to the immediate area of operation. They include removal of organisms at dredging sites and burial of organisms at disposal sites. Data indicate that the recovery of disturbed sites occurs over periods of weeks, months, or years depending on the type of environment. Possible mechanisms of recolonization include lateral and vertical migration of organisms and larval recruitment. Disturbed sites may be recolonized by opportunistic species which are not normally the dominant species occurring at nearby undisturbed sites.

Most organisms studied were relatively insensitive to the effects of sediment suspensions in the water. Dredging-induced turbidity is probably not of major environmental concern in most cases, but may be an aesthetic prob-

lem. The formation of fluid mud due to dredging and disposal is a poorly understood process and is of probable environmental concern. Available data indicate that suspensions of highly contaminated sediments have a greater potential for adverse effects than uncontaminated or lightly contaminated sediments.

Bioavailability of sediment-sorbed heavy metals is low. Release of sediment-associated heavy metals and their uptake into organism tissues have been found to be the exception rather than the rule. Research results suggest that there is little or no correlation between the bulk sediment content of heavy metals and environmental impact. Oil and grease residues, like the heavy metals, seem tightly bound to sediment particles and accumulation of these residues by organisms is minimal.

The diversity of variables that have the potential for direct and indirect effects on aquatic life argues for an integrated, whole-sediment bioassay, using sensitive test organisms. Such a procedure is currently under development by the Environmental Protection Agency and the Corps of Engineers and should uncover site-specific toxicity problems which can be addressed by appropriate chemical testing and biological evaluation of dredged material.

72. Hubley, R.C., Jr. Harvest and movement of channel catfish in the upper Mississippi River. Wisconsin Conservation Dept. Fish Management Division Investigational Memorandum No. 12:1-11; 1961.

The catfish fishery is one of the most valuable commercial fisheries of the Upper Mississippi River. Although three species of catfish are known to occur, only the channel catfish (Ictalurus punctatus) and the flathead catfish (Pylodictis olivaris) support the fishery in the upper reaches. The once-common blue catfish (Ictalurus furcatus) is taken very infrequently.

Information necessary for the proper management of the catfish fishery is incomplete. A tagging study was initiated in 1947, to determine the harvest, movements and possible homing tendencies of the channel catfish, as a basis for better understanding this species.

Annotation taken from Hazelton Environmental Corporation (1979).

73. Hurst, C.K.; Brebner, A. Shore erosion and protection. St. Lawrence River - Canada. Permanent International Association of Navigation Congresses, XXIInd International Navigation Congress, Paris, Section 1, Subject 6; 1969:45-56.

With the increase in ocean traffic on the St. Lawrence and the parallel increase of industries and population along its banks, the problem of bank protection has become important. The costs of protecting the banks are borne by the governments. The federal government bears the costs of erosion of the banks due to shipping; the local authorities pay the costs that result from natural erosion, effects of the current, and waves caused by wind or ice. The main cause of bank erosion is the passage of shipping. Measurements along the river indicate that the height of the waves and the lowering of the water level caused by shipping depend upon the velocity of

the ships and the width of the channels. For rivers having a width under 2,000 feet, navigation is the main cause of bank erosion. For widths over 4,000 feet the effect of navigation on the banks is negligible. Arrangements on the distribution of expenditure have been made. The article is written in English and contains a French summary.

74. Institute for Water Resources. Analysis of Environmental aspects of Waterways Navigation, Review Draft. Fort Belvior, VA: Water Resources Support Center; 1980.

It is the intent of this element report, Analysis of Environmental Aspects of Waterways Navigation, to identify the full range of environmental impacts of navigation, assess their significance and suggest measures to mitigate these impacts, where applicable.

Under topic findings, Section III the environmental impacts of navigation are presented on the basis of the following sub-topics: water quality and aquatic habitat impacts, terrestrial habitat impacts, air quality impacts, noise impacts, socioeconomic impacts, cultural resource impacts and impacts of different transportation modes. Each sub-topic is prefaced with a brief. , introductory statement which clarifies the format and organization of the specific impact section. In addition, Section IV, Recommendations for Further Investigation, discusses the drawbacks and potential constraints concerning the efficiency of the existing state-of-the-art environmental analysis of impacts and presents some suggestions as to how this analysis may be improved, including subject areas which require added emphasis. A brief discussion of secondary impacts is also included in this section.

The appendices contain a glossary of key terms and a complete bibliography, which is subdivided to correspond to the respective subject areas discussed under Findings. In addition, a comprehensive study, "Dredging and Dredged Matter Disposal Contraints," is included as an unattached technical appendix. This technical appendix discusses constraints on a waterways segment-specific basis and includes tabular summary of such segment-specific information.

75. Isom, B.G. The mussel resources of the Tennessee River. Malacalogia 7:397-425; 1969.

This study is an effort to assess the status of the mussel fauna in the Tennessee River as of 1965 and to compare it to the rich endemic fauna present prior to impoundment by the Tennessee Valley Authority in 1936. Many species have been important to the pearl button industry in the past and some are now important to the pearl culture industry.

Yearly harvests of about 10,000 tons of shells in the 1940's and 1950's have steadily declined, falling to 2,000 tons from 1964 through 1967. Mussel populations have been significantly affected by impoundment in species composition and in distribution. While impoundment has been the primary cause of decline by reducing suitable mussel habitats, overharvesting of mussels in the river-like portions below the dams (tailwaters) has recently resulted in a further rapid depletion of the mussel resource. Approximately 175 miles of suitable habitat remain in the first 531 miles of river, mostly in the tailwaters. The present fauna comprises 44 species as against about 100 formerly recorded. The drastic reduction of "Cumberlandian" species (6 against 25) was confirmed. Many of the species still present have become rare. Several specis have only recently become established in their present locations. Legislation regulating mussel harvesting, enacted in 1965-1966, should help halt the rapid depletion of mussel resources. The range of silt-tolerant species is gradually extending, but before the commercially important mussels, in particular Fusconia ebenus and Pluerobema cordatum can be successfully managed, their life histories will have to be elucidated. The future of the mussel industry remains uncertain at the present time.

76. Jackivicz, T.; Kuzminski, L. A review of outboard motor effects on the aquatic environment. Journal Water Pollution Control Federation 45(8):1759-1770; 1973.

Various aspects of outboard motor operation, including the magnitude of watercraft usage, operation and efficiency of a two-cycle engine, composition of outboard motor fuels, and compounds emitted during operation are reviewed. Compounds emitted to receiving waters originate from drainage of crankcase liquids and from unburned fuel passing through the combustion chamber. Over half the original fuel mixture for outboard motors may be emitted unburned into receiving waters. Factors affecting the quantity of compounds exhausted from outboard motors include horsepower rating, crankcase size, composition of fuel mixture, tuning of the engine, and speed of operation. Some of the compounds measured in water contaminated by motor exhaust include volatile and nonvolatile oil, lead, and phenols.

77. Jackson, H.O.; Starrett, W.C. Turbidity and sedimentation at Lake Chautauqua, Illinois. J. Wildl. Manage. 23:157-168; 1959.

A study was made of the causes and effects of resuspension of sediment particles at Lake Chautauqua, a 3562 acre, shallow, lateral reservoir lake along the Illinois River. Turbidity determinations were made with a Jackson turbidimeter from 346 water samples. 156 water-transparency readings were taken with a Secchi disk. Turbidity ranged from less than 25 ppm to 800 ppm. Potamogeton pectinatus is now the only submergent plant that ever occurs abundantly in the lake and its abundance varies with water levels. Water motion produced by wind caused an increase in turbidity in the absence of pondweed or ice cover (water depth less than 4.8 feet). Under such conditions turbidity tended to vary with wind velocity. Disturbance of the bottom by fish increased turbidity of the lake. Commercial removal of 2,022,965 pounds of fish from the lake during an 8-year period had no apparent effect upon vegetation or turbidity.

78. Johnson, J.H. Effects of tow traffic on the resuspension of sediments and on dissolved oxygen concentrations in the Illinois and upper Mississippi Rivers under normal pool conditions. Technical Report Y-76-1, U.S. Army Engineer Waterways Experiment Station, Environmental Effects Laboratory, Vicksburg, Mississippi; 1976; 181 p.

This study was conducted to determine the effects of single and multiple tow traffic on the resuspension of riverbed sediments and on dissolved oxygen concentrations at several locations on the Illinois and upper Mississippi Rivers during normal pool conditions. In total, 19 separate tows were monitored on the Mississippi River and 21 tows on the Illinois River at locations chosen to correspond to upper, middle, and lower river reaches. Specific sampling sites were selected so that maximum effects (changes in concentrations) of tow traffic on potentially productive side channel habitats could be tested. Besides side channel sampling stations, three other stations were positioned along a transect across the river proper to determine if sediments resuspended from the middle of the river move laterally to shoreward areas. Composite water-column samples were collected simultaneously at each sampling station at selected time intervals consisting of immediately before the passage of a tow(s) and at specific time intervals up to 180 min after each tow passed. Current velocity profiles, water depth, water temperature, and river stage were also measured. Dissolved oxygen measurements were made in situ at surface, mid-depth, and near-bottom strata in the main channel only. Water samples collected in the field were analyzed in the laboratory for suspended solids (a gravimetric measurement) and for turbidity (an optical measurement). Two-way analyses of variance were performed on replicate samples for each variable (suspended solids, turbidity, and dissolved oxygen) monitored during each tow traffic event to test for differences among sampling stations and differences over time. To determine how the means differed, a mean contrast test (the least significant difference test) was performed. These analyses indicated that tow traffic on the Illinois and upper Mississippi rivers during normal pool conditions does contribute to existing levels of suspended sediment measured as both suspended solids and turbidity, and, furthermore, that sediments resuspended from the main channel do move laterally to shoreward areas, including potentially productive side channel areas. Based on the relative responses of suspended solids concentrations and turbidity levels following the passage of tow traffic on both the Illinois and upper Mississippi rivers, the Illinois River appears to be. more susceptible to tow traffic effects than the Mississippi River.

79. Johnson, J.H.; Solomon, R.C.; Bingham, C.R.; Colbert, B.K.; Emge, W.P.; Mathis, D.B.; Hall, R.W., Jr. Environment analysis and assessment of the Mississippi River 9-ft. channel project between St. Louis, Missouri, and Cairo, Illinois. Vicksburg, MS: U.S. Army Engineers Waterways Experiment Station; Nov. 1974. 145 pp.

The Mississippi River 9-ft channel project was authorized by the River and Harbor Acts of 21 January 1927 and 3 July 1930, for the purpose of obtaining and maintaining a 9- by 300-ft channel for navigation from the confluence of the Missouri River (St. Louis, Missouri) to the confluence of the Ohio River (Cairo, Illinois). The main channel will be contracted to 1500 ft between riverward ends of dikes throughout the study area in order to maintain the 9-ft depth during periods of low flow. A comprehensive study of the historical geomorphology supplemented by physical models of the river and side channels was made by Colorado State University to determine the physical impact of river contraction works on river morphology and behavior. An intensive study of the terrestrial flora and fauna was conducted by Southern Illinois University to inventory the existing organisms

and communities located in the unprotected floodplain and to assess the impacts of operation and maintenance activities on these organisms and communities. In addition, the aquatic flora and fauna were studied by the Missouri Department of Conservation and the Waterways Experiment Station to inventory the aquatic communities present in the study area and to assess the importance of side channels to the riverine ecosystem. Biological, physical, chemical, and morphometric data, collected from side channels and river border areas, were subjected to various statistical analyses. The relative biological importance of each side channel established by ranking procedures provided a rational choice of those side channels that could provide maximum benefit to the river's ecology. Operation and maintenance activities of the St. Louis District in the Middle Mississippi include maintenance dredging, disposal of dredged material, and construction and maintenance of levees, dikes, and bank revetments. These activities were examined and the potential environmental impacts resulting therefrom were discussed. Based upon the overall results of these studies, the need for new and more intensive studies was obvious. These additional studies would define to a greater degree the impacts of the 9-ft channel on the environment.

80. Johnson, J.W. Ship waves in navigation channels. Proc. Sixth Conference on Coastal Engineering, Berkeley, California; 1958:666-690.

Ships moving through navigation channels generate waves which cause severe wave-wash damage to the banks. The study observed ship wave characteristics in deep-water conditions and shallow-water conditions. Also ships wave measurements were obtained using models and power boats. The study determined that models of sufficient size appear to produce a reliable prototype prediction of the waves generated by a particular hull shape.

81. Johnson, J.W. Ship waves in shoaling waters. Proc. 11th Conference on Coastal Engineering, London, England 2(4):1488-1498; Sept. 1968.

Models of two types of vessels were towed at various speeds in water of uniform depth. On one side of the sailing line the ship waves were allowed to move over reaches of various slopes. The wave heights were measured and compared at two points equidistant from the sailing line--patterns were determined by photographs.

82. Johnson, J.W. Ship waves at recreational beaches. Shore and Beach 37(1):11-15; 1969.

The above data provide some measure of the heights of waves resulting from the passage of typical ships moving at various speeds near sloping shorelines. The magnitude of such waves when ships travel at relatively high speeds obviously may create hazardous conditions to unobserving users of the shoreline. Floating equipment and docks along a shoreline are also subject to damage.

83. Jones, R.A.; Lee, C.E. Evaluation of the elutriate test as a method of predicting contaminant release during open-water disposal of dredged sediments and environmental impact of open-water dredged material disposal. TR

D-78-45, U.S. Array Corps of Engineers Waterways Experiment Station, NTIS No. AD-A064014.

Cited in U.S. Corps of Engineers (1980).

84. Kallemeya, L.W.; Novotny, J.F. Ecological evaluation of bank stabilization and channelization work on the Missouri River. Yankton, SD: U.S. Fish and Wildlife Service; 1976-1977.

The Missouri River flow is controlled by large reservoirs but there are 40 miles of unimpounded and unchannelized river below Fort Randall Dam, and 60 miles between Gavins Point Dam and Sioux City, Iowa. The river is channelized for navigation between Sioux City, Iowa and its mouth at St. Louis, Missouri.

Extensive bank erosion is occurring on the unchannelized river because of meandering and low sediment load. The Streambank Erosion Control Evaluation and Demonstration Act of 1974 authorizes the U.S. Army Corps of Engineers to develop methods for stabilizing river banks which would not radically change the river environment, and this section of the Missouri River is included in the authorization. Funds were appropriated for construction of the Missouri River and six crucial areas have been designated for bank stabilization work.

The objectives of this project are to (1) determine the species and abundance of plants and animals that utilize various river habitats in channelized and unchannelized sections of the Missouri River; (2) evaluate the effects of different methods used to stabilize banks of the Missouri River, on fish and wildlife; and (3) evaluate the ecological effects of modifying channelization structures on fish and wildlife in the Missouri River.

85. Karaki, S.; van Hoften, J. Resuspension of bed material and wave effects on, the Illinois and upper Mississippi Rivers caused by boat traffic. CER 74-75SKJV9, Colorado State Univ., Ft. Collins, Colorado; Nov. 1974.

The purpose of this study is to analyze qualitatively the effects of waterborne traffic on the Illinois and upper Mississippi Rivers with regard to the resuspension of bed sediments caused by boat passage and to estimate the increase in turbidity due to an increase in river traffic. The generation of turbulence by tow boats and other surface crafts is also discussed, along with the erosion of banks by boat generated waves. Aerial color infrared photographs and published information were used to aid the analysis.

86. Keenlyne, D.D. Upper Mississippi River Conservation Committee Investigational Reports. Upper Mississippi River Conservation Committee; 1974; 179 P.

This publication, a contribution by the Upper Mississippi River Conservation Committee, was prepared as an effort toward better management of the fishery resources of the Upper Mississippi River.

In a joint effort to better manage the common resource, the UMRCC was born. Organized in 1943 (on the upswing of several species in response to the dams), the Committee began to conduct fishery studies in view of better management of the common resource and to ivnestigate effects of certain operation features of pool regulation. These special investigative reports record the thoughts and findings of several of these early researchers.

87. Kennedy, D.M. Ecological investigations of backwaters along the lower Colorado River. Dissertation, Univ. Arizona; 1979. 218 p.

88. Kennedy, D.M. Memo to Jerry Rasmussen, USFWS, and K.S. Lubinski, Illinois Natural History Survey, regarding, "Review comments on the literature review of physical/chemical/biological effects of navigation - draft. Dated September 26, 1980." 1980; 8 p.

89. Klein, W.M.; Daley, R.H.; Wedum, J. Environmental inventory and assessment of navigation pools 24, 25, and 26, Upper Mississippi and Lower Illinois Rivers: A vegetational study. Vicksburg, MS Army Engineer Waterways Experiment Station. Missouri Botanical Garden, St. Louis; 1975; 151 p.

The purpose of the study was to provide a vegetation map and descriptions of vegetational types and their successional patterns to be used in an environmental impact analysis of the effects of maintenance and operation of the nine-foot navigation channel in pools 24, 25, and 26 on the Upper Mississippi and Lower Illinois Rivers. Seven vegetation types were described after field examination of 116 stands: two nonforest types, old fields and wetlands; and five forest types, willow, silver maple-cottonwood, silver maple-cottonwood-pin oak, pin oak, and oak-hickory. All of thse types were mapped with the exception of old fields, which were omitted because they are often subject to cultivation after a short period of abandonment. The silver maple-cottonwood community was found to be the most extensive type. Analysis of successional trends indicated that ash (Fraxinus spp.) and american elm (Ulmus americana) may become more important in many of the silver maple forests and that pin oak forests may also replace them particularly in areas protected from flooding by levees.

90. Kofoid, C.A. Plankton studies. IV. The plankton of the Illinois River 1844-1899, with introductory notes upon the hydrography of the Illinois River and its basin. Part I. Quantitative investigations and general results. Illinois State Lab. Nat. Hist. Bull. 2:95-630; 1903.

A detailed description of the physical and chemical parameters of the Illinois River, its tributaries, and basin is presented. Plankton seasonal and geographic distributions and abundance patterns are discussed. Fluctuation and changes in abundance patterns of plankton populations are related to environmental conditions.

91. Lee, M.T.; Stall, J.B. Sediment conditions in backwater lakes along the Illinois River. Contract Report No. 176, State of Illinois, Dept. Registr. Educ, Ill. State Water Surv. , Urbana; 1976.

The sediment yield leaving the mouth of the Illinois River is about 12.1 million tons per year. The sediment yields from the tributaries to the

Illinois River were estimated at 27.5 million tons per year. The difference of these two sediment yields is assumed to stay in the floodplain. Deposition in backwater lakes and rivers would yield 2.0 inches accumulation annually, while this amount of sediment spread over the floodplain equals 0.19 in.

Lake Meredosia and Lake Depue were studied with detailed cross section surveys. Reconnaissance surveys were made of 10 other backwater lakes. Sediment accumulation rates were determined, and hydrological data were accumulated.

The annual accumalated rising stage times the lake surface area was assumed to be the first approximation of the annual inflow to the lake. A rate of annual inflow and sediment deposition at Lake Meredosia was calculated. In the future, given the annual daily river stage or lake stage, the first approximated lake sediment deposition can be assessed based on this ratio for different reaches of the river.

92. Lee, M.T.; Stall, J.B. Sediment conditions in backwater lakes along the Illinois River - Phase 1. Contract Report, State of Illinois, Dept. Registr. Educ., Ill. State Water Surv., Urbana; 1977.

This research project has been a continuation of last year's project titled "Sediment Conditions in the Backwater Lakes Along the Illinois River."

Fifteen lakes were studied in all. Six of them had detailed cross section surveys, and nine of them were based on reconnaissance surveys. The sedimentation rates of thse 15 lakes were calculated. In addition to the quantity of sedimentation, we also sampled the lake beds. These sediment samples were analyzed for physical and chemical properties. Eighteen sediment samples were subjected to volume-weight and particle-size analyses. Five core samples were taken for detailed chemical analyses.

The lakes which were selected for this study were located along the Illinois River from river mile 5 in Alton pool to river mile 248 in the Marseilles pool. Two lakes are in the Alton pool, five in the LaGrange pool, seven in the Peoria pool, and one in the Marseilles pool. The surface areas range from 19 to 15,745 acres. The lake capacities range from 19 to 114,277 ac-ft.

The reductions of lake capacities due to sedimentation in the last 73 years range from 18% to 80% reduction. Most of the lake beds have risen from 0.3 to 0.5 inches per year. The surface areas of the lakes did not have significant changes.

93. Leopold, A.S. Notes on the Mississippi River pools and their effect on wildlife. Unpublished. 1939; 3 p.

94. Link, L.E., Jr.; Williamson, A.N., Jr. Use of automated remote sensing techniques to define the movement of tow-generated suspended material plumes on the Illinois and Upper Mississippi rivers. Vicksburg, MS: Army Engineer Waterways Experiment Station; 1976; 71 p.

Sequential color-infrared aerial photos and corresponding surface water samples were obtained at selected sites on the Illinois and Upper Mississippi Rivers to examine the movement of tow-generated suspended material plumes. The aerial photos were digitized with a scanning microdensitometer, and optical density values were extracted for correlation with suspended material concentration data obtained by laboratory analysis of the water samples. Correlation of the optical density and concentration values for each site and for sample positions at each site did not produce a statistically significant relation between the variables. The poor correlation between optical density and concentration values prevented quantitative definition from the imagery of the distribution of suspended material concentrations at the sites as a function of time. Digital data handling procedures were used to enhance the visibility on the imagery of the tow-generated plumes. The procedures applied were successful in delineating the movement and dissipation of the tow-generated plumes under favorable sun and water conditions.

95. Liou, Y.C.; Herbich, J.B. Sediment movement induced by ships in restricted waterways. Texas A & M Univ., TAMU-S6-76-209, COE Report No. 188; Aug. 1976.

A numerical model using the momentum theory of the propeller and Shields' diagram was developed to study sediment movement induced by a ship's propeller in a restricted waterway. The velocity distribution downstream of the propeller was simulated by the Gaussian normal distribution function. The shear velocity and shear stress were obtained using Sternberg's formulas. Once the ship's speed, depth of the waterway, RPM and diameter of the propeller, and draft of the ship are given, the velocity distribution and the grain size of the initial motion could be obtained from this model. A computer program was developed to solve it. Case studies are presented to show che influence of significant factors on sediment movement at the channel bottom induced by a ship's propeller.

96. Little, A.D. Report on channel modifications, vol. I and II. Prepared for Council on Environmental Quailty, Washington, D.C.; 1973.

The report is in three separate bindings. Volume I describes procedures, summarizes findings and presents nine chapters on contractual elements of the work. Volume II, Part One, and Volume II, Part Two, each contain 21 field evaluation reports.

This report assesses environmental, economic, financial and engineering aspects of channel modifications, and the availability and use of alternatives, as planned and carried out by the Corps of Engineers, Soil Conservation Service, Tennessee Valley Authority and Bureau of Reclamation. Our assessment has drawn upon the public record and literature, our observations in the field of 42 projects in 18 States and our discussions with at least 558 people in 30 public meetings throughout the Nation.

97. Livesey, R.H. The role sediments play in determining the quality of water. In: Proc. seminar on sediment transport in rivers and reservoirs, Corps of Engineers Hydrologic Engineering Center, April 7-9, 1970; Davis, California, Paper No. 9.

The purpose of this paper is to identify such sediment related problem areas by citing and discussing a broad range of specific examples. It is not intended that these comments be focused only on engineering applications but, rather, that they be oriented toward all disciplines associated with water resource planning. It is hoped that, regardless of whether the problem is faced by the conservationist or biologist, the economist or planner, the lawyer or politician, or the chemist or engineer, these comments will present a clearer insight into how sedimentation influences our environment.

98. Lovejoy, J.A.; Kennedy, D.M. Shoreline protection for habitat enhancement on the upper Mississippi River (an inventory of sites needing protection and a literature search and review). Prepared for the Fish and Wildlife Work Action Team. St. Paul, MN: U.S. Army Engineers, St. Paul District; 1979; 37 p.

Shoreline protection can provide significant enhancement to the Upper Mississippi River ecosystem by minimizing the impacts of sedimentation and by adding diversity and stability to its habitat.

Sand accumulations within the main channel area required dredging to maintain the 9-foot navigation project. Stabilized shorelines help maintain flow within the established channel 'so that shoaling is less likely to occur and coverage of habitat by dredge disposal operations is reduced. When dredging is required, stabilized sand piles will help prevent secondary sand movement caused by such erosional forces as flood flows, wind and boat generated wakes, and prop wash. Aggradation of fine sediments, in off channel areas can also be avoided when side channel openings are protected. Consistent flow through side channels and into backwaters will reduce changes of closure and help prevent decline of backwater area productivity by sedimentation. The use of riprap (rock) as a shoreline protection technique is of high biological value in terms of habitat enhancement. In the main channel area, typically dominated by shifting sand substrate, riprapped shorelines provide more diversity and stability to existing habitat. Benthic invertebrate production generally requires stabilized substrate for colonization. Benthos and periphyton production found at stable substrates are preferred fish feeding areas. Freshwater mussels also prefer stable substrates such as gravel beds in preference to shifting sand.

Caution should be take to avoid the negative impacts of channelization. Although diversity and stability of habitat and substrate are the desired results of shoreline protection, desirable aquatic organisms and habitat diversity can be adeversely affected if channelization occurs. Based on enhancement potential, the St. Paul District Corps of Engineers should immediately implement shoreline protection measures using rock riprap at those sites identified and prioritized in Table 1 of this report.

100. Marzolf, G.R. The potential effects of clearing and snagging on stream ecosystems. National Stream Alteration Project, U.S. Dept. Interior; 1978. 31 p.

Clearing and snagging, the removal of obstructions from streams to increase the channel's capacity to convey water, is conducted to drain floodplains

for agriculture, to protect citiznes from floods, or to maintain navigable waterways.

This review examines the widely held contention that such stream alteration reduces fish populations and is otherwise detrimental to the use of stream ecosystems. It was prepared for use in assessing the ecological impact of clearing and snagging projects. Because of the lack of direct quantitative evidence about clearing and snagging effects, the mechanisms involved in producing the effects are discussed indirectly as potential effects.

101. Mathis, B.M.; Cummings, T.F. Selected metals in sediments, water, and biota in the Illinois River, journal Water Pollution Control Federation 45:1573-1583; 1973.

In the present study an atomic absorption spectrophotometer was utilized to determine the concentrations of copper, nickel, lead, chromium, lithium, zinc, cobalt, and cadmium in water, bottom sediments, tubificids, clams, and fishes taken from the Illinois River.

The bottom-dwelling tubificids and clams closely reflected the concentrations of metals found in bottom sediments. A concentration gradient ranging from highest levels in worms, intermediate levels in clams, and lowest levels in fish fillets was observed for copper, nickel, lead, chromium, lithium, cobalt, and cadmium. Zinc, however, exhibited a partial reversal of this trend. It was present in highest concentrations in clams at intermediate levels in worms, and at lowest levels in fish fillets.

With the exception of copper in worms, metals were more highly concentrated in bottom sediments. The water components of the river exhibited the lowest concentration of metals with the exception of lithium.

102. Maurer, D.; Biggs, R.; Leethem, W.; Kinner, P.; Treasure, N.; Otley, M.; Watling, L.; Klemas, V. Effect of spoil disposal on benthic communities near the mouth of Delaware Bay. College of Marine Studies, Univ. Delaware, Lewes; 1974. 231 p.

Cited in Morton (1977).

103. McHenry, J.R.; Richie, J.C.; Verdon, J. Sedimentation rates in the upper Mississippi River. Third Annual Symposium on Waterways, Harbors, and Coastal Engineering Division, ASCE. Colorado State Univ., Ft. Collins, Colorado; 1976, vol. II.

During the 1930's the U.S. Army Corps of Engineers constructed a series of locks and dams on the Mississippi River from St. Louis to Minneapolis to maintain a "9-foot" shipping channel. This system of locks and dams created a series of pools and backwater lakes which have acted as settling basins for suspended materials brought into the system by the mainstem and its tributary streams. Concern has recently been expressed about the amount of dredging necessary to maintain the 9-foot channel and about the amount of fine sediment depositing in the backwater lakes, particularly in that reach of the river from Lock and Dam No. 3 through No. 10. The tributary rivers drain extensive areas of excellent farmland and their sediment contribution to the various pools and backwater lakes has been of concern to fishermen, hunters, and environmentalists as well as the Corps of Engineers. In 1975, representative sediment samples were collected from the pools and backwater lakes of the eight reaches between Dams Nos. 3 and 10; Lake Pepin to Guttenberg, Iowa. Profile samples were taken in 10-cm increments to the depth of the recently accumulated (post dam closure) sediment. The samples were analyzed for cesium-137 content using gamma differential spectrometry. The amount of sediment deposited since the introduction of Cs-137 into the environment (1957) was estimated, as well as the sedimentation rate since the intensity of fallout Cs-137 was maximum (1964), from the concentration of Cs-137 measured in the sediment profiles. The results indicated the amount of sediment deposited has ranged from 10 to 60 cm in the 11-yr period since 1964, with an average accumulation of 30 cm--2.5 cm/yr. Depths of sediments containing Cs-137, i.e., deposited since 1957, ranged up to 80 cm. The identification and quantification of Cs-137 in fine sediments deposited in major navigation systems is used to estimate recent (post 1957) rates and amounts of sedimentation.

104. McHenry, J.R.; Ritchie, J.C.; May J. Recent sedimentation rates in the lower Mississippi Valley - Lake Palourde, Louisiana. Proc. Mississippi Water Resources Conf., Jackson, Mississippi. 1975:13-23.

Cited in GREAT I Sediment and Erosion Work Group (1979:11).

105. Midwest Research Institute. Environmental and social consideration of Mississippi River year-round navigation program. Final report. Rock Island, IL: U.S. Army Corps of Engineers, Rock Island District; 1978; 72 p.

The various comments which were pertinent to the extended navigation season have been categorized, examined, and elucidated. This report is based on the Alternative D program which is a 12-month navigation season from Grafton, Illinois, now the head of year-round navigation, to Burlington, Iowa; a 46-week season to the Quad Cites, Illinois, and Iowa; and a 40-week season to Cassville, Wisconsin.

This reports identified salient concerns and the entities who expressed concern; discussed each problem or concern, and research needs; and evaluated the feasibility of a demonstration navigation program to resolve those concerns. There is a list which categorizes and rates the various concerns according to a subjective opinion of their significance. The rating of 1 to 3 is given, with "1" being of most importance for detailed consideration.

The desirability of a winter demonstration program in helping to quantify presently unknown effects is substantial. Many of the problems which are referred to above may only be resolved through a well-defined winter demonstration program which we hereby recommend.

106. Mills, H.B.; Starrett, W.C.; Bellrose, F.C. Man's effect on the fish and wildlife of the Illinois River. Ill. Nat. Hist. Surv. Biol. Note No. 57, Urbana; 1966; 23 p.

This is a documented report on changes in the Illinois River, primarily in the past 75 years, with emphasis on the biological modifications which have occurred and are occurring as a result of man's activities.

The river has not shown steady changes from year to year. Rather, many of them have occurred with great rapidity and some have not been permanent. For example, the acreage of water, which went up greatly due to diversion from Lake Michigan in 1900, was reduced almost to its pre-1900 surface by 1913. This reduction was due to the development of levee districts, which claimed and drained large areas of the floodplain, and subsequently to decreased lake water diversion in the 1930's.

Most of the observations in this publication relate to the main stream and its lateral bottomland lakes, but these areas are only what the basin makes them.

107. Morton, J.W. Ecological effects of dredging and dredge spoil disposal: a literature review. Technical Paper 94, U.S. Fish and Wildlife Service; 1977. 33 p.

The goal of this study was to prepare a comprehensive review of the literature on the physical, chemical, and biological effects of dredging and spoil disposal in estuaries and to identify alternative spoil disposal methods. Specific objectives were to identify the most critical problems relating to dredging and spoil disposal and to summarize the progress made to date in solving these problems. Using literature search facilities, bibliographies, and communications with experts throughout the United States, I screened about 520 scientific and technical articles on dredging and spoil disposal. Information extracted from selected articles is included in this review.

An important physical effect of dredging and open-water spoil disposal is alteration of circulation patterns that results when dredged channels and spoil mounds block and reroute tidal currents, induce shoaling, or alter flushing rates. A second important effect is the uncontrolled redistribution of sediments eroded from the spoil mound at the disposal site. Processes influencing erosion and sediment-transport mechanisms are too poorly understood to permit the construction of models for the preduction of long-term fate of dredge spoils after they are deposited at the disposal site.

Changes in the chemistry of the sediments at the dredging and disposal sites and of the water overlying these areas are likely to result from dredging and dumping, especially if the dredged sediments have a high organic content or are contaminated. One of the most critical, yet least understood, problems is the possible remobilization of contaminants as polluted sediments are dredged and deposited at the disposal site. Several interacting factors and processes are believed to control the flux of contaminants across the sediment-water interface: the sediment's clay fraction and organic content, redox (oxidation-reduction) potential, pH, bacteria, the sulfur cycle, and the iron cycle. A conceptual model of how these variables interact is presented.

Although direct burial of organisms and destruction of the habitat (altering it physical and chemical characteristics) are the two most obvious biological effects of dredging and dumping, the effects can be reduced by careful timing of the dredging and placement of the spoil. A critical problem requiring further study is the uptake and concentration of contaminants associated with polluted dredge spoils by marsh vegetation, phytoplankton, zooplankton, benthos, and fish.

To minimize the various physical, chemical, and biological effects of dredging and dumping, engineers and biologists are attempting to improve existing dredging techniques and find suitable alternatives to unconfined, open-water spoil disposal. Possible alternatives include the use of diked or confined disposal areas, construction of marshes and spoil islands, and treatment and inland transport of dredge spoils for landfills. Although construction of marshes and spoil islands is not yet operationally practical, this is one of the more promising alternative spoil disposal methods.

108. Moss, B. Conservation problems in the Norfolk broads and rivers of East Anglia, England: Phytoplankton, boats and the causes of turbidity. Biol. Conserv. 12:95-114; 1977.

The Norfolk Broads and river of eastern England (Fig. 1) comprise an area hitherto famed for the diversity of its wildlife and submerged aquatic plant communities. The latter have progressively disappeared since the early 1950's, until only four sites currently remain more than remnants of the original sub-aquatic macrophyte flora and its associated invertebrate fauna. Increases in turbidity of the water have been associated with the loss of macrophytes, and these increases have been variously contributed to phytoplankton and to disturbance of sediment by the many boats of visiting tourists and residents. Synoptic surveys of turbidity were carried out in the navigable waterways of Broadland in summer and winter 1973, and of phytoplankton summer 1973. The differential distribution of phytoplankton is discussed in terms of nutrient loading and flushing coefficients of the waterway. Highly significant correlations were obtained between phytoplankton numbers and turbidity in the system as a whole and in Broads and rivers considered separately. A very weak correlation between boat activity and turbidity was shown to be non-causative. It is concluded that increase in turbidity is a function of increased nutrient loading from human activities in the catchment area and that boat disturbance does not contribute significnatly to the sustained turbidity.

109. Mueller, A. Navigation effects in the open river. Written summary of paper presented before the Upper Mississippi River Conservation Committee; 1977.

Today, there are over 100 miles of effetive wing dikes in the 195 miles of the Middle Mississippi River. An effective wing dike is one with rock still sticking out into the current. Those portions of the wing dikes that have been silted in and covered up are not conisdered effective; so this is not the total amount of wing dikes that have been built, but only that which remains effective. More dikes are currently planned.

These 100 miles of effective dikes have certainly had their effect on both the main channel and the side channels. One of the most overlooked effects is the degradation of the main channel bed. Of course the whole idea of the wing dikes is to deflect the current to maintain the nine-foot navigation depth. There are some areas where the main channel is now 11 feet deeper than it was in the 1800's, before the implementation of the wing dikes. The river has also been significantly narrowed. In 1888, average river width was about 5,300 feet, while in 1968, it was calculated to be 3,200 feet. Thus, over an 80-year period, a relatively short period in the life of the river, its width was reduced by more than 2,000 feet primarily due to the action of the wing dikes. Of course, there has also been a very effective program of restricting flows in the side channels. These have been closed off, again increasing the sedimentation rate. This sedimentation process also occurs on the remainder of the Upper Mississippi River, but at a much slower rate because of the difference in sediment loads. The Missouri River contributes approximately 90% of the sediment load to the Middle Mississippi River. In other words, the remainder of the Upper Mississippi River carries only about one-tenth as much sediment as the Middle Mississippi.

110. Mueller, G. Effects of recreational river traffic on nest defense by long-ear sunfish. Trans. Am. Fish. Soc. 109:248-251; 1980.

An underwater camera system was. designed to record the behavior of male nest-guarding longear sunfish (Lepomis megalotus) during periods of boating activity. Boats traveling at slow speeds near nests usually drove males from their nests, increasing the likelihood of egg predation. Boats moving at higher speeds or further from nests caused little or no displacement of males, but increased turbidity and possible success of predators. Location of a nest near cover increased the male's ability to protect his nest during repeated surface disturbances.

111. Nunnally, N.R.; Keller, E. Use of fluvial processes to minimize adverse effects of stream channelization. Waters Resources Research Institute Report 144; July 1979; 115 p.

Stream restoration is a means for restoring flow efficiency in streams that have become debris-choked and eroded due to the direct and indirect actions of humans. Such degraded streams are typically characterized by debris jams, severe bank erosion, overwide channels, and heavy sediment discharge brought on by altered stream regimes, land use changes or prior channelization. Compared to channelization, stream restoration involves trading off some loss in flow efficiency for a more stable channel morphology and significantly better aquatic and fluvial ecosystems. Stream restoration is accomplished by removing debris jams and providing fairly uniform channel cross-section and gradients while preserving meanders, leaving as many trees as possible along stream banks, and stabilizing banks with vegetation and riprap where necessary. Economically, the cost of restoration is typically less than one-tenth of the cost of channelization. Experiments with stream restoration on Briar Creek, Gum Branch and Mallard Creek in Charlotte, North Carolina, have been extremely successful. Despite several storms with heavy rainfall, some of which exceeded ten-year design storms, few significant areas of bank failure have occurred in the restored sections even though massive failures occurred during the same period on untreated streams nearby. Public enthusiasm and support for the project is very high with most residents of flood proone neighborhoods perceiving considerable improvement in flood hazards and reduced erosion without significant reduction in wildlife.

112. Patrick, W.H.; Gambrell, R.P.; Khalid, R.A. Physicochemical factors regulating solubility and bioavailability of toxic heavy metals in contaminated dredged sediment. J. Environ. Sci. Health A12(9):475-492; 1977.

This report contains sections on: physicochemical changes following disposal of dredged material, chemical forms of metals in sediment-water systems, pH and redox potential levels in surface water and sediments, influence of dredging and dredged material disposal on pH and redox potential, and reactions of heavy metals in dredged sediments.

The results and examples cited in this report suggest that with proper management of dredged and fill material, it may be possible to control to some degree the movement of toxic heavy metals into the interstitial water and into the food chain. For most dredged material such precautions and treatments will not be necessary, but for the small percentage of dredged material that is contaminated, advantage can be taken of the chemical and biological properties of the heavy metals and the sediment to minimize the bioavailability of the heavy metals.

113. Peltier, W.H.; Welch, E.B. Factors affecting growth of rooted aquatics in a river. Weed Science 17:412-416; 1969.

Excessive aquatic plant growths in the Hoston River was not solely related to the presence of large amounts of nutrients in the water. Factors contributing to growth were the amount of nutrients in sediments, water depth and turbidity. Water depth and turbidity influence the amount of light which penetrates the water and is available for the growth of rooted plants.

114. Pflieger, W.L.. The fishes of Missouri. Missouri Department of Conservation; 1975; 343 p.

The purpose of this book is to acquaint the reader with the nearly 200 kinds of fishes found in Missouri; to provide keys, descriptions, and illustrations for identifying them; and to make available information on their distribution, life ways, and importance to man.

115. Poe, T.P.; Edsall, T.A.; Hiltunen, J.K. Effects of ship-induced waves in an ice environment on the St. Marys River ecosystem. Ann Arbor, MI: Great Lakes Fishery Laboratory; 1980. 125 pp.

In response to requests received in November-December 1978 from FWS-ES and the COE, the Great Lakes Fishery Laboratory (GLFL) agreed to undertake a COE-funded study during January-April 1979 at selected sites in the St. Marys River, to provide a base of information for evaluating the effects on fish, fish-food organisms, and fish habitat at those sites of ship-induced,

under-ice surge waves, created by vessel passage in the adjacent ice-covered navigation channel.

Sampling was conducted at Frechette Point and Six Mile Point in the St. Marys River during January 16-20, February 13-19, and March 13-18, when there was solid ice cover, and during April 17-21, immediately after the solid ice cover had been broken by heavy vessel traffic.

Examination of the drfit net fishing records and the records of vessel passages through the study area revealed a large increase in the amount of drift occurred as a result of vessel passage during the period of solid ice cover. Comparison of drift net catches in March when there was solid ice cover and moderate vessel traffic with catches in April when there was heavy floe ice and very heavy vessel traffic suggests the effect of vessel passage on drift was greater when solid ice cover was present.

The significance of the observed vessel-induced drift cannot be demonstrated with the available data. However, the biota and detritus represented in the drift net catches may constitute an energy resource that is important to production in the portion of the St. Marys River covered by the study. The accelerated transport of this material through the system in winter, when production approaches the annual minimum msy result in a considerable energy loss to the portion of the system from which the drift material was transported.

A total of 132 light penetration measurements made at different levels in the water column suggested that vessel passage increased turbidity; they also suggested that the disturbance of the sediments by vessel passage was less when solid ice cover was replaced with heavy floe ice cover.

116. Rasmussen, J.L., et al. A compendium of fishery information on the Upper Mississippi River. A Contribution of the Upper Mississippi River Conservation Committee. 2nd ed; 1979.

This is a reference volume for fisheries managers along the Upper Mississippi River. It contains descriptions of the river and ongoing management and research projects related to its fisheries. It also contains distribution and abundance data on UMR fishes, life histories of major species, analyses of the sport and commercial fisheries, results of mussel surveys, a recreation survey, and commercial fishing data and trend plots.

117. Rasmussen, J.L. Memo to Ken Lubinski, Illinois NAtural History Survey regarding "Review of Draft Summary of Physical, Chemical, and Biological Effects of Navigation." 1980.

118. Richardson, E.V.; Stevens, M.A.; Simons, D.B. The design of spurs for river training. In: Fundamental tools to be used in environmental problems. Proc. 16th Congress on International Association for Hydraulic Research, Sao Paulo, Brazil, July 27-Aug. 1, 1975; 2:382-388.

Spurs are stone, gravel, rock, earth or pile structures built at an angle to a river bank to deflect flowing water away from critical zones, to pre-

vent erosion of the bank, to establish a more desirable channel for flood control, navigation and erosion control. They are used on wide braided rivers to establish a well defined channel that neither degrades nor shifts its location from year to year. In this case, the spurs may have long dikes at their outer end to help define the channel and many miles of a river are controlled by spurs. Spurs are also used on meandering rivers to control flow into or out of a bend or through a crossing. The basic quantities to be considered in the design of spurs are discussed in this paper.

119. Saucier, R.T.; Calhoun, C..C, Jr.; Engler, R.M. ; Patin, T.R; Smith, H.K. Executive overview and detailed summary. Dredged Material Research Program. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station; Dec. 1978.

Recognizing a need for a comprehensive nationwide research program on the effects of dredged material disposal, Congress authorized and the Corps of Engineers accomplished the Dredged Material Research Program (DMRP). Over 250 individual studies were conducted between 1973 and 1978 at a cost of $32.8 million. In contrast to previous largely site-specific project investigations, these studies were generic in nature with the intent of developing methods of predicting effects before a project is carried out. Results of conceptual and laboratory studies were tested in the field under actual project conditions to improve the applicability of the predictive capability.

Specific goals of the DMRP were to define the water quality and biological effects of open-water, upland, and wetland disposal; improve the effectiveness and acceptance of confined land disposal where it is a desirable alternative; test and evaluate concepts of wetland and upland habitat development using dredged material; and develop and test concepts of using dredged material as a productive natural resource. The large volume of information generated in pursuit of these goals has been transmitted to Corps operation elements in various formats, incorporated into formal directives, and used extensively in the criteria and guidelines established for regulatory programs.

120. Schneeberger, E., Funk, J.L. Stream channelization, a symposium. Special Publ. No. 2, N. Central Div. A.F.S.; 1971; 83 p.

More and more people are becoming concerned about alteration of our streams and their flood plains. To channelize a stream is to convert it into a ditch. Channelization may be undertaken for navigation, flood control, or to increase arable land. It is usually planned and carried out with little consideration to the natural environment. It may be accomplished by attrition. A ditch has little aesthetic appeal but more than aesthetics is involved. Aquatic animals and many terrestrial animals and birds in a watershed live there because of the stream and a ditch does not provide suitable habitat. Many agencies, local, state and federal, are responsible for the planning, financing and implementation of channelization projects. A committee of the North Central Division, American Fisheries Society, investigated channelization in the Midwest, calling a meeting of representatives of the 15 state and provincial conservation departments, to discuss the nature and extent of the problem and avenues of action. Both the amount of channelization being done and the apparent concern about it varied among

the states and provinces. Although most departments had jurisdiction over the fish in the streams, the streams were privately owned and, under the riparian doctrine, many departments felt they lacked authority to deal with the problem. In most states and provinces another agency had direct responsibility for regulation of the waters. Only one state seemed to have made a serious attempt to estimate past losses to channelization (Minnesota, 22,000 miles of stream). Five reported uncompleted projects which would channelize 2,400 miles of stream. No state reported satisfactory mitigation of fisheries losses from stream channelization. Local opposition is probably the most effective avenue of action to prevent channelization. Classification of a stream as a Scenic River presumably would remove it as a target. No channelization project will be activated if the Governor of the state opposed it. Sound information is needed to sway Governors, legislators, and the public to oppose channelization of streams.

121. Schubel, J.R.; Bokuniewicz, H.J; Gordon, R.B. Transportation and accumulation of fine-grained sediments in the estuarine environment: recommendations for research. Marine Sciences Research Center, State University of New York, Stony Brook; July 1978.

Schemes for classifying the hydraulic regimes of estuaries have been developed and widely used. There is, however, no comprehensive method for comparing different estuarine sedimentary regimes. Such a classification could be based on the hypothesis that there are a small number of parameters that characterize any estuarine sedimentary system. Although these parameters have not yet been identified, one possible quantitative classification would include: (1) The rate of sediment supply. (2) The amounts of sediment in the water column, in temporary storage on the sea floor, and in permanent deposits. (3) The rate at which transport proceeds; this rate is expected to be proportional to the power available to move sediment particles. (4) The total amount of time that a particle is in the water column. (5) The final partitioning of material between the ocean and the permanent estuarine deposits. A classiciation based on these, or other similar parameters, would be useful not only for comparing different estuarine sedimentary systems, but also for recognizing the range of different conditions controlling a particular estuary's sedimentation. Emery and Uchupi are correct in pointing out that far more effort has gone into making detailed studies of the sediments of individual estuaries than either into comparing results from a variety of estuaries with similar physical and geological characteristics, or into critical evaluations of processes.

122. Seibert, P. Importance of natural vegetation for the protection of the banks of streams, rivers and canals. In: Freshwaters, Council of Europe, Nature and Environmental Series 2:35-67; 1968.

A general discussion of the advantages of biotechnical engineering for bank protection is followed by specific analyses of the protective effect and implantation techniques of specific plants, separately for water courses and stagnant waters.

123. Simons, D.B.; Chen, Y.H.; Lagasse, P.F.; Schumm, S.A. A summary of the river environment. Fort Collins, CO: Colorado State Univ.; 1976; 78 p.

This report is supplemental to the reference document, The River Environment (Simons et al. 1975). The purposes of this summary report are: (1) to provide a basic understanding of the river environment, (2) to serve as an index guide to the basic reference document, and (3) to illustrate the application of current knowledge and techniques to analyze river problems. Chapter 1 establishes the central theme of the summary report. That is, it is an absolute necessity of viewing rivers as dynamic physical/ecological systems, and this chapter outlines the ecological considerations and engineering requirements for river development programs. The basic concepts of river mechanics and river morphology are presented in Chapter 2. Chapter 3 briefly presents the techniques of river training and development works with emphasis on river modification using dikes and dredging. Response of the Mississippi River above Cairo, Illinois to development is briefly discussed in Chapter 4. Numerical examples to illustrate the application of hydraulic and geomorphic concepts and theories to analyze a river system are presented in Chapter 5. Chapter 6 summarizes the data necessary to complete an analysis of the response of river systems to development, and it tabulates primary data sources.

124. Slotta, L.S.; Sollitt, C.K.; Bella, D.A.; Hancock, D.R.; McCauley, J.E., Parr, R. Effects of hopper dredging and in channel spoiling in Coos Bay, Oregon. Corvallis, OR: Oregon State University; 1973. 141 p.

Cited in Morton (1977).

125. Smith, P.W. Illinois streams: a classification based on their fishes and an analysis of factors responsible for disappreance of native species, Ill. Nat. Hist. Surv. Biological Notes No. 76; 1971. 14 p.

Analysis of data has made it possible to assign virtually all of the streams in the state ratings of excellent, good, fair, or poor. The. ratings are based on the species composition of the hundreds of collections available. It has also been possible to detect long-term changes, and to identify factors that are responsible for each stream's deterioration and each species' change of status.

126. Solomon, R.C.; Parson, D.R.; Wright, D.A.; Colbert, B.K.; Ferris, C.; Scott, J.E. Environmental inventory and assessment of navigation pools 24, 25, and 26, upper Mississippi and lower Illinois Rivers: summary report. Vicksburg, U.S. Army Engineering Waterways Experiment Station; 1975; 97 p.

The River and Harbor Act of 3 July 1930 authorized the construction and maintenance of a 9-ft deep by 300-ft wide channel for commerical navigation of the upper Mississippi and lower Illinois rivers. Construction of locks and dams supplemented by dredging and bank stabilization was required to maintain the 9-ft depth, particularly during periods of low flow. An investigation was performed by Colorado State University to evaluate the river reaches before and after man-made changes and overall changes in geomorphology. Additionally, trends of future geomorphic changes that could result from existing and potential future developments were addressed with the aid of a mathematical simulation model. Vegetation and vegetative successional patterns of the floodplain were characterized by the Missouri 3otanical Gardens. Vegetation maps were produced delineating vegetational communities adjacent to the rivers and on islands. An inventory of the animals and their habitats was conducted by Southern Illinois University. Seven habitats were distinguished in the unprotected floodplain. Based on literature, 49 species of mammals, 286 species of birds and 81 species and subspecies of amphibians and reptiles were expected to occur in the study area. Members of the Waterways Experiment Station study team collected water and sediment samples for chemical and physical analysis and biological samples from four habitat types. The data were subjected to various statistical analyses to determine if there were differences between habitats and sampling dates. Fish samples were collected from the Illinois River by the Illinois Natural History Survey and results were compared with literature to determine temporal and spatial changes in distribution. The overall impacts of operation and maintenance of the 9-ft channel were discussed relative to the effects on the biological, chemical, and physical system in the study area. Recommendations were made for further studies th at are needed to define impact more adequately.

127. Sorenson, R.M. Investigation of ship-generated waves. Journal Waterways and Harbors Division, ASCE 93(WWI):85-99; Feb. 1967. Proc. Paper 5102.

Maximum ship-generated wave heights and the related wave half-periods were measured (with a step-resistance wave gage) at various distances from the sailing line for several vessels operating at a range of speeds in the Oakland Estuary. The methods and results of these measurements are reported and evaluated together with the pertinent background information on the nature of ship-generated waves.

128. Sorenson, R.M. Water waves produced by ships. Journal Waterways, Harbors, and Coastal Engineering Division, ASCE 99(WW2):245-256; May 1973. Proc. Paper 9754.

A knowledge of the height and period as well as the crest line pattern of waves generated by a particular ship as a function of ship speed and water depth is of value to coastal and waterway engineers. The characeteristics of ship-generated waves are reviewed briefly. Some data on the wave heights generated by a variety of ships moving at a range of speeds are presented. Known sources of data on ship-generated waves are referenced and areas for future research are suggested. This is the last of seven state-of-the-art papers on the design of navigation channels, written by members of the ASCE Task Committee on Ship Channels.

129. Sparks, R.E. Possible biological impacts of wave wash and resuspension of sediments caused by boat traffic in the Illinois River. Appendix J of Supplement, Environmental Statement, vol. Ill Biological Appendices - Animals. Locks and Dams No. 26 (Replacement) Upper Mississippi River Basin, Mississippi River, Alton, Illinois, Missouri and Illinois. St. Louis, MO: U.S. Army Engineer District; June 1975.

The purpose of this report is to evaluate the impact of increased frequency of wave wash and resuspension of sediments, resulting from increased boat traffic, on the biota in the channel and lateral areas of the Illinois River. The section on wave wash includes subsections on wave effects produced by different craft, biological impacts in the main channel, and biological impacts in side channels. The section on resuspension of sediments includes subsections on impacts in the main channel, and impacts in lateral areas.

130. Sparks, R.E. Effects of sediment on aquatic life. Statement before Subcommittee on Soil Erosion and Sedimentation, Illinois Task Force on Agriculture Nonpoint Sources of Pollution; 1977.

This generaly summary of relationships between sediment and aquatic life includes sections on: reduction of light penetration, reduction of visibility, abrasion and clogging, habitat attention and destruction, interactions between sediment and other factors, and ecosystem effects. Table 1 contains reported levels of effects of sediment and turbidity on aquatic life.

131. Sparks, R.E. Bibliography of publications relating to Lock and Dam 26, Waterways Experiment Station, Turbidity and Navigation Effects, the Mississippi River, and the Illinois River. Photocopied memo to Pool 26 research team. Havana, IL: 1980.

132. Sparks, R.E.; Bellrose, F.C.; Paveglio, F.L., Jr.; Sandusky, M.J.; Steffeck, D.W.; Thompson, C M. 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. St. Louis, MO: U.S. Army Corps of Engineers; 1979. 208 p.

Subjects include both immediate and long-term impacts of construction of the 9-foot channel, as well as impacts of operation and maintenance of the channel and direct effects of navigation. The report reviews previously unpublished reports and data, as well as published literature. The pools formed by the navigation dams in the 1930's initially increased shallow, slack water habitats and marshes, at the expense of bottomland forests and mudflats. Winter drawdown of the pools in the 1940's resulted in large fish kills, but winter drawdown has not been practices since 1970. Dam 26 stabilized water levels in the spring and summer, resulting in excellent growth of aquatic plants in most years between 1948-1968. Pool 25 was subject to frequent and sometimes severe fluctuations in 1948-51, 1954, 1958, 1961, and 1967 which adversely affected wetland vegetation. Since wetland vegetation furnishes food and habitat for muskrats and waterfowl, these species were probably adversely affected. Sedimentation has subsequently decreased the area of backwater habitat to the acreage existing before the construction of the dams, and sedimentation and turbidity together adversely affected aquatic and marsh plants, thereby adversely affecting muskrats and causing declines in use of the area by widgeon, green-wing teal, and lesser scaup ducks. Sedimentation has produced mudflats which provide feeding areas for shore birds. Moist soil plants which volunteer on these mudflats, or which are seeded by wildlife managers, provide food for mallards, Canada, blue, and snow geese. Declines in some aquatic species such as the yellow sand shell mussel and various species of minnows probably indicate the trend of increasing turbidity and reduced currents in some portions of the Upper Mississippi River.

134. Sparks, R.E.; Thomas, R.C.; Schaeffer, D.J. The effects of barge traffic on suspended sediments and turbidity in the Illinois River. Rock Island, IL: U.S. Fish and Wildlife Service; 1980. 68 p.

An increase in tow traffic from few or no tows in August and September, 1978, (when 3 locks on the Upper Illinois Waterway were closed for repairs) to normal levels in October, 1978 (when the locks opened) significantly increased total suspended solids (TSS) concentrations at 8 of 9 study sites, according to a nested analysis of the variance (ANOVA) of the data. Using 2-way ANOVA, 1-way ANOVA, and a t-test, tow traffic had significant effects at 6 of 9 sites. Both discharge and tow traffic had separable, significant effects at 4 of 9 sites. The return of tow traffic to normal levels increased TSS an average of 19 mg/l, representing a contribution of approximately 30-40% to the average TSS concentrations at all sites in October.

Lack of significant interaction terms between tow traffic and station locations or depths in the ANOVA indicates that effects of tow traffic on TSS were transmitted uniformly across all station, including side channel stations. Hence, tow traffic increased TSS levels significantly and consistently near the surface and near the bottom in the main channel, the main channel border, and side channels. Since side channels lead into backwaters in many reaches of the Illinois River, tow traffic presumably increases the input of suspended sediment to backwaters would have to be determined by measurement of annual sediment budgets for representative backwaters. In Upper Peoria Lake in particular, tow traffic normally contributed to TSS lelves in a side channel leading into the lake, but on at least one occasion, wind-generated waves roiled the bottom of the lake and pushed turbid water from the lake into the side channel.

135. Spence, J.A.; Hynes, H.3.N. Differences in benthos upstream and downstream of an impoundment. J. Fish. Res. Board Can. 28:35-43; 1971a.

Pronounced differences were found in the macroinvertebrate riffle fauna upstream and dowsntream of a flood control impoundment. Downstream differences were comparable with those occurring after mild organic enrichment. Plecoptera were absent, but numbers of Baetis and Caenis (Ephemeroptera) increased, and the abundance and number of species of Stenonema were considerably reduced. Numbers of Chironomidae, Simuliidae, Optioservus (Coleoptera), Hydropsychidae, and Hyaella azteca (Amphipoda) increased downstream. These changes are associated with downstream increase in the availability of detritus, a lag of about 4 weeks in the early summer rise in water temperature and a maximum temperature more than 6 degrees C lower than upstream, and alteration of other environmental factors.

136. Spence, J.A.; Hynes, H.B.N. Differences in fish populations upstream and downstream of a main-stream impoundment. J. Fish. Res. Board Can. 26:45-46; 1971b.

Four species of cyprinid fishes, Hybopsis bigutta, H. micropogon, Pimephales notatus, and Notropis spilopterus found in a river upstream of a flood control dam are absent downstream. With the release downstream of cold hypolimnial waters from the dam there was a lag of about 4 weeks in the spring rise of water temperatures and a maximum summer temperature 7 C

lower than upstream. Of the fish present in the river these four species had the most southerly distributions, all south of the 64 F (17.8 C) July isotherm, and it is concluded that the lower water temperatures are mainly responsible for their absence downstream of the dam.

137. Sport Fishing Institute Bulletin. Stream destruction by channelization No. 226, July 1971. Washington, D.C.: Sport Fishing Institute; 1971.

The straightening and ditching of the natural meandering channels of winding rivers and streams is known as channelization. It is carried on relentlessly, under the misplaced banner of conservation, by several federal agencies - notably the Soil Conservation Serivce of the Department of Agriculture, and the U.S. Army Corps of Engineers - as well as by local governments and private drainage districts. The stated purpose of channelization is to control or prevent floods, by speeding the surface runoff of rainwater that falls on the watersheds.

What this really accomplishes is to destroy the natural features of the land that serve to retard runoff, and thereby ameliorate the acute severity of downstream flooding and attendant erosion, as well as destroying the biological productivity of the original water courses and adjacent flood plain. In effect, it moves the flood problem downstream and increases its acute severity in the downstream location. Aggravated flooding in the western drainage of the Red River by the early sixties was attributed by North Dakota Cass County Commissioners and Davenport Township Supervisors to agricultural drainage practices of the previous 20 years. They proposed as corrective measures a series of small dams to retain water in streams for a few days after spring runoff of heavy rains (SFI Bull. No. 163:6, June 1965).

138. Stall, J.B.: Melsted, S.W. The silting of Lake Chautauqua, Havana, Illinois. Ill. State Water Surv. Rept. of Inves. 8:1-15; 1951.

The Chautauqua Drainage and Levee District was organized in 1916 and constructed the levees which were later to form Lake Chautauqua. The levees were built along the floodplain of the Illinois River north of Havana, Illinois, in Mason County. After being farmed for several years, the area was permanently flooded in 1926.

In December, 1936 the federal Fish and Wildlife Service acquired the area and formed the present Lake Chautauqua for use as a refuge for migratory waterfowl. Spillways and control gates were constructed in the levees to allow control of the water level in this side-channel reservoir.

The water level in the lake is controlled as nearly as possible to provide good feeding conditions for waterfowl. The only water entering the lake comes from the flow of the Illinois River. The lake has no direct drainage area.

The 1950 sedimentation survey of this reservoir showed that in 23.8 years the storage capacity of the lake had been reduced from 14,290 acre feet to 11,680 acre feet, or 18.3 per cent.

The average annual sediment deposition in the lake has been 83,230 tons.

The average rate of rose of the bed of Lake Chautauqua is 1 foot in 32 years, which is approximately twice as great as the average for the entire unlevied area of the Illinois River floodplain.

Sediment analyses show extremely high carbon and nitrogen contents far in excess of that to be expected from sediment derived from normal soil erosion. This is attributed to the presence of wildlife excreta.

The sediment deposited in the lake is quite high in total fertility.

139. Starrett, W.C. A survey of mussels (Unionacea) of the Illinois River a polluted stream. Illinois Nat. Hist. Sur. Bull. 30:1-403; 1971.

The Illinois River is 272.9 miles long and is formed by the confluence of the Des Plaines and Kankakee rivers southwest of Chicago. It empties into the Mississippi River at Grafton, Illinois. Since 1900 Lake Michigan water has been diverted through the Chicago Sanitary and Ship Canal into the Des Plaines River and thence into the Illinois. Through the years this canal has transported the treated and untreated wastes from the Chicago area into the Illinois River system. These wastes together with those from other cities, industries, and agriculture along the Illinois waterway have drastically affected the biota of the river. There were only minor sources of domestic and industrial pollution along the lower 150 miles of the river. Locks and dams, together with dredging, maintain a 9-foot navigation channel to form the Illinois waterway connecting the Mississippi River with Lake Michigan.

140. Stefan, H.; Anderson, K.J. Wind-driven flow in Mississippi River impoundment. Journal of Hydraulics Division, American Society of Civil Engineers, 106:HY9; Sept, 1980.

The analysis is made in order to determine: (1) how much of the Sturgeon Lake flow is drawn into the cooling water intake of the plant; and (2) by how much effluent cooling water of blowdown water is diluted by Sturgeon Lake effects of wind stress on the water surface in addition to bed shear stress and local (minor) energy losses, was made to provide the required information. The Sturgeon Lake/North Lake system was studied before the complete analysis was made. In the absence of wind, flow through Sturgeon Lake amounted to about 22% of total river flow. At low plant withdrawal rates and at zero wind, the flow through the backwater channel in front of the plant outlet was about 10% of total river flow. Winds from 5 mph to 30 mph had a very noticeable effect on flows through Sturgeon Lake, particularly when total river flows were less than 10,000 cfs. The analysis was made without consideration of stratification effects near the plant intake and outlet.

141. Task Committee Assigned to Inventory Sedimentation Research Needs Related to Water Quality. Influences of sedimentation on water quality: an inventory of research needs. Journal Hydraulics Division, ASCE 97(HY8):1203-1211; Aug. 1971. Proc. Paper 8325.

Sediments play a predominate role in determining the quality of water. Their physical influence not only ranks as a major pollutant but they also serve as a transporting or catalytic agent. This capability can both amplify or diminsh the severity of other forms of pollution. An ASCE Sedimentation Committee task group was assigned the responsibility of identifying and cataloguing these many diverse influences plus evaluating the priority of research needs. Fifty-four authoritative respondents, representing many professional disciplines, contributed 196 specific comments on research needs. A condensed and paraphrased summation of these comments, by 11 catagories, expresses their viewpoints. The extremely broad and varied range of problem areas establishes than an interdisciplinary approach is necessary to both define research needs and formulate acceptable problem solutions. Recommendations are outlined that are believed paramount toward satisfying future professional needs.

142. Terpening, V.A. et al. Environmental inventory and assessment and navigation pools 24, 25 and 26, upper Mississippi and lower Illinois Rivers floodplain animals and their habitats. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station, CE; 1975.

Objectives of the study were to develop a comprehensive bibliography of literature pertaining to animals and their habitats; to inventory the mammals, birds, amphibians, reptiles, macroinvertebrates of public health significance, and habitats of the Lower Illinois and Upper Mississippi River floodplains; to describe rare and endangered species present; to evaluate fauna for public health, economic, scientific, and aesthetic purposes; to examine the effects of periodic inundation on floodplain animal life; and to assess the effects of pool regulation, bank revetment, wing dike maintenance, and disposal of fredged material on wildlife. Seven study sites were selected along the two rivers.

143. Trotzky, H.M; Gregory, R.W. The effects of water flow manipulation below a hydroelectric power dam on the bottom fauna of the Upper Kennebec River, Maine. Tran. Amer. Fish. Soc. 103:318-324; 1974.

We studied the effect of severe fluctuations in flow on the distribution of bottom fauna of the upper Kennebee River. During the years 1964-1970, discharges below Wyman Dam ranged from 8.5 m^3/sec to an average daily high of about 170 m/sec. Slow currents resulting from low flows appeared to limit the diversity and abundance of swift-water aquatic insects on the river-bottom below the dam. Sampling stations above the impoundment averaged 19 aquatic insect genera, while those below the dam averaged 11. About 19 genera were found at stations where the current near bottom fluctuated from 0.5 m/sec to 0.9 m/sec while only 4 genera were found at stations where the fluctuations were from 0.1 to 0.5 m/sec. Aquatic insects adapted for swift water such as *Rhyacophila*, *Chimmarra*, *Iron*, *Blepharocera*, *Acroneuria*, and *Paragnetina* were more abundant above the impoundment than below, and were absent from those stations below the impoundment with the lowest current velocities.

144. Underhill, J.C.; Eddy, S. Northern Fishes. 3rd ed. Minneapolis, MN:Univ. Minnesota Press; 1974; 276 p.

In the 27 years since the second revised edition of this book was published, there have been significant changes in the distribution of Minnesota fishes and important additions to the list of species known from Minnesota waters. New species have been introduced, intentionally or accidentally (for example, the coho salmon and the alewife). Continued collecting and improved collecting techniques have revealed the presence of several species which were not thought to exist in the state and have provided further information on the abundance of several species which formerly were known from only a few localities. Although further changes will occur in the fish fauna, it seems appropriate at this point to bring the record up to date with a thorough revision of Northern Fishes.

145. Upper Mississippi River Basin Commission. Report on the Upper Mississippi River Main Stem Level B (draft) Study; June 1980. 132 p.

This report contains findings of a two year study conducted by federal and state agencies in cooperation with local government and the public. The study focuses on the publicly identified problems of flooding and interior drainage, recreational boating safety, the relationship between navigation and the environment, water quality management planning, and land use management planning in and along the Main Stem of the Mississippi River from Prescott, Wisconsin to Cairo, Illinois. Alternative policies and actions for the future management of the water and related land resources along the Main Stem are outlined. Recommended regional resource strategies and ongoing and proposed structural and non-structural projects and programs are identified, along with an evaluation of their beneficial and adverse effects on national eocnomic development, environmental quality, regional development, and the social well-being of the study area populace.

146. U.S. Army Corps of Engineers. Mississippi River year-round navigation. Chicago, Illinois; 1973.

Waterborne commerce on the Mississippi River from Minneapolis, Minnesota, to the Gulf of Mexico has increased from 150 million tons in 1962 to 255 million tons in 1971, an increase of 70 percent in the 10-year period. Associated with the operations of the Mississippi River and the movement of this tonnage are the problems of maintaining adequate facilities to sustain the steady increase in traffic which results from the demand for bulk commodities throughout the United Sates and foreign markets. For a maritime economy to grow and accomodate the diversified needs of its dependents, adequate navigation channels and facilities must be provided. These facilities and navigation channels, if kept open through the year, could further enhance the economy of the Midwest. The study area for this report is defined as the Mississippi River from the mouth of the Ohio at Cairo, Illinois, to Minneapolis-St. Paul, Minnesota. The Illinois Waterway is maintained for navigation on a year-round basis. Therefore Locks 26 and 27 on the Mississippi River are operable on a year-round basis. Problems that have occurred during the winter are expected to be resolved by the replacement of Lock and Dam 26. Thus, the emphasis in this report is in the reach of the Mississippi River between the mouth of the Illinois River at Grafton, Illinois, and the Twin-Cites in Minnesota. The questions to be addressed in this study and report are "how" and "if" the navigation season should be extended on the upper Mississippi River between Grafton, Illinois, and the Twin-Cities.

147. U.S. Army Corps of Engineers. Letter and enclosures dated 3 November 1980 from James W. Forsythe, North Central Division, Corps of Engineers, to Mr. Dan Galloway, Master Plan Study Manager, Upper Mississippi River Basin Commission, regarding review of "Draft information summary of the physical and biological effects of navigation."; 1980.

148. U.S. Army Corps of Engineers. Huntington District. Appendix J, vol. 1: Environmental and social impact analysis. Gallipolis Locks and Dam replacement, Ohio River. Phase 1, Advanced engineering and design study, general design memorandum. 1980.

The impacts appendix was organized to present data and conclusions related to continued navigation use of the Ohio River and, most particularly, to address impacts from that increment of increased use resulting from improvements at Gallipolis Locks and Dam.

Program scone was initially defined by District personnel and finalized after discussions with consultants, Ohio River Division, and Chief of Engineers Office staff. Intents were to address both phsyical and biological effects directly attributable to tow transit and frequency of tow passage, and to assess these effects within the water column and on the bed of the river during tow passage. Site-specific studies included monitoring the bank areas, collection of geotechnical and biological data, and establishment of meteorological stations during monitoring periods. Additionally, reach-of-river reconnaissance surveys were conducted to place in perspective the conditions encountered at five demonstrative sites.

Principal mechanisms and open channel flow theorem were addressed in defining seasonal and episodic changes in riverbed and bank. These efforts were necessary both to place navigation-use impacts in proper perspective and to determine the relative significance of those changes that occur during storms and flood flows. All theory confirmed by field obsevation supports the concept that a river's capacity to erode and transport sediments increased exponentially with an increase in flow velocity. Thus, the Ohio River has many-times the capacity for change throughout the river system during flood flows, and in fact, most changess noted in the field during these study programs occurred episodically. Natural river concepts are most important to the Ohio in the context of navigation use improvements and retainage of navigation pools. Regulation to certain higher flow rates is effected by passage of water through locks and dams, and gates are raised out of the river during excessive flow events. Thus, these structures have no impact on through movement of sediments at these times nor are these events significantly altered in duration or stage.

The Ohio River beds and bank are composed in large part of sand and gravel materials. In a habitat context, these materials were historically, and are now, affected by flood flows and, more recently, navigation use. These surficial sediments are subject to movement during relatively low velocities and during a great number of annual events. Limited resuspension and downriver movement of sand-size and finer surficial sediments do occur immediately within the sailing-line area as a result of tow passage. These physical impacts frequently result in impacts on the biological systems that vary and are species-dependent and functional-group-related.

149. U.S. Army Corps of Engineers, Rock Island District. Mississippi River year-round navigation study; Stage 2 Final Feasbility Report. Rock Island, IL: U.S. Army Corps of Engineers; 1980 draft.

Sufficient public interest supporting the implementation of an extended winter navigation season or a closed navigation season to warrant further detailed feasibility studies does not exist at this time.

The economic benefits of extended winter navigation are marginal and may not be large enough to support the potential environmental project costs.

A closed navigation season resulting in a curtailment in the current or future winter navigation operations may be beneficial but considerable environmental studies are required to substantiate the need for a closed season and the establishment of criteria upon which to base such an action on an annual basis.

Additional knowledge and base line data concerning the environmental impacts of winter navigation are needed from an overall viewpoint to evaluate the present winter operations and future operations of the 9-foot navigation project and entire Upper Mississippi River System.

150. U.S. Army Engineer Division, North Central. Summary report of fish and wildlife habitat changes resulting from the construction of a nine-foot channel in the upper Mississippi River, Minnesota River, St. Croix River, Illinois Waterway. Chicago, IL: U.S. Army Engineer Division; 1978.

This report is on fish and wildlife habitat changes resulting from the construction, operation and maintenance of the nine-foot navigation channel in the upper Mississippi River and the Illinois Waterway. The report relates to that portion of the Upper Mississippi River from St. Anthony Falls Lock and Dam (river mile 853.3) to Lock and Dam 22 at Saverton, Missouri (river mile 301.0), to that portion of the Illinois Waterway between LaGrange Lock and Dam (river mile 80) and Lockport Lock and Dam (river mile 291), and to portions of the Minnesota and St. Croix Rivers.

Specific objectives of the study are to establish an historical context in which to examine current changes in the environments of the two rivers, and to provide quantitative analysis of habitat changes with some qualitative interpretation of changes. Except for the quantitative measurements of change in pre and post project periods, the report is not held up as new information. It is, instead, an effort to collate many pieces of existing information into a comprehensive overview of habitat changes. The time frame of this report is limited to the period covering only the construction, operation and maintenance of the nine-foot navigation channel project, i.e., the early 1930's to 1976. It is hoped that this report will encourage additional studies of man's impact on the rivers prior to 1980, additional studies of man's impact within the time frame of this report (1930-1976) and, ultimately, identification of specific present and future management needs along the subject waterways.

151. U.S. Congress, House of Representatives. Report of the Chief of Engineers to the Secretary of the Army on a study of streambank erosion in the United States. 91st Congress, 1st session, Committee on Public Works; Oct. 1969; 22 p.

Only one percent of the nation's streams have been subjected to prior study. Eight percent of total stream bank miles are currently experiencing erosion to some degree. A candid admission of data insufficiency and inaccuracy is included. Factors considered important in the process of bank erosion included bank resistance, streamflow, sediment, channel equilibrium, and activities of man. Three federal agencies--the Departments of the Army, Agriculture, and Interior--are charged with the primary responsibility for the development, conservation, and management of the nation's water resources. Previous efforts to control erosion by these agencies have usually been undertaken as an integral feature of a project designed to accomplish different purposes such as flood control, navigation, irrigation and others. Precise quantitative analysis and evaluation of damages from bank erosion are difficult to obtain. The annual cost of prevention exceeds the amount of damages severalfold.

152. Waite, S.W. Zooplankton. In Projected effects of increased diversion of Lake Michigan water on the environment of the Illinois River valley. Havana and Urbana, IL: Illinois Natural History Survey; July 1980:17-1—17.38.

This chapter includes results of zooplankton sampling in the Illinois River in 1978, comparisons of 1978 results with previous surveys, and distribution, abundance, and diversity analyses.

153. Wang, W.C. Effects of turbidity on algal growth. Urbana, IL: Ill. State Water Survey; 1974. 12 p.

154. Ward, J.V.; Standford, J.A. Ecological factors controlling stream zoobenthos with emphasis on thermal modification of regulated streams.. Ward, J.V.; Stanford, J.A. eds. The Ecology of Regulated Streams. Plenum Press, N.Y.; 1979. 398 pp.

This book is a collection of 21 papers designed to summarize current understanding of regulated streams. Included in the topical review session are papers on stream ecosystems, phytobenthos, zoobenthos, fishes, chemical modifications and channel morphology. Geographical reviews include Africa, Australia, Great Britain, central Europe, Norway, and North America. Eight special topics papers and symposium summary and conclusions are included.

155. Yeager, L.E. Effect of permanent flooding in a river-bottom timber area. Ill. Nat. Hist. Surv. Bull. 25(2):33-65; 1949.

The objective of the study on which the present report is based was to determine the rate of flooding mortality in various Mississippi River valley tree species and the rate and effect of tree fall; in the course of the study, brief consideration was given to plant and animal succession following the death of timber stands. The report covers principally the period begining in September 1939 and ending in October 1946.

to emphasize the importance of analyzing the Locks and Dam #26 issue in the context of the entire inland water system; and to call the Task Force's attention to what we believe are some major conflicts in federal policies and programs." The statement contains sections on water quality, impact of commercial navigation on Illinois River water quality, and conflicts in federal policies and goals. Data on barge traffic generated turbidity, suspended solids and iron concentration increases are presented.

158. GREAT II. Plan formulation addendum. GREAT II Upper Mississippi River; 1980.

The purpose of this appendix is to provide a document that details the GREAT II plan formulation process. Essentially, the entire appendix represents this process. However, data and information developed through the GREAT II process are included as reference materials. The GREAT II was published in May 1980. The responsibilities of the Plan Formulation Work Group and the 12 functional work groups were absolved. The Team (based on public and agency comments), revised the GREAT II recommended plan. The results of Team activities are contained in the GREAT II Main Report and two supplements to the Main Report: (1) the Channel Maintenance Handbook and (2) the Environmental Report. Therefore, Team activities are not discussed in this appendix, except where necessary to provide continuity.