REPORT
of the
1993 FLOOD-RELATED WATER QUALITY MONITORING WORKSHOP

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Upper Mississippi River Basin Association

Report of the 1993 Flood-Related Water Quality Monitoring Workshop

Table of Contents

(Continued)

Table of Contents
(Continued)

Appendices

INTRODUCTION

Background on the 1993 Midwest Flood

The 1993 Midwest Flood was an unprecedented hydrometerological event in terms of its magnitude, severity, timing, and destructiveness. Snowmelt in late winter and early spring; frequent, heavy rainfall from April through August; and saturated soil conditions combined to create flood conditions in large parts of the Upper Mississippi River and Missouri River Basins during the spring, summer, and fall of 1993. (Bhowmik, 1994) It is notable that the 1993 flooding was not the result of one large precipitation event. Instead, according to U.S. Army Corps of Engineers, it resulted from "numerous smaller scale and shorter duration, but more locally intense, thunderstorm events that were much more widespread and longer lasting than individual events of this kind usually are." [U.S. Army Corps of Engineers (USACE), 1994] In many areas, there were multiple flood crests rather than a single peak.

The flood-affected area consisted of large portions of the Upper Mississippi River Basin and the Missouri River Basin. Together these basins encompass 714,000 square miles, including all or part of 14 states and a small portion of Canada. (USACE, 1995) Land use within the basins is mixed and includes woodlands, heavily agricultural areas, and major urban centers. The Upper Mississippi River, the Missouri River, and several of their major tributaries are vital resources for the Midwest, providing water for drinking, industry, agriculture, power production, and wastewater assimilation. The Upper Mississippi, Missouri, and Illinois Rivers, as well as portions of the Minnesota, St. Croix, Black, and Kaskaskia Rivers, also support commercial navigation and provide significant recreational boating opportunities. In addition, the rivers are a significant ecological resource, providing habitat for a wide range of resident and migratory species.

The 1993 flooding began as a result of heavy rainfalls in the northern portions of the Upper Mississippi and Missouri basins. Runoff from these northern areas moved downstream at the same time that increased precipitation was also beginning to affect the lower portions of the basins. Precipitation during July was more than 200 percent of average over parts of nine Midwest states. The areas most affected by flooding from mid-June to early August 1993 included southern Minnesota; southwestern Wisconsin; Iowa; western Illinois; northern and eastern Missouri; southern North Dakota; and eastern South Dakota, Nebraska, and Kansas. While the Mississippi River at St. Louis reached its record peak stage on August 1, precipitation continued to be heavy and the river at St. Louis did not fall below flood stage until October 10, 1993. (Bhowmik, 1994; Parrett et al., 1993; USACE, 1995)

Flooding on the Upper Mississippi River and the Missouri River was generally more severe on the rivers' downstream reaches. The Corps of Engineers estimated the flooding on the Mississippi River at St. Paul, Minnesota as approximately a 20-year event. In contrast, according to the Corps' *Floodplain Management Assessment of the Upper Mississippi and Lower Missouri Rivers and Their Tributaries,* "every gaging station on the Mississippi River below Lock and Dam 15 to Thebes, Illinois, experienced a new flood of record." Citing data from U.S. Geological Survey gaging stations in the nine flood-affected states, the Corps noted that "measured discharges exceeded the 10-year event at 154 stream gaging stations, exceeded the 100-year event at 46 stations, and exceeded the flood of record at 42 stations.... Flood frequencies exceeded the 500-year event at some locations along the Missouri and Mississippi Rivers, as well as some of their tributaries." (USACE, 1995)

Estimates of damages from the 1993 flood vary substantially, but there is general agreement that the flood was the most destructive in U.S. history in terms of property damage, economic disruption, and human trauma. Millions of acres of farmland were flooded, resulting in damage to agricultural lands and farm infrastructure as well as direct crop losses. Both overland and riverine transportation routes were closed for weeks in many areas. In some areas, damages to commercial, industrial, and residential structures were also severe, as were the costs associated with temporary dislocation and job loss. With the inundation of both industrial and agricultural areas, there were also impacts associated with industrial chemicals, sewage effluent, and agricultural chemicals in the floodwaters and associated sediments. President Clinton's Interagency Floodplain Management Review Committee estimated total quantifiable damages at between $12 and $16 billion. (Interagency Floodplain Management Review Committee, 1994)

Flood-Related Water Quality Monitoring

Responding to the flood required a tremendous allocation of resources at all levels of government. Immediate threats to public health and safety were of paramount concern. These threats included contamination of drinking water supplies, disruption of wastewater treatment plants, and failure of septic systems as well as risks associated with the inundation of facilities that handle hazardous materials. Longer term water quality impacts from the flooding, such as the potential for remobilization of contaminated sediments, were also a significant concern. As a result, Congress provided $3.2 million to the U.S. Environmental Protection Agency (U.S. EPA) to support special flood-related water quality monitoring efforts. This funding was provided as part of the $5.7 billion Fiscal Year 1994 Emergency Supplemental Appropriations bill signed into law on August 12, 1993. Of the total, $2.2 million was allocated to ambient monitoring and approximately $1.0 million went to support sediment monitoring work.

The U.S. EPA made these emergency monitoring funds available to the states through grants, with the general directive that the states "use the ambient monitoring funds for projects that first address immediate human health concerns related to ambient waters, then for other ambient monitoring that addresses environmental and secondary human health concerns, and finally for other flood-related monitoring concerns with less immediate emphasis." Within this general framework, each flood-affected state designed projects to respond to its particular problems and needs. Some states entered into agreements with other federal agencies to assist in these monitoring efforts. In addition, some federal agencies, including the U.S. Geological Survey (USGS) and the National Biological Service also conducted additional water quality monitoring efforts using other funding sources.

The flood-related water quality monitoring projects undertaken by the states with the U.S. EPA funds included analyses of water and sediment contamination, sedimentation rates and patterns, and bioaccumulation of contaminants in fish and macroinvertebrates. Monitoring sites included various reaches of the Upper Mississippi River and the Missouri River, as well as major tributaries and other flood-affected areas.

The 1993 flood not only stimulated immediate monitoring efforts, it also raised a number of important, longer-term questions about how to optimize future water quality monitoring efforts undertaken in response to flood events. Specifically, how can a state or region's flood-related water quality monitoring needs be identified in advance? How can state and federal agencies work more effectively together to ensure that limited resources are applied most effectively toward meeting these needs?

A federal interagency Flood Event Water Quality Monitoring Working Group, under the joint leadership of the USGS and the U.S. EPA, was established to address some of these questions. As this group finalizes its guidance, observations and recommendations based on experiences with the 1993 Midwest Flood have the potential to enhance flood event monitoring efforts in the future.

Workshop Purpose, Format, and Participants

The Upper Mississippi River Basin Association sponsored the 1993 Flood-Related Water Quality Monitoring Workshop in part to provide just this sort of regional perspective to the federal Working Group. An organization formed by the Governors of Illinois, Iowa, Minnesota, Missouri, and Wisconsin to facilitate the states' coordination on a wide range of water resource issues, the Association received financial support from the U.S. EPA to provide a non-technical summary of the EPA-funded flood monitoring work and to elicit the states' views regarding future flood-related monitoring in the region.

The Association's workshop was designed to bring together a multi-disciplinary group of researchers, state managers, and federal agency personnel to discuss the specific findings of their monitoring efforts, consider those findings in a broader geographic context, and develop consensus recommendations regarding future monitoring. This report serves as the proceedings document for that workshop and as a final report of the EPA-funded 1993 flood water quality monitoring effort. It contains abstracts of the EPA-funded monitoring work conducted in the five Upper Mississippi River basin states, highlights of the major themes that emerged during the workshop discussions, and a listing of the participants' consensus conclusions and recommendations.

The workshop was attended by 29 individuals, including 3 Association staff members. State agencies represented included the Illinois Department of Health, the Illinois Environmental Protection Agency, the Illinois State Water Survey, the Iowa Department of Health, the Iowa Department of Natural Resources, the Kansas Department of Health and Environment, the Minnesota Pollution Control Agency, and the Wisconsin Department of Natural Resources. Federal agencies represented included the Centers for Disease Control and Prevention, the National Biological Service, the U.S. Environmental Protection Agency, and the U.S. Geological Survey. (A complete list of attendees is included as Appendix A.)

The workshop included four major components. The initial session provided overviews of two major regional study efforts related to the flood. One of these was an evaluation of agricultural chemical contaminants by the USGS that is part of a multi-year effort by the Survey to assess water quality along the entire length of the Mississippi River. The session also provided an overview of a private well survey conducted through an interagency effort involving 9 states and the Centers for Disease Control and Prevention. The second portion of the workshop consisted of presentations by state and federal researchers who received funding from the U.S. EPA to conduct monitoring related to the 1993 flood. Discussion periods following the monitoring presentations provided workshop participants with an opportunity to ask questions and share their perspectives on various aspects of the flood. The third portion of the agenda included a review of the federal "Water Quality Monitoring Guidance for Major Floods" and related issues and an opportunity for participants to provide feedback on the guidelines. The final wrap-up session included a discussion of lessons learned from the 1993 flood-related water quality monitoring. These lessons are expressed as a series of conclusions and recommendations offered by workshop participants for the consideration of the federal Flood Event Water Quality Monitoring Working Group and others. (A complete workshop agenda is included as Appendix B.)

Caveats

The following report provides a summary of the discussions, conclusions, and recommendations of those in attendance at the 1993 Flood-Related Water Quality Monitoring Workshop. While there is clearly room to expand and refine these discussions, conclusions, and recommendations, this summary is limited to the ideas and perspectives actually expressed at the workshop. As such, the conclusions and recommendations do not necessarily represent the formally adopted positions of the workshop participants' agencies. The abstracts compiled in this report relate primarily to EPA-funded monitoring efforts and by no means represent the full body of scientific investigations related to the water quality impacts of the 1993 Midwest Flood. Because a consensus did not readily emerge on every issue, an effort has been made to highlight all major conclusions and perspectives, together with sufficient background to understand the context in which the discussions unfolded.

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ABSTRACTS

Overview of Flood Studies — Regional Perspective

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Heavy rainfall and severe flooding in the Upper Mississippi River Basin during mid-June through August 1993 flushed abnormally large amounts of agricultural chemicals into the Mississippi River, many of its tributaries, and ultimately into the Gulf of Mexico. Even through record streamflows occurred during the flood, concentrations of herbicides such as atrazine, alachlor, cyanazine, and metolachlor were similar to the maximum concentrations measured during normal streamflow in the spring and summer of 1991 and 1992. It was anticipated that the higher streamflows during the flood would dilute the herbicides that are usually flushed into streams each year in the late spring and summer. Instead, concentrations were typical for this time of year, but daily fluxes of herbicides in some reaches of the Mississippi River were as much as seventy percent larger than those measured previously. Atrazine and cyanazine exceeded health-based limits for drinking water, in a few samples, but the average annual concentrations did not exceed these limits. Therefore, drinking water regulations for herbicides were not violated.

Nitrate concentrations during the flood were similar to those measured in late spring and summer of 1991 and 1992. The daily fluxes of nitrate during July and August were much higher than are typically measured at this time of year, but similar to those normally measured in the spring of the year. There is evidence that the discharge of abnormally large amounts of nitrate and freshwater into the Gulf of Mexico in 1993 during midsummer, when primary production was highest, caused an increase in the normal phytoplankton biomass and temporarily affected the Gulf ecosystem along the Louisiana-Texas coast.

(Note: This study was not funded by the U.S. Environmental Protection Agency.)

Summary of Well Water Survey

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State health and environmental departments of nine upper midwestern states and the Centers for Disease Control and Prevention conducted a survey to measure the bacterial and chemical contamination of water drawn from private wells. The survey was conducted in the summer of 1994, one year after the 1993 flood of the Upper Mississippi River Basin. Water was collected from 5536 wells located near the intersections of a ten-mile grid overlaid on a map of nine upper midwestern states.

Coliform bacteria were present in 41.3 percent of the water samples with a mean MPN of 9.2 per 100 mls. Eschericia coli was detected in 27.1 percent of the water samples with a mean MPN of 1.1 per 100 mls. Nitrates were present in 65.4 percent of the wells (average = 8 mg/l) with 13.7 percent of the wells exceeding the 10.0 mg/l health advisory level established by the Environmental Protection Agency (EPA). Triazines were detected in 24.7 percent of the sampled wells (mean = 0.1 *m*g/l) with 0.4 percent of the wells exceeding the lifetime health advisory of 0.3 *m*g/l as recommended by the EPA.

Water samples were considered contaminated when total coliforms were present for concentrations exceeding EPA's lifetime health advisory levels. The older, shallower, and larger diameter dug and bored wells with stone or tile casings were more likely to be contaminated than the deeper, drilled wells with steel casing. Presence of total coliforms in the well water correlated with the presence of nitrates.

(Note: This study was not funded by the U.S. Environmental Protection Agency.)

Flood Effects on the Physical and Chemical Properties of Bed Sediments in the Mississippi River

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Others

The Upper Mississippi River is an impounded river system consisting of 26 locks and dams that create navigation pools which are known to trap and store sediment and some chemical contaminants. During 1991 and 1992 representative samples of surficial bed sediments were collected from the navigation pools. The samples were analyzed for particle size, total organic carbon (TOC), nitrogen, sterols, linear alkylbenzene sulfonates (LAS), polynuclear aromatic hydrocarbons (PAH), organochlorines, polychlorinated biphenyls (PCBs), and trace elements. Representative samples were collected after the flood in 1994 in an identical manner and analyzed by the same or comparable methods to determine the effects of the flood.

Calculations and measurements indicated that frictional water velocities during the flood were not fast enough in any pool to resuspend the cohesive surficial bed sediment (primarily fine silt and clay size fractions) and that the median particle diameter of the sediment was significantly (based on a paired t-test at the 95-percent level) coarser after the flood than before — especially in the downstream navigation pools. TOC decreased significantly after the flood and the greatest change occurred in the downstream navigation pools, which is consistent with the increase in particle size. There was no significant change in the pre- and post-flood carbon:nitrogen ratio. Coprostanol levels increased significantly after the flood. PAHs remained essentially the same for all pools before and after the flood as did organochlorines such as chlordane, dieldrin, and DDT. PCB concentrations generally decreased in most pools. Pre- and postflood cadmium concentrations were below the detection limit, and mercury concentrations indicated no change; but lead concentrations had a significant decrease in postflood sediments and especially in the upstream navigation pools. These decreases in chemical concentrations after the flood of 1993 could be a result of the dilution by coarser and relatively less contaminated sediments that were mobilized and transported into the Mississippi River from the tributaries.

Impacts of the 1993 Flood on the Chippewa River Contaminated Sediments

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The former Eau Claire Waste Water Treatment Plant (WWTP) discharge site in the Chippewa River backwaters is known to have contaminated sediments. The site is located in a seven acre backwater slough of the Chippewa River [West of the City of Eau Claire] (T27N, R10W, S36, NWNW). The area resembles a shallow open water wetland, which experiences daily fluctuations over one foot due to hydropeaking. The site received partially treated waste water from the 1930s to 1980 where billions of gallons of waste water were deposited. Past waste water discharges resulted in elevated sediment concentrations of cadmium, chromium, copper, lead, mercury, nickel, and zinc; and polychlorinated biphenyls are also elevated. Scouring conditions are not normally present in this area, even during high spring flows. However, during 1993, the Chippewa River experienced a 25-50 year event causing concern that this area would be scoured and the contaminants carried downstream. Because the contaminants posed a potential human health and environmental impact, the sediments were sampled and evaluated. The substrate was sampled using a three inch diameter four foot long Lexan piston corer. The samples were then analyzed by the State Laboratory of Hygiene in Madison, Wisconsin. When comparing the data collected in 1989 and 1994, it was found that two of the four sites did indeed experience scouring. However, it was found that the worst sites of contamination experienced no change or scouring due to the flooding in 1993.

Investigation of the Vertical Distribution of Sediment Contaminants in Pool 2 and Lake Pepin of the Upper Mississippi River after the 1993 Flood

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Channelization of the Mississippi River below Minneapolis began in the late 1800s with the creation of 4 1/2 foot channels. By the 1940s, the current 9 foot navigation channel in the Mississippi River was largely complete. This manipulation of water flow required the construction of numerous locks and dams, behind which pools of slower moving water formed. These pools and natural riverine lakes such as Lake Pepin serve as sediment traps where the current is not strong enough to carry the heavier suspended particles. Because hydrophobic organic contaminants (HOCs) and heavy metals have a high affinity for fine grained sediments, some of these sediment-associated contaminants are also trapped in the river pools, lakes and other depositional areas. Numerous contaminants enter the river system from such sources as agricultural runoff, stormwater discharges, municipal wastewater and industrial discharges. These inputs include PCBs, mercury and other heavy metals. The Mississippi River lakes, backwater areas and pools serve as sinks for a portion of these contaminants.

Chemical profiles in sediment cores provide a picture of historic contaminant inputs to aquatic systems. In 1989, the U.S. Fish and Wildlife Service (USFWS), the Wisconsin Department of Natural Resources (WDNR) and the Minnesota Pollution Control Agency (MPCA) collected sediment cores from Pool 2 and the upper and lower reaches of Lake Pepin in the Mississippi River. The cores were dated and analyzed for polychlorinated biphenyls (PCBs). The most highly contaminated sediments were buried 30 - 60 cm below the sediment-water interface and were deposited between 1950 and 1965 (MPCA and USFWS, unpublished data). These more highly contaminated sediments had total PCB concentrations 5 - 20 times greater than the surficial sediments. A 1981 study of the vertical distribution of cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb) and zinc (Zn) in sediment cores from Lake Pepin found that the most highly contaminated sediments were typically associated with sediments deposited in the early 1970s and that metal contaminant inputs began decreasing in the late 1970s (Rada et al., 1990).

The flooding that occurred during the spring and summer of 1993 was considered to be a 1 in a 100 year flood. This severe flooding caused concern about the redistribution of sediment-associated contaminants. Severe flooding creates the potential to expose the more contaminated, buried sediments by scouring the overlying, cleaner sediments. Conversely, contaminated sediments may be further buried by increased deposition of cleaner sediments onto the bed sediments.

In order to elucidate the effects of the 1993 flood, the MPCA proposed to collect sediment cores during the summer of 1994 from those sites for which historical core data was available. The pre and post-flood vertical distribution of several contaminants could then be compared.

The post-flood sediment cores were collected from Pool 2 and the upper and lower reaches of Lake Pepin during the summer of 1994. PCBs were chosen as the primary tool to investigate the physical effects of the flood for a number of reasons. They are a significant contaminant in the Mississippi River, they are entirely anthropogenic with a known chronology of production and use, they are persistent in the environment and there are relatively recent PCB sediment core data from the Upper Mississippi River. The post-flood cores were also analyzed for a number of metals including Hg, Cr, Cu, Pb and Zn for comparison to the 1981 Lake Pepin cores. However, no attempt was made to re-sample the exact locations of the 1981 core sampling for heavy metals.

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Impacts on Sedimentation and Sediment Quality in Backwater Lakes

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Backwater lakes along the Illinois and Mississippi Rivers are important ecological, recreational, and economical resources of the state of Illinois that are under stress because of continuous sediment accumulation. The impact of a major flood like the 1993 flood on backwater lakes has not been investigated before. The main goal of this project was therefore to assess the status of selected backwater lakes and to evaluate how the 1993 flood might have impacted them. After evaluating existing information on backwater lakes along the Illinois and Mississippi Rivers, four backwater lakes were selected for detailed investigation. Three of the lakes, Swan, Stump, and Meredosia, are located on the Illinois River while the fourth, Quincy Bay, is located on the Mississippi River. Water and sediment samples were also collected from Silver Lake at the junction of the Mississippi and Illinois Rivers. Complete sedimentation surveys of the four lakes were conducted and compared to previous surveys when available. Six sediment cores were also collected from the five lakes for Cesium-137 analysis to determine their rate of sedimentation for different periods since 1952, the start of atmospheric testing of nuclear weapons. Water and sediment samples were collected at 17 sampling sites from the five lakes. Four of the sampling sites were in Lake Meredosia, five in Quincy Bay, one in Silver Lake, four in Swan Lake, and three in Stump Lake. The water samples were tested for organics, total metals, total nutrients, volatile organic chemicals, and toxicity. The sediment samples were tested for organics, metals, and toxicity. Sediment samples for chemical and toxicity analysis were collected at the top of the sediment core representing recent sediment layers, and the bottom of the sediment core representing older sediment.

Agricultural Chemicals in Alluvial Aquifers in Missouri after the 1993 Flood

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Intense rains produced flooding during the spring and summer of 1993 over many agricultural areas of Missouri. Because of potential contamination from flood water, an investigation was conducted to determine how concentrations of agricultural chemicals in water samples from alluvial wells in Missouri measured before the 1993 flood had changed after the flood.

Water samples from 80 alluvial wells with historical data were collected in March, July, and November 1994 and analyzed for dissolved herbicides, herbicide metabolites, and nitrate. There were no statistically significant differences in the distribution of alachlor, atrazine, and nitrate concentrations between pre- and post-flood samples. The frequency of detection of alachlor and atrazine in post-flood samples was lower than the frequency in pre-flood samples.

Analyses of agricultural chemicals in water samples from an intensely sampled well field indicate small, but significant differences between the distribution of dissolved phosphorus concentrations in pre- and post-flood samples. However, no significant differences were detected between the pre- and post-flood distributions of nitrate or ammonia concentrations.

Because of the numerous sources of variability, and the relatively short record of water quality data for the study wells, a cause and effect relation between changes in agricultural chemical concentrations and a single factor, that is, the 1993 flood, is difficult to determine. Based on the results of this study, the 1993 flooding did not result in widespread or long-term significant changes in concentrations of agricultural chemicals in water from alluvial aquifers in Missouri.

Scour and Sedimentation at Levee Break Sites from the 1993 Missouri River Flood

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Failure of levees during the 1993 Missouri River flood caused discharges with large hydraulic heads to flow through constricted openings. These discharges produced deep, extensive scours and large quantities of sediment on the Missouri River flood plain. Six representative sites were selected to study the effects of levee breaks on flood plain sedimentation and scour. Emphasis was placed on determining whether these sites were net sinks or sources for flood sediment and on documenting particle-size and chemical characteristics of the sediment. Four of the sites have scours that remain connected to the Missouri River during low flow whereas two sites have unconnected scours.

Scour volumes ranged from 150 to 720 acre-feet at the connected scour sites and were less than 94 acre-feet at the unconnected scour sites. Scour volumes at depths below the mean pre-flood elevation of the flood plain ranged from 89 to 95 percent of the total scour volume at the four connected scour sites and was 65 and 89 percent of the total scour volume at the two unconnected scour sites. Eroded levee material removed was approximately 2 to 10 percent of the total scour volume. The maximum scour depths ranged from 20 to 51 feet below the mean pre-flood elevation of the flood plain. Maximum scour depths were at or near the levee axis at all but one site.

The net sediment volumes (total sediment deposited during the 1993 flood minus the scour volume) ranged from 110 to 4,200 acre-feet at the four connected scour sites and was less than 20 acre-feet at the two unconnected scour sites. Deposits thicker than 1 foot consisted mostly of sand-size sediment. The areas covered with 2 feet or more of sand-size sediment ranged from 2.3 to 840 acres at the connected scour sites and were less than 35 acres at the unconnected scour sites. Scour volume ranged 15 to 390 percent of sediment volume at the unconnected scour sites. Ratios for the connected scour sites indicate that some of the sites were net sources for sediment in transport by the flood, whereas others were net sinks. The ratios at the unconnected scour sites indicate that most of the sediment deposited down stream from the sites came from the scours.

The potential significance of connected scour sites as sinks for transported flood sediment is exemplified by a site 5.5 miles downstream of Hermann, Missouri. The net mass of flood sediments (9.26 to 14.8 million tons) deposited on the flood plain was estimated to be 10 to 16 percent of the total sediment load transported by the Missouri River past Hermann. In contrast, a connected scour site near Arrow Rock, Missouri, had a scour volume that was 190 percent of the sediment volume. The net loss of sediment from this site may be related to local flow hydraulics or increased sediment transport capacity of the river because of extensive sedimentation in a levee-break complex just upstream of the site.

Flood-sediment samples and pre-flood soil samples were collected for herbicides, inorganic soil chemistry, and soil organic carbon analyses at two sites. Herbicide concentrations in the flood-sediment samples were not substantially different than concentrations in the pre-flood soil samples. Of the 15 different herbicides analyzed, atrazine had the highest median concentrations in all four sample sets. It was detected in 23 of 24 flood sediment samples and in 23 of 24 pre-flood soil samples. Median atrazine concentrations, in micrograms per kilogram, were 1.4 and 2.3 in the flood-sediment samples and 4.4 and 2.3 in the pre-flood soil samples. Relative to the pre-flood samples at the two sites, the mean percentage of the total extractable cations for calcium in flood-sediment samples increased 6 and 9 percent, magnesium decreased 5 and 6 percent, and potassium plus sodium decreased 1 and 3 percent. Flood-sediment samples had less-negative differences between the sum of the extractable cations and the cation exchange capacity than pre-flood soils, indicating that the flood-sediment samples have more soluble cations readily available for uptake by plants or leaching.

Impacts of the 1993 Flood on the Illinois and Mississippi Rivers

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Hydrology, climate, geology, land uses, and land covers are major factors contributing to the quality and quantity of water in a river basin. The 1993 Flood was an unusual hydrometeorologic event that had significant effects on these factors. In order to determine the flood's impact on the Illinois and Mississippi Rivers, the Illinois State Water Survey and the Illinois Environmental Protection Agency (IEPA) have conducted a joint investigation of selected water and sediment parameters in these two rivers. As part of this study, inorganics and organics in water (CORE 1 and PEST 1 groups in IEPA's ambient water quality program), organics in sediment (CORE 3), and metals in sediment (CORE 4) were collected from four stations on the Mississippi River bordering Illinois and two stations on the lower part of the Illinois River from December 1993 to June 1994.

The collection, preservation, and transportation of the water and sediment samples followed the procedures given in the *IEPA Quality Assurance and Field Method Manual*. Lab analyses of most CORE 1, PEST 1, and CORE 4 parameters were completed. The results showed that many parameters had concentrations below detection limits during this period. Parameters that showed detectable values were chloride, sulfate, alkalinity, and TKN in CORE 1; and alachlor, atrazine, cyanazine, and metolachlor in PEST 1. These CORE 1 parameters are correlated with natural composition of river water, but can also be affected by human activities. The PEST 1 parameters are related to herbicide application. No clear trends in these parameters were observed. In the limited CORE 3 samples, traces of PCBs were found in sediment at Valley City on the Illinois River but none were found at other stations. Overall sediment samples contained high concentrations of TKN, total phosphorous, and heavy metals.

The results showed that, in general, higher concentrations of the CORE 1 and PEST 1 parameters appeared in the Illinois River during this post-flood period. A wide range of water quality parameters were measured in both water and sediment, but not all the parameters had complete historical data for comparison on a monthly interval. Concentration of those parameters with historical monthly data stayed mostly within the range defined by the historical maximum and minimum values.

Water Quality Impacts of 1993 Flooding on Iowa Rivers

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A comparison of monitoring data collected through routine water quality monitoring shows relatively little impact of flooding in 1993 on chemical water quality of the Des Moines and Cedar Rivers in Iowa. Levels of dissolved oxygen, ammonia, nitrate, and bacteria during the 1993 floods were similar to levels seen in more typical spring/early summer flood events of other years. Special sampling conducted by U.S. EPA showed that levels of pesticides and toxic metals were relatively low and that levels of volatile organic compounds were less than levels of detection. Evaluation of data from routine versus special monitoring efforts suggests that routine monitoring provides the most useful data for examining flood-related impacts to water quality.

Water Quality of the Des Moines, Missouri, and Mississippi Rivers During the Flood of 1993

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Seven U.S. Geological Survey long-term record gaging stations on the Des Moines, Missouri, and Mississippi Rivers were the focal points of a water quality investigation during the mid-western flood of 1993. Water samples from multiple verticals were collected and composited according to U.S. Geological Survey methods once during the peak and twice during the recession of the flood. Each composite was analyzed for more than 250 physical and chemical variables including field parameters (pH, specific conductance, dissolved oxygen, for example), indicator bacteria, phenols, BNAs (basic, neutral, and acidic semivolatile organic compounds), VOCs (volatile organic compounds), PCBs (polychlorinated biphenyls), oil and grease, major inorganic ions, trace elements, nutrients, and pesticides.

No PCBs were detected above the minimum reporting level of 0.1 mg/L in samples from any of the seven stations. However, some BNAs and VOCs were detected at the reporting level concentrations (0.01 mg/L) in samples collected from three of seven stations. Total phenols were measured in samples from three of seven stations ranging in concentrations from 1.0 to 3.0 mg/L. Oil and grease were determined to be below the minimum reporting level of 0.01 mg/L for samples from six of seven stations. Nutrient concentrations in samples from all seven stations did not vary significantly from historical ambient concentrations; however, the loads of nitrogen and phosphorus (217,500 kg/hr and 29,900 kg/hr, respectively) determined at the peak of the flood on the Mississippi River near St. Louis, were three times the historical ambient loads. Atrazine, cyanazine, metolachlor, deethylatrazine, simazine, prometon, alachlor, and diazinon were detected in samples from all seven stations throughout the flood hydrograph. Atrazine, cyanazine, and metolachlor were present in the largest concentrations throughout the flood event. The transport rates of these pesticides near the peak of the flood in the Des Moines, Missouri, and Mississippi Rivers were (respectively in kg/hr) 25, 150, and 200, for atrazine; 6.0, 80, and 80, for cyanazine; 10, 110, and 70, for metolachlor. The bulk of the pesticide transport occurred on or before the peak of the flood — average decrease in the transport rates during the flood recession was 70 to 90 percent for atrazine, 20 to 90 percent for cyanazine, and 20 to 80 percent for metolachlor.

Contaminants in Mississippi River Suspended Sediment Collected with Cylindrical Sediment Traps

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Wisconsin Department of Natural Resources

Glass sediment traps have been deployed in the Upper Mississippi River to collect composite samples of suspended sediment for contaminant testing since 1987. The objectives of this work were to assess the contaminant concentrations, assess temporal trends and compare contaminant levels in suspended sediments to other contaminant studies on the river. As a result of the summer flood of 1993, this monitoring effort was expanded to include the river reach extending from Champlin, Minnesota to Dubuque, Iowa.

Polychlorinated biphenyls (PCBs) and cadmium concentrations in trapped sediments exhibited a distinct longitudinal profile with highest concentrations (180 ng/g and 2 ug/g, respectively) observed in suspended material collected from navigation pools immediately below the Twin Cities metropolitan area down to Lake Pepin, a distance of 75 miles. PCBs were substantially lower below Lake Pepin and decreased to 2 ng/g at Dubuque, Iowa. The spatial concentration of PCBs and Cd observed in trapped suspended sediment paralleled longitudinal contaminant profiles that have been reported for bed sediments, mayflies, fish and other environmental matrices in the Upper Mississippi River. Other trace elements (copper, mercury, lead and zinc) showed a more variable spatial profile and no clear enrichment from local point or nonpoint source inputs.

A definite seasonal pattern (spring versus fall) was observed in the gross sedimentation rate, total volatile solids and manganese content of trapped materials. Changes in river flow and differences in the contribution of allochtonous versus autochthonous organic matter in the river were believed responsible for these observations. Spring samples were characterized as having higher sedimentation rates, lower organic matter content and increased particle size than fall-deployed traps. Suspended organic matter in fall samples likely contained a greater proportion of autochthonous organic matter. These seasonal differences influenced contaminant concentrations since organic contaminants and trace elements have a strong affinity to bind to fine particles, especially those high in organic matter content.

Long term monitoring near Red Wing, Minnesota between 1987 to 1994 indicated a significant reduction in PCBs, cadmium, copper, chromium, mercury, lead, zinc bound on suspended sediment (mass basis). However, when contaminants were normalized for organic matter content and particle size (manganese content), temporal trends were weak and not observed.

The major factor influencing long term suspended sediment contamination was river flow which showed a significant increase during the 7 year study. Higher flows increased the size of the particles in suspension and resulted in a reduction in the surface area (binding sites) of the particles in suspension. This contributed to lower contaminant concentrations on a mass basis. In contrast to contaminant mass concentration, particulate-bound contaminant loadings and whole water particulate-phase concentrations increased due to greater total suspended solid concentrations during high flows.

Relatively accurate estimates of whole water particulate-phase trace element concentrations were derived from sediment trap contaminant and total suspended solid data collected near Red Wing, Minnesota. This was based on a comparison to the Department's low-level trace element work for the Mississippi River. Maximum particulate-phase concentration estimates for PCBs and mercury were 5.5 and 11 ng/L, respectively. These concentrations exceeded Wisconsin's water quality standards by more than five fold. The actual exceedance was greater since dissolved and colloidal phases were not included.

Lake Tomah Sediment Trap Evaluation

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Lake Tomah is located in a 30 square mile primarily agricultural drainage basin, located 40 miles east of La Crosse, Wisconsin. The 225 acre lake is located in the northwest corner of the City of Tomah. Results from a nonpoint source inventory estimate that 80 percent (2,200 tons) of total sediment contribution to Lake Tomah is due to agricultural practices.

The primary objective of the 1991-1993 Lake Tomah Restoration Project was to reduce sediment loading into Lake Tomah. At a cost of nearly 5 million dollars, Lake Tomah was dredged, and a new dam and sediment trap were constructed. The purpose of the sediment trap is to collect sediment transported by the South Fork of the Lemonweir River before it reaches the lake basin. River flows are diverted into an easily accessible sediment trap. This trap is approximately 800 feet long, 100 feet wide, and 10 feet deep. This provides a reduction in stream velocity thereby allowing sediment to settle upstream from the lake.

Upon completion of the dredging and restoration project, Lake Tomah was allowed to refill in the spring of 1993. Heavy rains during this period allowed the lake to refill three times faster than what was estimated. High stream flows throughout the summer of 1993 transported 6,200 cubic yards of sediment into the sediment trap. This influx of material reduced the water volume capacity of the sediment trap by 22 percent. The primary particles deposited within the trap are sands ranging from 2.0 mm to 0.05 mm.

Mercury Cycling in Reservoirs: Sources and Transport in Lake Arbutus, Wisconsin

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Extreme flooding in the Black River threatened to wash out the Hatfield Dam which impounds 839 acre Lake Arbutus. The lake was rapidly drawn down exposing large areas of sediment. Lake Arbutus and the Black River currently have fish consumption advisories due to elevated levels of Hg in many fish species. This study was intended to determine if the exposure of sediments to air has altered the bioavailability of Hg to the fishery in Lake Arbutus and will define post-flood bioavailabilty of sediment Hg in the Black River.

The external delivery and internal cycling of Hg was assessed in the Lake Arbutus Reservoir of Black River, Wisconsin. Tributary inputs were the major sources of Hg to the lake and hydraulic residence times of the lake water ranged from 2-54 days during the study. Tributary unfiltered total Hg concentrations ranged from 2.2 to 6.9 ng/L while MeHg ranged from 0.21 to 1.6 ng/L. In Lake Arbutus, unfiltered total Hg ranged from 2.2 to 7.8 ng/L while unfiltered MeHg ranged from 0.16 to 1.9 ng/L. Elevated MeHg levels were observed in hypolimnetic waters during stratification. Comparison of percent MeHg from tributaries to that of Lake Arbutus suggests that the lake is a net producer of MeHg to the Black River system. Since a significant portion of the external Hg load to Lake Arbutus is associated with particles, this study also emphasizes the potential importance of this internal reservoir cycling to remobilize Hg which may have been considered inert due to its association with particles.

Round and Long Lakes Paleoecological Study

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The study is being conducted to ascertain the effect of climate upon the limnology on two lakes in northwest Wisconsin. Specifically we are investigating whether periods of above normal rainfall causes a degradation of water quality. Round Lake is a 87 ha softwater, shallow, seepage lake. Empirical and anecdotal evidence indicates that algal blooms occur during years of above normal rainfall. For example, in 1993, a year of abnormally high rainfall, an algal bloom occurred that was worse than any previously recorded levels. A paleoecological study was initiated to determine if increased algal productivity has occurred in other years when rainfall was above normal and also to determine any changes in water quality in the last 150 years.

In contrast, nearby Long Lake is a 426 ha deep, drainage lake that did not experience an algal bloom in 1993. This lake was not thought to experience increased algal productivity during wet years, therefore it is used as a comparison lake for Round Lake. The study of this lake will also determine if increased algal productivity has occurred in years when rainfall was above normal and also determine any changes in water quality in the last 150 years.

Because the dating (^{210}Pb) has not been completed, it is not possible to relate changes in water quality to above normal rainfall years. However, we are able to ascertain long term changes in the lakes.

The shoreline of Long Lake has possessed a number of cottages, homes, and resorts since the late 1800s. The watershed was logged in the 1870s and 1880s. Since the cores have not been dated, it is not possible to put exact time lines to the cores but at least in Long Lake an approximation is possible. Loss on ignition (LOI) (approximation of organic matter) begins to decline at about 30 cm. This depth likely represents the late 1800s. The decline in LOI is a result of increased erosion of inorganic materials from the watershed. This likely occurred during logging in the 1880s. With increased erosion, nutrient input also increased. The diatom community indicates that water quality began to decline at about this time. This is indicated by decline in the dominant taxa, *Aulacoseira ambigua* and *Tabellaria flocculosa* and short term increases in *Cyclotella michiganiana* and *C. glomerata*. These taxa soon declined and were replaced by *Fragilaria crotonensis* and *Asterionella formosa*. These latter two taxa are usually found in lakes with elevated nutrient levels. The highest production of diatoms occurred at 25 cm when the diatom community was undergoing the greatest changes and in the surface sediments. It appears that the development around the lakeshore as well as the watershed disturbances have had an adverse affect upon the lake's water quality.

Round Lake is a much different lake than Long Lake. It is smaller and does not stratify. Disturbance around the lake does not have as big an impact on the lake because there are no inflowing streams. Loss on ignition does not decline in response to land clearing in the watershed as it did in the Long Lake core so it is not possible to estimate a time line for the core. The core does indicate that profound changes have occurred within the lake. The bottom portion of the core (90-102 cm) contains evidence of a bog which indicates the lake's water level likely was much lower than it is at the present time. In fact, there are few diatoms below 50 cm indicating either that few diatoms were produced or more likely that their preservation was not good, perhaps because of shallow water levels. Diatom taxa exhibited profound changes in the upper 40 cm of the core. The percentage of planktonic taxa (74 percent) is much greater at the top of the core than at 40 cm (16 percent). This is most likely because increased water levels as well as increased nutrients which favor the planktonic taxa. The increased nutrients in the lake most likely are the result of cottage development around the lake shore. Dominant taxa in the recent sediments are *Tabellaria flocculosa, Asterionella ralfsii* var. *americana,* and *A. formosa.* All of these taxa are planktonic. The dominant taxa at 40 cm was the benthic dwelling species *Fragilaria pinnata*. With cottage development on the shoreline the increased input of base cations resulted in an increase in the pH of the lake of about 0.1 pH units to about 6.4.

The water quality of both of these lakes has degraded in the last century most likely as a result of development on the shorelines of the lakes and within the watershed. Round Lake in particular has undergone significant changes as a result of increasing water levels.

Toxicity Evaluation of Urban Stormwater Runoff in Lincoln Creek, Milwaukee, Wisconsin

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Recent initiatives by the U.S. Environmental Protection Agency will bring stormwater runoff from large metropolitan areas under the purview of state water quality agencies. Yet, there is little information concerning the toxicological effects of stormwater runoff on aquatic biota on which to base new regulations. This study addressed acute and short-term chronic effects of stormwater runoff to aquatic biota in an urban stream, Lincoln Creek, in Milwaukee, Wisconsin. Samples of stormwater and baseflow for acute and short-term chronic tests were collected during runoff events and baseflow beginning with snowmelt March-October, 1993. Stormwater samples were collected with a stream gauge-actuated automatic sampler programmed to collect up to eight sequential samples from the stream during each runoff event. Baseflow samples were a grab collected every other week from the drop structure located at 47th Street and Congress Avenue. A total of 24 runoff events and 12 biweekly baseflow samples were tested. A total of 316 laboratory toxicity tests were performed on serial dilutions of the stormwater runoff with *Ceriodaphnia dubia, Daphnia magna* and *Pimephales promelas*. In addition, 34 in-situ toxicity tests, fish and macroinvertebrate assemblages indigenous to Wisconsin were exposed in flow-through aquaria housed in a U.S. Geological Survey gauging station adjacent to Lincoln Creek.

The short term (less than 8 days) toxicity tests used in this study appear to have underestimated toxic effects of Lincoln Creek stormwater. No short term, acute or 7-day chronic toxic effects, which could be solely attributed to stormwater runoff, were identified with the three laboratory test species. In-situ acute tests with 23 families of macroinvertebrates (2-day) and 10 species of fish (7-day) detected only slight toxicity for some species. Significant mortality in *Rhinichthyes atratulus,* possibly caused by stormwater or baseflow water quality, occurred in one of 26 tests with indigenous fish. Significant mortality in the caddisfly family Hydropsychidae occurred in one of 8 tests. It appears conventional short-term toxicity tests which include the 7-day *Ceriodaphnia dubia* reproductive test lack the sensitivity to detect the type of biological degradation seen in Lincoln Creek. Test organisms were exposed to a variety of metal contaminants in stormwater and baseflow samples at levels that exceeded Acute Toxicity Criteria and Chronic Toxicity Criteria values for metals established by Wisconsin Department of Natural Resources. Polycyclic aromatic hydrocarbon concentrations in stormwater runoff were much greater than at baseflow samples collected from Lincoln Creek and were found at concentrations that are reported toxic to aquatic life. Although little acute mortality was recorded, there was evidence that longer exposure produced extensive mortality that could in part explain the paucity of aquatic biota in Lincoln Creek. Juvenile and adult *Pimephales promelas* exposed on-site to Lincoln Creek water for greater than 14 days suffered substantial mortality. Chronic (greater than 14 days) toxicity tests are more sensitive and appear better suited to identify biological impairment caused by stormwater runoff.

Water Resource Assessment of 1993 Flooding in the Middle Kickapoo Watershed

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The Middle Kickapoo Watershed is 250 square miles and is located in Vernon, Richland and Monroe Counties in Western Wisconsin. The topography of the watershed is steep and much of the land is used for agricultural purposes (Schreiber 1991). Stream flow records obtained from USGS on the Kickapoo River at LaFarge indicate higher than average annual flow in 1993. In 1993, annual mean flow was the highest ever recorded for the Kickapoo River and was 74 percent above the 33 year average mean flow for the river. High stream flows during the flooding in 1993 may have impacted streams in the watershed.

In 1989, the Middle Kickapoo Watershed was selected as a priority watershed project under the Wisconsin Nonpoint Source Water Pollution Abatement Program. Substantial water resource data was collected as result of this project. Fish habitat assessments, macroinvertebrate sampling, and streambank erosion inventories were completed on streams throughout the watershed. Since data collected in 1989-90 was used to establish watershed project objectives and conditions to measure project success by, it was important to determine if flooding had altered stream conditions. The purpose of this study was to evaluate impacts the 1993 flood had on streams in the watershed. Pre-flood data collected in 1989-90 was compared to post-flood data collected in 1994 to evaluate impacts of the flood.

Fish habitat surveys were conducted following procedures described by Lyons (1990). Data collected as a part of these surveys include stream width and depth, substrate type, stream flow, streambank use, and measurement of stream features (length and distance of bends, pools, riffles, and runs). Statistical analysis was used on stream width and depth at each site using a student's t-test to determine if changes were significant. Habitat at each site was also qualitatively rated using an evaluation designed by Lyons (1992). Macroinvertebrate sampling was conducted on streams in the watershed following methods described by Hilsenhoff (1987). Four metrics were used to evaluate streams in the watershed to determine if changes to the macroinvertebrate community occurred as a result of flooding. The four metrics include Hilsenhoff Biotic Index (HBI); Tolerance Value Index (TBI); Margelef's species diversity index; and Ephemeroptera, Plecoptera and Trichoptera Percent Genera Index (EPTPG).

Evaluation of habitat and macroinvertebrate communities suggest few significant changes have occurred due to flooding in 1993. Habitat surveys in 1994 indicate width and depth significantly changed at 18 percent of the sites. Three sites were significantly deeper and one site was wider. The overall macroinvertebrate community has either improved or changed little based on data collected in 1994. All streams surveyed improved or changed little in the HBI and TBI indexes (no stream had a decrease in HBI and TBI ratings) during 1994 surveys. Two streams decreased in species diversity while 13 streams changed little between the 1990 and 1994 surveys. EPTPG index increased in five streams while little change occurred in ten streams.

The 1993 annual mean flow was the highest ever reported for the Kickapoo River. The Kickapoo River's 1993 peak flow was in the range of annual peak flow, however; the longer duration of the high flows in 1993 may have caused the changes found by the study. The time between pre- and post-flood surveys (1990, 1994 respectively) allows three other possible years for changes in the watershed to occur. Also, since monitoring of the 1993 flood began one full year after the event, any changes to habitat and macroinvertebrate communities that have been caused by the event had one year to recover.

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Water Resource Assessment of 1993 Flooding on PCBs in the Black River

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The Black River originates at Black Lake in northeast Taylor County, Wisconsin. The river flows southwest 198 miles and enters the Mississippi River near Lake Onalaska. Three dams exist on the Black River, the furthest downstream located in Black River Falls. The river is then free flowing until it reaches the Mississippi River, 62 miles downstream. Polychlorinated biphenyls (PCBs) have been detected in fish samples from the Black River and are frequently found in fish below the Black River Falls dam. Fish consumption advisories are listed for the Mississippi River which include the river at its confluence with the Black River (Wis. DNR 1994). Currently, a fish advisory for PCBs does not exist on the Black River. Contaminated fish could be migrating up the Black River from the Mississippi River, or PCB sources may exist in the Black River system. Peak flow in 1993 on the Black River near Galesville was nearly 31 times greater than the river's mean discharge (USGS 1993). Extreme flooding in 1993 could have disturbed PCB sources and increased their bioavailability in the river. The purpose of this study was to determine in-water PCB concentrations and possible sources of PCBs in the Black River.

Semi-Permeable Membrane Devices (SPMDs) were used to measure PCB concentrations. SPMDs are low density polymeric tubing each filled with one ml of lipid (triolein) and sealed at both ends to form a mobius strip (Huckins 1990). SPMDs imitate the bioaccumulation of PCBs in fish by using triolein, a neutral lipid found in many aquatic organisms. SPMDs were deployed at 11 locations, including nine in the Black River, one in Halls Creek, and one in the Mississippi River. The devices were deployed for 34 days, frozen and sent to Custom Industrial Analysis Laboratories (CIA Labs) for dialysis on both the membrane and lipid for each SPMD. CIA Labs shipped the ampules of dialysates to the Wisconsin State Lab of Hygiene (SLOH) for analysis. The SLOH analyzed the samples using capillary column gas chromatrophy with electron capture detection to identify individual congeners.

In-water PCB concentrations were calculated from SPMD results using a formula developed by James Huckins (1995). SPMDs located above the Black River Falls dam did not detect PCBs in the river. SPMDs below dam detected PCBs but the highest calculated in-water concentration found was 0.21 ng/l, 59 percent lower than the established Wisconsin standard of 0.49 ng/l. The Mississippi River had calculated in-water PCB levels three times higher than the state standard.

A bioconcentration factor model (BCF) was used to predict PCB levels in fish using calculated in-water PCB concentrations, detected aroclors and lipid content of fish species. Fish tissue contaminant data from both the Mississippi and Black Rivers was used in conjunction with the BCF model. Channel catfish (*Ictalurus punctatus)*, common carp

(*Cyprinus carpio)*, and walleye (*Stizostedion vitreum*) were collected from both rivers in the last seven years. The three fish species were used when comparing PCB concentrations in fish to levels predicted by the model. Fish collected from the Mississippi River had PCB levels which were similar to concentrations predicted by the BCF model. However, 77 percent of Black River fish exceeded PCB levels predicted by the model. Black River fish that exceeded the model's predicted PCB levels had concentrations similar to those found in fish from the Mississippi River.

Study results suggest contaminated fish below Black River Falls are migrating up from the Mississippi River and are not accumulating high levels of PCBs from the Black River. The Black River Falls dam acts as a barrier to fish migration and prevents contaminated fish from moving upstream. According to the BCF model, PCB concentrations in the Black River would not produce the PCB levels found in Black River fish. The 1993 flood apparently had minimal effects in altering the bioavailability of PCBs in the Black River because PCB levels and inputs appear to be low.

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WATER QUALITY MONITORING GUIDANCE FOR MAJOR FLOODS

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In response to the Midwest Flood of 1993, a federal interagency Flood Event Water Quality Monitoring Working Group (FEWQM) was established in September 1993 by the Subcommittee on Water Quality of the Interagency Advisory Committee on Water Data. The group, under the joint leadership of the U.S. Geological Survey and the U.S. Environmental Protection Agency, was formed to develop a plan for federal agency water quality monitoring during major flood events. During January 1994, the Working Group conducted interviews with representatives of federal and state agencies in Missouri and Iowa regarding their experiences during the 1993 flood. Conclusions from these interviews and recommendations made by the Working Group were included in a document entitled, "Water Quality Monitoring Guidance for Major Floods," which was outlined at the 1993 Flood-Related Water Quality Monitoring Workshop by Joann Kurklin of the U.S. Geological Survey.

Conclusions From Interviews in Iowa and Missouri

- Lack of assured funding source impeded ability to sample during early phases of flood event.
- Lack of coordinated plan probably resulted in some duplication of efforts and an excessive lead time for sampling resulted in missed opportunities.
- Turnaround time for results, especially those related to public health, was too long.
- There was a need for coordinated effort to disseminate water quality information after it was available.

FEWQM Recommendations

The Working Group developed a series of recommendations regarding activities during different phases of a flood as well as related resource and implementation issues. Those recommendations are outlined below. The group emphasized that activities during all phases require collaboration at the community, state, tribal, regional, and federal levels.

Pre-flood Activities

Pre-flood is defined as the time between the forecast and onset the flood.

- Identify potential flood areas

- Identify other federal agencies having flood water quality monitoring concerns in the potential flood areas and invite them to any flood emergency planning or implementation meetings or discussions

- Discussion should:

  - identify water quality programs of federal (local offices), state, tribal, and local agencies;

  - discuss the relation between water quality monitoring efforts to address public health questions and long-term environmental health concerns;

  - prioritize sampling efforts that will provide the data required to answer as many public health and environmental concerns as possible;

  - identify the need for or interest in forming a Command Team or Command Center for water quality monitoring during a flood; and

  - identify availability of resources and consider sharing of resources to the extent possible among agencies.

Flood Activities

The flood is defined as the period when flooding is occurring.

- Decision on when to implement monitoring plan in connection with other emergency event activities

- If necessary, implement the plan:

  - activate a command center
  - collect and analyze samples
  - evaluate and disseminate data and information

- Consider advising the Governor to request federal assistance for a disaster situation

Major Flood Activities

A major flood is one that is likely to prompt a Federal Disaster Declaration and a federal response.

- President declares emergency
- Governor appoints a State Coordinating Officer (SCO)
- Presidents appoints a Federal Coordinating Officer (FCO)
- Implement the Federal Response Plan; federal support agencies activated
- Open operational disaster field offices with federal support agencies present
- Coordinate and integrate water quality monitoring plan with emergency support function activities

Post-Flood Activities

The post-flood is defined as the period when waters recede to normal seasonal levels and flood-related water quality monitoring activities are no longer necessary.

- Analyze data and consider further activities or studies
- Critique the pre-flood and flood activities
- Modify the water quality plan as needed
- Assign writing responsibilities for report on water quality as related to the flood
- Disseminate the report as related to the flood

Resources

- Pre-flood activities are assumed to be funded within existing local, state, tribal, and federal agency budgets.
- Major flood water quality activity funding can be requested by states from the Federal Emergency Management Agency (FEMA) after an emergency is declared by the President

Future Resource Recommendations

- Establish a permanent revolving fund for flood event water quality sampling within a designated federal agency; or
- Amend existing legislation such as the Stafford Act so FEMA could reimburse federal, state, tribal, or local agencies for pre-declaration activities

Sample Collection and Safety Issues

- Constituent selection
- Sampling sites for surface water and ground water
- Sampling techniques and equipment for surface water and ground water
- Health and safety
- Quality assurance
- Data release

Federal Implementation of Guidelines

- Coordinate with primary agencies for relevant emergency support functions (ESF) under the Federal Response Plan
    - Emergency Support Function #3 - Public Works and Engineering
    - Emergency Support Function #8 - Health and Medical Services Annex
    - Emergency Support Function #10 - Hazardous Materials Annex
- Incorporate water quality monitoring as a recognized activity within the scope of ESF #'s 3, 8, and 10
- Delineate monitoring activities and responsible agencies in the Standard Operating Procedures of ESF #'s 3, 8, and 10

DISCUSSIONS

This section highlights the discussions that followed the workshop presentations of the EPA-funded monitoring work and the federal "Water Quality Monitoring Guidance for Major Floods." It is organized by general themes that ran through the discussions. No attempt has been made to capture the discussions in their entirety. Nor do the observations noted necessarily represent the group's consensus except where specifically noted. Specific conclusions and recommendations offered by the workshop participants are detailed in subsequent sections.

General Observations on the Impacts of the 1993 Flood

Most participants agreed that flood-related monitoring did not reveal significant water quality impacts on the Upper Mississippi River and the Missouri River as a result of the 1993 flood. There was concern, however, that impacts occurring during the pre-peak and peak discharge stages of the flood may have been missed because little sampling was done during these phases. Other observations and concerns expressed during this discussion included:

- In general, concentrations of contaminants in the Upper Mississippi and its tributaries during the flood were not significantly above those typically observed under normal flow conditions. This was due in large part to dilution by the increased water volume. Contaminant loads carried by the flood waters were significantly above those commonly experienced under normal flow conditions.

- Increased loadings of nutrients and other contaminants may have had significant impacts on the water quality of the Gulf of Mexico.

- Problems associated with increased concentrations of various contaminants in the Upper Mississippi River may be more likely to occur during low flow rather than high flow conditions.

- The flood may have had significant geomorphologic and ecological impacts on the river system. However, few resources have been made available to assess the flood's physical and ecological effects. As a result, the nature and extent of these impacts are uncertain. For example, the flood resulted in an increased need for dredging to maintain the navigation channel, but little is known regarding the impacts of this increased dredging and the secondary movement of material due to that dredging.

- The flood increased risks to water quality associated with the storage, processing, and transport of hazardous materials on and near the river.

- Not finding significant impacts on water chemistry from the 1993 flood was itself a valuable lesson learned. However, scientists' understanding of this flood remains limited. It would be difficult to extrapolate these limited findings to other flood events.

- There is not enough scientific knowledge about the dynamics or behavior of the river system to completely answer all questions regarding the impacts of the flood on water quality.

Pre-Flood Planning

Participants recognized the importance of advance planning to successful flood monitoring, both in terms of efficiency and effectiveness. Establishing a water quality monitoring plan before a major flood would enable agencies to:

- Develop clear and achievable water quality monitoring objectives. Knowing what these objectives are before an event occurs would also help agencies allocate supplemental funding when received.

- Determine what specific monitoring activities should be undertaken to meet the stated objectives.

- Identify key water quality data sets. Where possible, parameters chosen should be easily replicated and analyzed in the interest of reducing monitoring costs.

- Be prepared to do water and suspended sediment sampling on the rising limb (i.e., pre-peak) and at the peak discharge of a flood.

- Identify internal and external coordination mechanisms.

- Expand beyond flood planning to prepare monitoring plans for other special events, such as droughts or major spills.

Interagency Coordination

In addition to pre-flood planning within individual agencies, workshop participants discussed the value of enhanced interagency coordination at all levels of government. Interagency coordination could serve to:

- Bring water quality monitoring personnel together to determine what critical questions are to be answered regarding floods and other special events in general. More detailed coordination would follow in the context of particular events.

- Provide the means by which agencies could set goals and establish objectives that would be mutually beneficial. Answering questions that are of joint interest to the different agencies could facilitate the selection of monitoring approaches, including the choice of cost-effective parameters and analytical methods.

- Eliminate duplication of monitoring efforts while ensuring that critical sampling is not missed.

- Identify agreed upon quality-control measures for data collection and laboratory analysis.

- Provide a mechanism for information sharing and comparison.

- Maintain contact lists, including telephone numbers and organizational units, for personnel with flood water monitoring responsibilities within the various agencies. This would facilitate interagency communication and coordination for routine as well as special event monitoring.

Some participants suggested that an entity such as the Upper Mississippi River Basin Association could be used as the facilitating mechanism by which the agencies in this region could coordinate their flood-event monitoring activities. In addition to providing a forum for state, federal, and tribal personnel to plan and coordinate their efforts and exchange data, the facilitating agency could ensure that technical information is disseminated in non-technical terms to water resource policy makers and the public.

Standard Protocol for Monitoring

Workshop participants observed that there was no standard protocol for flood-event water quality monitoring in place during the 1993 flood. Moreover, there are currently no plans to develop such a protocol for future floods in this region. While generally acknowledging the value of pre-flood planning and interagency coordination, workshop participants expressed a variety of reservations regarding development of a standard monitoring protocol.

- The preparation and implementation of a standardized flood monitoring protocol would involve some expense on the part of the participating agencies.

- Reaching consensus among all affected agencies regarding such a protocol would be extremely difficult given differences in agency resources, objectives, mandates, etc. Because various water resource agencies tend to ask different questions when monitoring, distinct approaches may be needed to answer questions specific to their needs. Rather than attempting to standardize water quality monitoring during an event, the use of comparable approaches among participating agencies appears to be both more feasible and more productive.

- Even if a standard monitoring protocol were developed, it would be difficult to remain prepared to implement the protocol over the many years between major flood events.

Importance of Baseline Monitoring

Participants' presentations and discussions repeatedly underscored the importance of baseline data in interpreting the results of event monitoring. For example, a cooperative effort by the Centers for Disease Control and Prevention and the states to assess private wells after the 1993 flood found high rates of nutrient contamination. However, there is very little baseline data on private wells available for comparative purposes. Researchers are thus unable to distinguish between flood impacts and the more pervasive problem of decaying rural infrastructure. Participants' observations regarding baseline monitoring included:

- Long-term water quality monitoring is essential if scientists and resource managers are to accurately identify long-term trends as well as describe the impacts of floods and other relatively short-duration events. This ability is critical in order to respond to the questions most important to public officials and citizens.

- Reference sites could be used to establish a long-term water quality characterization of particular areas. Public water intakes are considered to be a natural place to institute long-term monitoring because water suppliers continually monitor for parameters related to human health concerns.

- During a major flood event or during a severe drought, established monitoring sites could be sampled more frequently and/or additional sites could be added to the sampling regime to improve temporal and spatial evaluation.

- Although there are good surface water records available in some areas for some parameters, there are still significant gaps in the baseline data for surface water. Even less information is available on sediment and ground water. In general, there is not enough baseline data available to fully characterize the water quality of the Upper Mississippi River and its major tributaries, which form a very dynamic river system.

- Methods by which water and sediment samples are analyzed may change over time, thereby limiting the comparability of data sets. For instance, analytical methods for detecting contaminants in sediment have improved over the last 15 years. As a result, researchers wishing to compare current sediment sampling results with historic data must consider whether any apparent increases in contamination are due to actual increases or to enhanced detection capabilities.

- Long-term monitoring requires significant investments of time, money, and personnel. Agencies at both the state and federal levels have very limited resources available to support or expand current monitoring efforts on the river or its tributaries.

Funding Limitations

Participants shared the following perspectives regarding the availability and allocation of funding for routine and special event monitoring:

- Monetary resources for routine baseline monitoring are limited. Generally, if baseline funds are used for event monitoring, part of the core effort must be foregone.

- Supplemental event-specific monitoring funds are unpredictable and typically are not available in time to capture the entirety of the event. For example, the emergency federal funding that supported much of the 1993 flood monitoring was not appropriated until after the peak discharge.

- All funding, both baseline and supplemental, comes with statutory and administrative restrictions and obligations governing its use. While both appropriate and inevitable, these restrictions and obligations impose very real constraints on the ability of scientists to respond effectively and flexibly to something as dynamic as a flood.

- When funding is available for event monitoring, provisions are needed to ensure that a sufficient portion of the money is allocated for analysis and integration. Without such provisions, researchers may have substantial amounts of data with no means of interpreting it and communicating their results.

CONCLUSIONS

Workshop participants offered the following conclusions based on their monitoring studies and discussions:

- ***The monitoring did not reveal significant flood-related water quality impacts in terms of contaminant concentrations. However, there were substantial increases in contaminant loadings. These increased loadings, particularly the increased delivery of nutrients and herbicides, may have had significant impacts on the Gulf of Mexico.***

  Not enough information is known about the dynamics or behavior of the river system to draw conclusions about the longer term impacts of the contaminants that remain in the river system.

- ***It is not possible to draw conclusions regarding water quality impacts during the pre-peak portion of the 1993 flood due to lack of monitoring data.***

  Little or no sampling was done by most water quality researchers during the first pulse of the flood, due in part to lack of funding and pre-event planning, but also due to the inherent difficulty of recognizing the rising limb (i.e., pre-peak) of a flood. The leading edge of a flood is when one would typically expect to see the highest contaminant concentrations.

- ***The EPA-funded monitoring studies were focused on direct water quality impacts and did not provide extensive insights into the physical and ecological impacts of the 1993 flood.***

  Findings from research funded from other sources as well as some insights gained through the EPA-funded studies suggest that the flood may have had significant impacts on the geomorphology and ecology of the river system. However, gaining a basic understanding of these impacts would require a significantly greater study effort. Funding for such work has not generally been available since the 1993 flood.

- ***Available baseline data frequently does not provide an adequate context for interpreting the results of special event monitoring.***

  Although there are good surface water records available in some areas for some parameters, less information is available for sediment or ground water. In general, there is not enough baseline data available to confidently identify long-term trends or isolate the impacts of specific events.

- ***Monitoring efforts related to the 1993 flood would have been enhanced by a clear articulation of purpose and prioritization of monitoring needs.***

  Although several agencies did prepare workplans and address the purpose and priorities of their water quality monitoring efforts, this was not universally done.

- ***Monitoring efforts related to the 1993 flood would have benefited from interagency coordination of sampling locations, parameters, finances, and personnel.***

- ***The EPA-funded flood-related monitoring studies did not include adequate resources for data analysis and integration.***

  Substantial data was generated by the flood-related water quality studies. However, time and money constraints limited scientists' ability to interpret this data and communicate their results. Some researchers also encountered difficulties getting the necessary laboratory support for their work. Data analysis and information dissemination are critical if scientists are to answer the questions posed by resource managers, political leaders, and members of the public.

RECOMMENDATIONS

Workshop participants developed the following recommendations for future flood event monitoring efforts:

- ***Flood event monitoring efforts should be shaped by answering the following:***

  - **What information is needed?**
  - **What questions must be answered to get the information?**
  - **What data are needed to answer the questions?**
  - **What monitoring and analysis will yield the data and quality assurance needed?**

  Knowing what is of greatest concern in terms of human and environmental health is essential to well-targeted and cost-effective water quality monitoring during and after a major flood event. An interagency strategic plan for water quality monitoring developed before such an event can help ensure that monitoring efforts are appropriately focused by answering the questions highlighted above. Of course, such a plan must also be sufficiently flexible to respond effectively to the exigencies of a particular event as it unfolds.

- ***A National Water Quality Monitoring Council should be formed, with a subcommittee established to address data comparability issues.***

  It would be quite helpful to have an interagency group, with both state and federal representation, to address monitoring issues at the national level. Such an entity could catalyze regional interagency coordination efforts, in part by providing information and guidance to statewide or watershed-based attempts to develop and implement coordinated monitoring plans. There is currently a proposal to convert the existing Intergovernmental Task Force on Monitoring Water Quality into a National Water Quality Monitoring Council that could serve this purpose. When formed, the Council should place special emphasis on addressing data quality and comparability issues.

- ***The National Water Quality Monitoring Council should promote the use of water quality indicators that are cost-effective and readily transferable.***

  Some water quality parameters are difficult and expensive to sample and analyze. For example, laboratory analysis of polychlorinated biphenyls (PCBs) is very expensive and variability in analysis methods often makes PCB data difficult to replicate and limits the transferability of results. The Council should attempt to identify parameters that measure, or are indirect indicators of, contaminants of concern and that can be sampled and analyzed in a timely manner at a relatively low cost. The selection of these parameters should be based on the likelihood of water quality standard exceedances.

- ***State and federal agencies and tribal governments should establish mechanisms for at least annual coordination of flood-related monitoring. Coordination should include planning for information dissemination.***

  Coordination could greatly benefit those agencies involved in flood-related water quality monitoring by reducing costs, clarifying interagency objectives, avoiding duplication of effort, and facilitating information transfer. In addition, the same mechanism developed to coordinate flood-related monitoring could also serve as a vehicle for coordinating other event-driven monitoring as well as routine baseline monitoring activities.

  Effective interagency coordination could take place at the state or watershed level. One benefit of state level coordination is that many key resource allocation decisions are made at the state level not only by the states themselves, but also by federal agencies. However, state and federal agencies are increasingly looking at water resource issues on a watershed basis. The impacts of events such as floods and droughts often manifest themselves on a watershed basis. Moreover, in large watersheds such as the Upper Mississippi River Basin, taking a watershed approach could greatly facilitate interagency coordination across state lines. Regardless of whether a state- or watershed-based approach is employed, it would be preferable to use an existing entity, such as a state agency or the Upper Mississippi River Basin Association, to facilitate coordination.

- ***Event monitoring should be designed to enhance systems understanding to the extent consistent with event-specific information needs. It should also be designed in a way that is consistent across agencies to the extent possible given variations in the agencies' objectives.***

  Our understanding of how the Upper Mississippi River and its tributaries function as a system is quite limited, which in turn limits scientists' ability to draw conclusions regarding the water quality, physical, and ecological impacts of the 1993 flood. An enhanced systems understanding would not only enable scientists to explain what has happened but would also increase their capacity to predict the impacts of future floods. This in turn could allow individuals, managers, and policy makers to take steps to reduce damages from future flood events.

Appendix A

LIST OF ATTENDEES

at the

1993 FLOOD-RELATED

WATER QUALITY MONITORING

WORKSHOP

1993 Flood-Related Water Quality Monitoring Workshop
October 30-31, 1995

List of Attendees

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Dr. David Soong
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Appendix B

AGENDA

for the

1993 FLOOD-RELATED

WATER QUALITY MONITORING

WORKSHOP

October 30-31, 1995

Jumer's Castle Lodge

Bettendorf, Iowa

A Workshop on

1993 Flood-Related Water Quality Monitoring

AGENDA

Monday, October 30

10:00 a.m. • Registration

Background

10:30 • *Welcome, Introduction, Purpose of Workshop —*
Barb Naramore, Upper Mississippi River Basin Association
John Helvig, U.S. Environmental Protection Agency, Region 7

11:00 • *Overview of Flood Studies/Regional Perspective —*
Don Goolsby, U.S. Geological Survey

11:30 • *Overview of Public Health Studies —*
Kent Gray, Centers for Disease Control and Prevention

12:00 p.m. • Question and Answer Period

12:15 • Lunch

Research Presentations and Discussion

Sediment Monitoring

1:15 • *Mississippi River Sediment Contaminant Investigations —*
John Moody, U.S. Geological Survey

1:40 • *Impacts on Chippewa River Contaminated Sediments —*
Jeff Pippenger, Wisconsin Department of Natural Resources

2:05 • *Comparison of Pre- and Post-1993 Flood Sediment Cores From Pool 2 and Lake Pepin —*
Patti King, Minnesota Pollution Control Agency

2:30 • *Impacts on Sedimentation and Sediment Quality in Backwater Lakes —*
Mike Demissie, Illinois State Water Survey

2:55 • *Herbicide Contamination in Floodplain Wells*
Impacts of Failed Levees on Sedimentation and Erosion —

David Heimann, U.S. Geological Survey

3:35	• Break	
3:55	• Discussion Period	
5:00	• Adjourn for the Day	
5:15-6:15 p.m.	• Informal Reception and Cash Bar	(Garmisch Room)

Tuesday, October 31

7:30 a.m. • Continental Breakfast

Research Presentations and Discussion

Surface and Groundwater Monitoring

8:00 • *Impacts on the Mississippi and Illinois Rivers* —
David Soong, Illinois State Water Survey

8:25 • *Impacts on the Mississippi and Iowa Rivers* —
John Olson, Iowa Department of Natural Resources

8:50 • *Impacts on the Des Moines, Missouri, and Mississippi Rivers* —
Emitt Witt, U.S. Geological Survey

9:15 • *Contaminants in Mississippi River Suspended Sediment* —
John Sullivan, Wisconsin Department of Natural Resources

9:40 • Break

10:00 • Discussion Period

Flood Event Water Quality Monitoring Framework

11:00 • *Review of the Federal Water Quality Monitoring Guidelines and Related Issues* —
Joann Kurklin, U.S. Geological Survey

Discussion/Brainstorming

11:30 • Discussion to focus on:
- lessons learned during 1993 flood water quality monitoring
- future coordination and research needs
- additional recommendations for future flood-related water quality monitoring

Workshop Summary

12:30 p.m. • *Closing Remarks* —
John Helvig, U.S. Environmental Protection Agency, Region 7

Barb Naramore, Upper Mississippi River Basin Association

12:45 p.m. • Adjourn

Note: All workshop sessions will be held in the Mozart I ballroom.

Appendix C

SOURCES

for

1993 FLOOD-RELATED

WATER QUALITY MONITORING

STUDIES AND RELATED INFORMATION

Sources for 1993 Flood-Related Water Quality Monitoring Studies and Related Information

For general information about the EPA-funded flood monitoring work, contact:

Bill Franz
U.S. Environmental Protection Agency, Region 5
Upper Mississippi Team Manager
77 West Jackson Boulevard
Chicago, IL 60604
Phone: 312/886-7500

In addition, copies of the final reports submitted by the individual EPA-funded researchers may also be obtained from Mr. Franz.

For information about the federal interagency Flood Event Water Quality Monitoring Working Group or copies of its "Water Quality Monitoring Guidance for Major Floods," contact:

Mary Belefski
U.S. Environmental Protection Agency
Monitoring Branch
Office of Wetlands, Oceans, and Watersheds
401 M Street, S.W.
Mail Code 4503 F
Washington, D.C. 20460
Phone: 202/260-7061

For more detailed information regarding the individual studies summarized in this report, contact the study author or designated agency point of contact listed below (studies are listed in the same order in which they appear in the workshop report):

Overview of Flood Studies — Regional Perspective*
Donald Goolsby, U.S. Geological Survey

Contact:
Donald Goolsby
U.S. Geological Survey, WRD
Box 25046, MS 406
Denver Federal Center
Denver, CO 80225
Phone: 303/236-5950, ext. 203

Request the U.S. Geological Survey 1120 Series from:
USGS Map Distribution
Box 25286, MS 306
Denver Federal Center
Denver, CO 80225

* Note: This study was not funded by the U.S. Environmental Protection Agency.

Summary of Well Water Survey*
Edwin Kent Gray, Centers for Disease Control and Prevention

Contact:
Edwin Kent Gray
Chief of Emergency Response
Centers for Disease Control and Prevention
1600 Clifton Road NE M/S F-38
Atlanta, GA 30333
Phone: 770/488-7100

Flood Effects on the Physical and Chemical Properties of Bed Sediments in the Mississippi River
John Moody, U.S. Geological Survey; John Sullivan, Wisconsin Department of Natural Resources; and others

Contact:
John Sullivan
Wisconsin Dept. of Natural Resources
State Office Building
3550 Mormon Coulee Road
La Crosse, WI 54601
Phone: 608/785-9995

Duane Schuettpelz, WR-2
Wisconsin Dept. of Natural Resources
Box 7921
Madison, WI 53707
Phone: 608/267-7610

Impacts of the 1993 Flood on the Chippewa River Contaminated Sediments
Jeffrey Pippenger, Wisconsin Department of Natural Resources

Contact:
Duane Schuettpelz, WR-2
Wisconsin Department of Natural Resources
Box 7921
Madison, WI 53707
Phone: 608/267-7610

Investigation of the Vertical Distribution of Sediment Contaminants in Pool 2 and Lake Pepin of the Upper Mississippi River after the 1993 Flood
Patti King, Minnesota Pollution Control Agency

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Minnesota Pollution Control Agency
Water Quality Division
520 Lafayette Road
St. Paul, MN 55155
Phone: 612/296-8723

* Note: This study was not funded by the U.S. Environmental Protection Agency.

Impacts on Sedimentation and Sediment Quality in Backwater Lakes
M. Demissie, Illinois Stater Water Survey

Contact:
Mike Demissie
Office of Sediment and Wetland Studies
Illinois State Water Survey
2204 Griffith Drive
Champaign, IL 61820
Phone: 217/333-4753

Agricultural Chemicals in Alluvial Aquifers in Missouri after the 1993 Flood
David Heimann, U.S. Geological Survey

Contact:
Brenda Smith
U.S. Geological Survey
1400 Independence Drive, MS 200
Rolla, MO 65401
Phone: 314/341-0830

Scour and Sedimentation at Levee Break Sites from the 1993 Missouri River Flood
Gregg Schalk, U.S. Geological Survey

Contact:
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Impacts of the 1993 Flood on the Illinois and Mississippi Rivers
David Soong, Illinois State Water Survey

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Illinois State Water Survey
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Water Quality Impacts of 1993 Flooding on Iowa Rivers
John Olson, Iowa Department of Natural Resources

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900 E. Grand Avenue
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Water Quality of the Des Moines, Missouri, and Mississippi Rivers During the Flood of 1993
Emmitt Witt III and Joseph Richards, U.S. Geological Survey

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U.S. Geological Survey
1400 Independence Drive, MS 200
Rolla, MO 65401
Phone: 314/341-0830

Contaminants in Mississippi River Suspended Sediment Collected with Cylindrical Sediment Traps
John Sullivan, Wisconsin Department of Natural Resources

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Lake Tomah Sediment Trap Evaluation
Carlton Peterson, University of Wisconsin - Stevens Point

Contact:
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Box 7921
Madison, WI 53707
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Mercury Cycling in Reservoirs: Sources and Transport in Lake Arbutus, Wisconsin
Jeffrey Pippenger, Wisconsin Department of Natural Resources

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Round and Long Lakes Paleoecological Study
Paul Garrison, Wisconsin Department of Natural Resources

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Toxicity Evaluation of Urban Stormwater Runoff in Lincoln Creek, Milwaukee, Wisconsin
Ron Crunkilton, Wisconsin Department of Natural Resources

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Water Resource Assessment of 1993 Flooding in the Middle Kickapoo Watershed
Mark Hazuga, Wisconsin Department of Natural Resources

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Madison, WI 53707
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Water Resource Assessment of 1993 Flooding on PCBs in the Black River
Mark Hazuga, Wisconsin Department of Natural Resources

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