CHAPTER 7

Water and Sediment Quality

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The Upper Mississippi River (UMR) is an essential habitat for many aquatic species and migratory birds. The river also is a source of water for cities, towns, and industries and a conduit for storm water, waste discharges, and sediment. In this chapter, we emphasize the ecology of the river and indirectly address the human use of this resource. We will concentrate on selected physical and chemical aspects of water and sediment known to affect ecological structure and functioning within the river.

Numerous studies have examined a wide range of sediment and water conditions in the Upper Mississippi River System (UMRS) and its watershed. We do not attempt to provide an exhaustive review of the literature here. Instead, we discuss selected issues that pertain to sediment and water quality and encourage readers to examine the cited sources for more detailed information. Separate chapters in this volume provide related information on the watershed, hydrology and the Illinois River (see Chapters 5, 6, and 14). The Missouri River and its watershed are largely excluded from this discussion.

The quality of water and sediment in the UMR reflects both natural processes and human influences that occur across varying scales of time and space (Figure 7-1). Long-term fluctuations in flow can span periods of 10 years or more (see Figure 6-3). Sediment and nutrient inputs to the system have been altered by land-use changes that occurred over more than a century and nearly 200,000 square miles (500,000 km^2) of land surface. Many features of the river change naturally from upstream to downstream. For example, the reach below the confluence of the Missouri River has long differed from the reach upstream. Human activity accentuates these differences. Important natural and human-caused events also occur on small scales of space and time: localized sources of contaminants, large floods, and spills of toxic substances can have a significant effect on sediment and water quality.

Figure 7-1. Human influences have long been factors—along with natural processes—affecting the quality of water and sediment on the Upper Mississippi River.

Table 7-1. Major tributaries (drainage area greater than 4,000 square miles [10,000 km^2]) to the Upper Mississippi River. Drainage areas and annual average discharges are approximate and based on water resources data from the U.S. Geological Survey.

Tributary or location	**Drainage area** (10^3 km^2)	**Annual average discharge** (m^3/sec)
Upper Mississippi above St. Paul	50	260
Minnesota River	44	160
St. Croix River	20	150
Chippewa River	26	230
Wisconsin River	32	280
Iowa-Cedar River	33	220
Rock River	28	180
Des Moines River	39	260
Illinois River	74	650
Missouri River	1,400	2,200
Mississippi River at Grafton, IL	440	3,500
Meramec River	10	90
Kaskaskia River	14	110
Mississippi River at Thebes, IL	1,850	5,800

Aquatic life in the river depends on suitable habitat, and the suitability of aquatic habitat is tied to water and sediment characteristics. The physical structure (morphology) of the channel and floodplain, the climate, watershed inputs, and human activity all have an influence on habitat in the river.

Habitat requirements differ among species, can vary with the season, and be difficult to define (see Chapters 8 and 12). Yet most aquatic species share some common habitat requirements such as sufficient concentrations of dissolved oxygen and adequate water clarity. These basic requirements are most important for maintaining the ecological structure and functioning of the system. Beyond these, the diversity and abundance of species found in the river depends on the diversity and abundance of the habitat. A rich assemblage of river species requires an appropriate mix and variety of physical, chemical, and biological features—such as water depth, current velocity, water-level fluctuations, sediment (substrate) characteristics, temperature, light levels, food or nutrient supply, and physical structure. Shallow vegetated areas, for example, provide spawning and nursery habitat for many fishes (Littlejohn et al. 1985; Fremling et al. 1989) and are important to nesting and migratory waterfowl (Korschgen et al. 1988; Korschgen 1989). Deep, swift water is needed by channel-dwelling fishes, whereas some backwater species require deep, quiescent water during winter (Fremling et al. 1989). Human alteration of habitat can enhance or diminish the extent and diversity of aquatic habitat.

Tributary Influences

Tributaries influence the river in ways that depend on the shape, size, land use, hydrology, and chemical characteristics of their basins. Twelve major tributaries account for about 95 percent of the drainage area and about 80 percent of the average flow in the Upper Mississippi River (Table 7-1). Four sub-basins within the Upper Mississippi drainage (the Upper and Lower Illinois, Iowa-Cedar, and Upper Mississippi above Lake Pepin) are study areas for the National Water-Quality Assessment (NAWQA) Program begun in 1991. Detailed water-quality information is becoming available for these basins (Sullivan and Terrio 1994; Andrews et al. 1996; Stark et al. 1996).

The tributaries that drain into the Upper Mississippi differ in their physical and chemical characteristics (Table 7-2) and have distinct effects on the water quality of the river. The Missouri River, which enters near St. Louis, Missouri, is by far the largest tributary to the UMR (Table 7-1) and greatly alters the Mississippi River downstream of St. Louis. The Missouri River drainage area is more than double and its flow is about two-thirds that of the

Table 7-2. **Approximate average concentrations (milligrams per liter [mg/L]) of suspended sediment, nitrogen, and phosphorus near the mouths of selected Upper Mississippi River tributaries and at the upstream and downstream ends of the Long Term Resource Monitoring Program monitoring area from 1993 to1996. Sites are listed from upstream to downstream.**

Tributary or location	Suspended solids (mg/L)	Total nitrogen (mg/L)	Nitrate+ nitrite nitrogen (mg/L)	Total phosphorus (mg/L)
Mississippi River above Lake Pepin	40	3	2.0	0.2
Cannon River, MN	40	4	4.0	0.2
Chippewa River, WI	20	2	0.7	0.1
Black River, WI	10	2	0.8	0.2
Wisconsin River, WI	20	2	0.6	0.2
Makquoketa River, IA	200	7	6.0	0.4
Wapsipinicon River, IA	200	5	4.0	0.3
Illinois River, IL	80	5	4.0	0.3
Missouri River, MO	300	3	1.0	0.3
Headwaters Diversion, MO	40	1	0.5	0.2
Mississippi River near Cape Girardeau, MO	200	3	2.0	0.4

UMR above St. Louis (Table 7-1). It also carries a suspended sediment load more than twice that of the UMR (Meade 1995) but a relatively low nitrogen concentration (Table 7-2 and Antweiler et al. 1995).

Apart from the effect on water quality, tributary inflows alter the physical configuration of the river. Sediments deposited at the mouths of tributaries tend to reduce the bed slope directly upstream of the confluence, which causes pooling, while the bed slope directly downstream is increased and produces channel braiding (Nielsen et al. 1984). The most obvious example of this effect is Lake Pepin, formed upstream of deposits at the mouth of the Chippewa River.

Drought and Flood Cycles

Flow (discharge) is perhaps the single most important dynamic variable in a river system. It is in fact a central feature of riverine habitat in that it determines the availability of aquatic and terrestrial area and regulates many biological and physical processes (Junk et al. 1989). Extremes in water quality and sediment transport associated with large floods or extended droughts can have long-lasting effects on the plants and animals in the river. At the shorter scale of days or months, flow influences a host of habitat characteristics such as water depth, clarity, sedimentation, current velocity, temperature, dissolved-oxygen concentration, and contaminant distribution.

Maximum flows typically occur in spring during snowmelt and high precipitation (see Chapter 6). This annual flood pulse triggers a host of water-quality changes and stimulates a wide range of biotic responses among species adapted to it (Junk et al. 1989). Human activity in the watershed and the floodplain has influenced long- and short-term patterns of flow (Fremling and Claflin 1984; Sparks 1984; Chen and Simons 1986; Demissie and Khan 1993) and disrupted the natural flow and river stage relationships in some portions of the river (Sparks 1995).

Present Status and Recent Changes

Dissolved Oxygen

Dissolved oxygen is crucial for many aquatic species and because depletion of oxygen caused by untreated sewage has highly visible

Figure 7-2. The Twin Cities (Minneapolis-St. Paul, Minnesota) Metropolitan Waste Treatment Plant was instrumental in improving water quality downstream to Lake Pepin. Prior to completion of secondary treatment capabilities in 1978, low dissolved oxygen led to declines in macroinvertebrate and fish populations. More recently, sanitary and storm sewers were separated to reduce waste discharge during heavy rains (Source: Kent Johnson, Metropolitan Council, Environmental Services).

effects (e.g., fish kills), dissolved oxygen levels have long been a primary indicator of pollution (Goldman and Horne 1983). In the past, sewage pollution strongly affected oxygen concentrations in the river. The 60-mile (100-km) reach downstream from the Minneapolis-St. Paul, Minnesota, metropolitan area was polluted with sewage for many decades, which in turn degraded water quality and depleted dissolved oxygen downstream through Lake Pepin in Pool 4 (Wiebe 1927; Fremling 1964, 1989). Depletion of dissolved oxygen adversely affected fish and pollution-sensitive organisms such as nymphs of burrowing mayflies, which were absent from or scarce in the reach—including Pools 2, 3, and 4—until the mid-1980s (Fremling 1989).

To reduce the impact of pollution and protect human health, the Twin Cities Metropolitan Wastewater Treatment Plant in St. Paul (Figure 7-2) was built in 1938. It was upgraded from primary to secondary treatment in 1978. This plant now treats about 80 percent of the wastewater generated in the metropolitan area. About 225 million gallons (0.85 million m^3) of treated wastewater are discharged daily into the Upper Mississippi River at Pool 2, river mile 834.5 (1,343 km; Boyer 1984; D. K. Johnson, Metropolitan Council, Environmental Services, St. Paul, Minnesota, personal communication). Improvements to the plant in recent decades have reduced effluent biochemical oxygen demand and concentrations of solids and toxic substances (e.g., heavy metals, ammonia, and chlorine). By 1995 separation of storm and sanitary sewers was largely completed in Minneapolis, St. Paul, and South St. Paul. This improvement helps prevent untreated sewage from overflowing into the Mississippi River during heavy rains.

Water quality in the river downstream of the Twin Cities improved by the early 1980s. Soon afterwards burrowing mayflies began recolonizing suitable habitats (Fremling 1989; Johnson and Aasen 1989; Fremling and Johnson 1990). Algal blooms, oxygen depletion, and fish kills did occur in Lake Pepin again during the summer of 1988 coincident with a severe drought that produced unusually low flows and high water temperatures in the river.

The reach downstream of St. Louis (the other major metropolitan area on the Mississippi) and the Illinois River downstream of Chicago (see Chapter 14) also have suffered the effects of sewage discharges. St. Louis began using the river for municipal waste disposal in 1850 when cholera epidemics swept the city (Corbett 1997). The river near St. Louis also has received slaughterhouse waste and industrial discharges. An estimated 300 tons (270 metric tons) of ground garbage was dumped into the river daily in 1957 (Missouri Department of Natural Resources 1994). Earlier, the Bi-State Development Agency (1954) reported the hazard of bacterial contamination was increasing steadily and sewage sludge deposits and oil pollution (including oily mud) were evident along the shore of the river for more than 90 miles (145 km) downstream. The agency also reported that commercial fishermen downstream of St. Louis complained of reduced catches as well as taste and odor problems that rendered their catches unmarketable.

Raw sewage discharge from St. Louis and surrounding areas continued until 1970 when the first of two major treatment plants was opened by the Metropolitan Sanitary District (Corbett 1997). Water quality in this reach has since improved in response to wastewater treatment. The last large primary treatment facility was upgraded to secondary treatment in 1993 (Missouri Department of Natural Resources 1994). On the other hand, environmental studies in the Unimpounded Reach have been of such short duration or have covered so few sites, that long-term and widespread trends in water quality are difficult to assess.

The Long Term Resource Monitoring Program (LTRMP) data for 1988–93 do not show the effects of gross sewage pollution so evident earlier in this century. In reaches upstream of St. Louis monitored by the LTRMP, oxygen concentrations, particularly in the main channel, are close to saturation (defined as the maximum concentration in equilibrium with the atmosphere). In the main channel below the Missouri River confluence, oxygen concentrations are higher than the level generally considered marginal for most aquatic biota (i.e., 5 ppm or milligrams per liter, mg/L), yet are significantly below saturation (median concentration = 80 percent of saturation). Likewise, subsaturated oxygen values are seen in the Illinois River near Havana, Illinois (median concentration = 72 percent of saturation). In all the LTRMP data, measured dissolved oxygen concentrations less than 5 ppm (mg/L) were uncommon in 1988–96. During these years, 6 percent of all oxygen measurements were below

Zebra Mussels

Existing problems that stem from inadequate dissolved oxygen in the Upper Mississippi River System (UMRS) could be worsened by the exotic zebra mussel (*Dreissena polymorpha*), which has invaded the river and expanded its range and abundance since 1991 (Cope et al. 1997; see Chapter 11). Densities exceeding 25,000 zebra mussels per square yard (30,000 per square meter) have depleted dissolved oxygen in reaches of the Seneca River in New York (Effler and Siegfried 1994), the Illinois River (Sparks et al. 1994), and most recently, in UMRS Pools 9 and 10 (Kurt Welke, Wisconsin Department of Natural Resources, Prairie du Chien, Wisconsin, personal communication). In the Illinois River, oxygen declined to 1.5 ppm (mg/L), an insufficient concentration for many native aquatic animal species (see Chapter 14). This invasive species also affects water quality by filtering small particles from water, including suspended clay, silt, bacteria, phytoplankton, and small zooplankton (MacIsaac 1996, Silverman et al. 1996, Roditi et al. 1996), thus reducing turbidity and increasing water clarity (Effler et al. 1996, MacIsaac 1996). In the Seneca River, water-quality alterations attributed to zebra mussels have included reduced concentrations of total chlorophyll and increased concentrations of soluble-reactive phosphorus and ammonia (Effler et al. 1996), changes that indicate modified food webs.

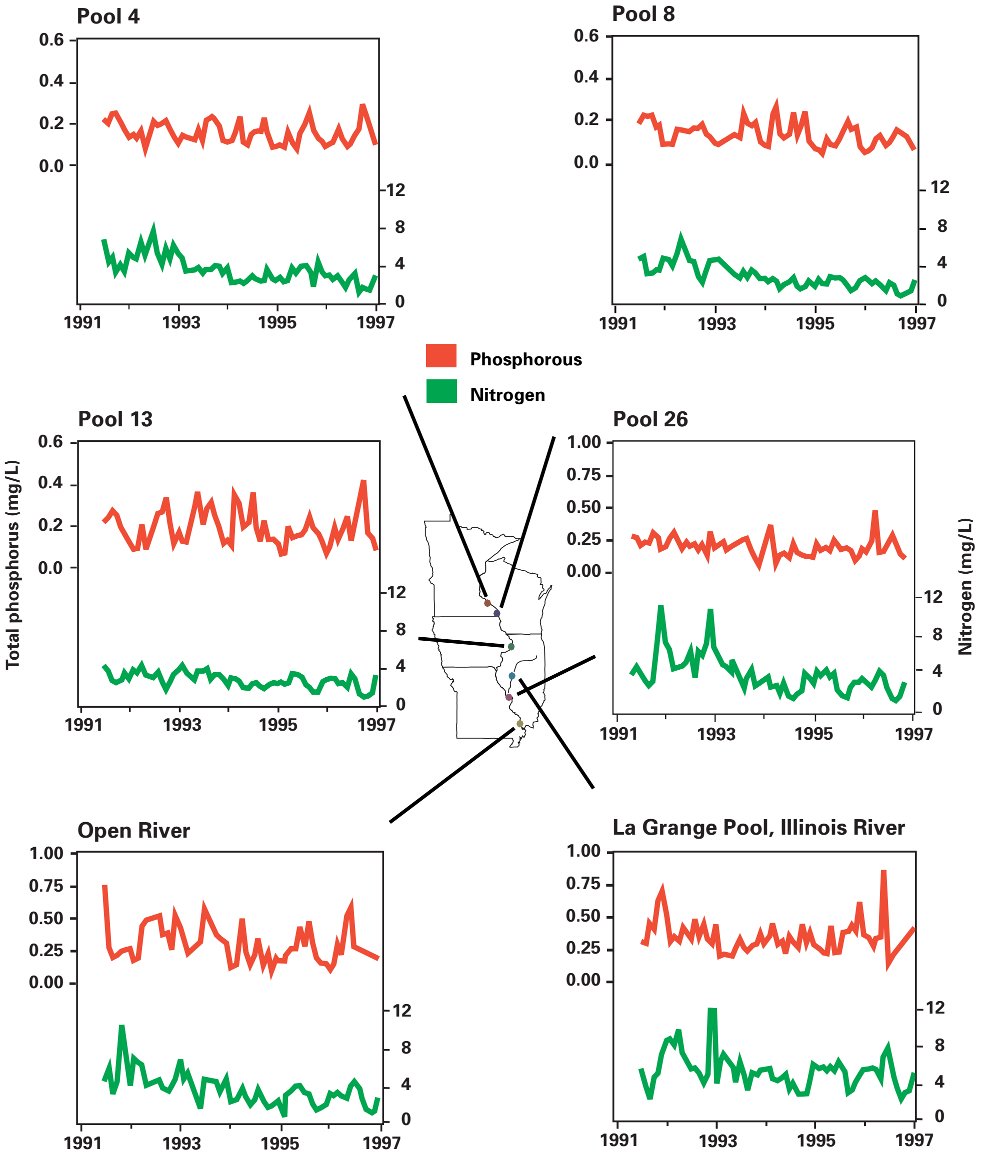

Figure 7-3. The Long Term Resource Monitoring Program monitors selected main-channel and impounded sites in the Upper Mississippi River System. Monthly average concentrations (measured in milligrams per liter, mg/L) of nitrogen and phosphorus show seasonality and discharge effects.

5 ppm (mg/L), and fewer than 1 percent were 1 ppm (mg/L) or less. Extremely low and high oxygen concentrations were found primarily in off-channel locations with low current velocities (LTRMP unpublished data).

Daily variations (from early morning minima to mid-day maxima) in dissolved oxygen concentration are driven by the balance among photosynthesis, by algae and other aquatic plants, by oxygen consumption in respiring organisms, and by exchange with the atmosphere. The LTRMP oxygen data show the greatest variations during late summer in off-channel areas. In winter, oxygen conditions can change quickly in both space and time beneath ice cover. Solid ice cover is uncommon in the southern portions of the river downstream from Keokuk, Iowa (Pool 19), but in the reaches upstream from the Quad Cities (Pool 14), low oxygen concentrations are sometimes observed beneath the ice in off-channel areas that receive little or no flow. Because monitoring by the LTRMP and others has emphasized mid-day readings; it should be cautioned that LTRMP dissolved oxygen data are probably near daily peak concentrations. Daily minimum oxygen concentrations, which tend to occur near sunrise, are not represented in the LTRMP database.

Major Plant Nutrients

Agricultural fields, animal feedlots, and urban areas are principal sources for plant nutrients that enter the river (Goolsby et al. 1993; Mueller et al. 1993; Follett 1995; Mueller and Helsel 1996), and much of the Upper Mississippi River Basin is farmed and fertilized intensively (Goolsby et al. 1993; Lander and Moffitt 1996; also see Chapter 4). As a result, the UMR carries moderate to high concentrations of nitrogen and phosphorus. The LTRMP data confirm that concentrations of these constituents vary with the season and discharge (Figure 7-3) as well as among the reaches and years. Data from two U.S. Geological Survey cruises (Figure 7-4), the National Stream Quality Accounting Network (Alexander et al. 1996), and the LTRMP (Table 7-2) show a substantial difference in nutrient concentrations among the tributaries.

Excessive nutrient inputs to lakes and rivers can alter the flora and fauna and produce a host of negative effects, including noxious algal blooms that cause taste and odor problems (Hutchinson 1973; Vallentyne 1974; Goldman and Horne 1983; Wetzel 1983). Moreover, it is possible that plant nutrients, particularly nitrogen, exported from the Upper Mississippi River Basin (Goolsby et al. 1993) may contribute to degraded water quality and biotic declines in the Gulf of Mexico (Turner and Rabalais 1994; Rabalais et al. 1996; Sen Gupta et al. 1996).

Enrichment of the river with nitrate (NO_3^-) creates an added concern: some municipalities rely on the river for drinking water, therefore high nitrate concentrations can have an adverse affect on health, particularly of infants (Muchovej and Rechcigl 1994;

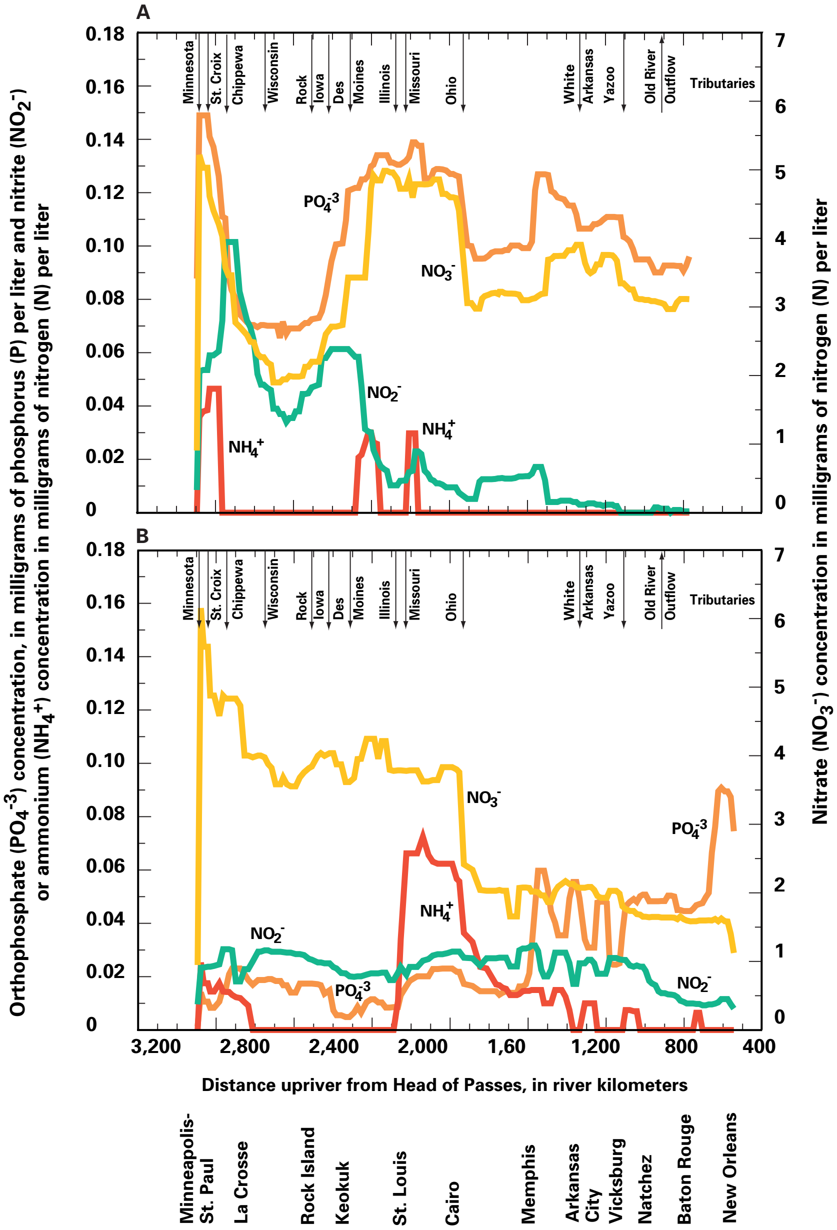

Figure 7-4. Results of nutrient analyses of water samples from the U.S. Geological Survey's river sampling cruises in (A) summer 1991 and (B) early spring 1992. Nutrient concentrations were influenced by a variety of factors, including proximity to urban areas, land use in the basin and tributary inputs. See text for discussion. Reprinted from Antweiler et al. (1995).

Follett 1995). Nitrate moves freely between surface water and groundwater (Muchovej and Rechcigl 1994; Follett 1995) so shallow wells are contaminated easily. The U.S. Environmental Protection Agency (EPA) maximum contaminant level (to protect human health) for nitrate-nitrogen in domestic water supplies is 10 ppm (mg/L; USEPA 1991). Nitrate concentrations in the Upper Mississippi River typically are high (2–3 mg/L) and occasionally exceed 10 ppm (mg/L). Data from Goolsby et al. (1993) and the LTRMP indicate that the extreme floods of 1993 transported large amounts of nitrate from the basin to the Gulf of Mexico.

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Ammonia

Ammonia is produced during the decomposition of nitrogen-containing organic matter. It is an important nutrient for aquatic plants but can be toxic to aquatic animals. Ammonia has been implicated in die-offs of fingernail clams in both the Illinois River (see Chapter 14) and in the upper reaches (Pools 2–19) of the Upper Mississippi River (Wilson et al. 1995). In water, ammonia exists in un-ionized (NH_3; ammonia) and ionized (NH_4^+; ammonium) forms. Un-ionized ammonia is toxic to aquatic animals and can harm fish and aquatic invertebrates at concentrations as low as 0.02 ppm (mg/L; USEPA 1986).

The relative abundance of both un-ionized and ionized ammonia is controlled by pH and to a lesser extent temperature. In pH-neutral or acidic water, the less toxic ionized form dominates. However, the relative abundance of the toxic un-ionized ammonia increases markedly with a higher pH (more basic). For example, un-ionized ammonia composes 3 percent of total ammonia at pH 8 and 50 percent at pH 9 (USEPA 1986).

Photosynthesis by algae and aquatic plants, especially in summer, can increase the pH of river water to 9 or greater (Dawson et al. 1984, LTRMP unpublished data). At such high pH, even low total concentrations of ammonia can be toxic. Decomposing organic matter in the sediment can be a significant source of ammonia; and total ammonia concentrations between 1 and 10 ppm (mg/L; as nitrogen) are not uncommon in sediment pore waters (Frazier et al. 1996). Given such high concentrations of total ammonia, the un-ionized fraction could have an adverse affect on burrowing organisms exposed to sediment pore water (e.g., Ankley et al. 1990), but the long-term impact from brief toxic episodes on the river's benthic fauna has not been evaluated adequately.

Ammonia is a source of energy and nitrogen for bacteria. Algae and other aquatic plants will use ammonia rapidly as a nitrogen source. In the presence of oxygen, ammonia is converted readily to nitrite, nitrate, and various organic forms of nitrogen. Consequently, ammonia concentrations usually are low in well-oxygenated surface water with a healthy microflora and warm temperatures. Elevated ammonia levels in oxygenated river water—especially during warm weather—suggest the presence of a nearby ammonia source, such as sewage discharge, untreated run-off, or nitrogen-enriched, organic sediments.

Sewage effluents from the Twin Cities metropolitan area increase ammonia concentrations in the river (Maschwitz 1984). During 1977–1991, concentrations of total ammonia and un-ionized ammonia at 11 stations in Pools 1 through 19 were greatest near the Twin Cities and decreased with distance downstream (Metropolitan Waste Control Commission 1990; J. F. Sullivan, Wisconsin Department of Natural Resources, La Crosse, Wisconsin, personal communication). In this reach, total concentrations of ammonia were greatest in winter, whereas concentrations of un-ionized ammonia (the more toxic form) were greatest in summer.

Suspended Material, Turbidity, and Sedimentation

Many large rivers, particularly those draining basins with erodible soils or extensive agriculture, carry moderate to high concentrations of suspended material (Meade et al. 1990). Sediment loads in many North American rivers have been increased markedly by certain human activities, particularly row crop farming, timber harvesting, surface mining and urban development (Meade et al. 1990; Waters 1995). The discharge of sediment from many tributaries to the Upper Mississippi River, exclusive of the Missouri River, has increased substantially over presettlement rates (Knox et al. 1975; Knox 1977; Demissie et al. 1992). In addition, many environmental contaminants are adsorbed strongly onto suspended particles. The transport and fate of such contaminants are therefore, physically linked to that of suspended material.

The Upper Mississippi River transports moderate to high quantities of sediment. Moving downriver, the concentration of suspended materials increases and the Upper Mississippi becomes more turbid as tributary streams that drain agricultural watersheds enter the river, particularly in the reach downstream of Pool 13 (Table 2; Nielsen et al. 1984). Just upstream from St. Louis, the Missouri River joins the Upper Mississippi River from the west. The Missouri River Basin contains highly erodible soils and the Missouri River has long been the major source of sediment for the Mississippi River (Meade and Parker 1985; Meade et al. 1990). Construction of a series of large dams in the Missouri River Basin in the 1950s and 1960s created deep cold-water reservoirs that trap sediment and have reduced the Missouri's total contribution of sediment to the Mississippi by more than half since 1953 (Meade et al. 1990).

Pools in the Upper Mississippi River created by navigation dams clearly have accumulated sediment since their construction in the 1930s (Bhowmik et al. 1988). In addition, large amounts of sediment have been stored in the banks and beds of tributaries during the past century, providing a potential source of sediment to the main stem river for decades (Knox 1977; Demissie et al. 1992). Movement of sediment in the river and the effects of the dams on this movement are complex and poorly understood. Many deep (low elevation) areas on the floodplain rapidly filled with sediment after they were inundated permanently by navigation dams (Rogala and Boma 1996). Conversely, since impoundment for navigation, much fine sediment also has been resuspended by wind and wave action from shallow areas and removed (i.e., transported downstream) during high-flow events.

Sediment deposited on the floodplain above the regulated water level is not subjected to wind-driven resuspension and transport during the subsequent low-water period. Consequently the floodplain is a significant site of sediment accumulation (Beach 1994). Compared to permanently inundated sediment, the drying and compaction of sediments deposited on the floodplain might make them more resistant to resuspension when floodwaters return. An occasionally inundated floodplain may trap sediment more efficiently than the shallow, rapidly flushed impoundments formed by navigation dams. But we do not know whether the impounded Upper Mississippi River is accumulating more or less fine sediment within its total floodplain than it did as a free-flowing river.

As large quantities of sediment continue to enter the river, permanently inundated areas may be converted to shallow, sandy deltas or silty marshes. The progress of this conversion in space and time is uncertain, however, because (1) unpredictable large floods, such as the flood of 1993, can reverse

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Figure 7-5. The Minnesota River (shown in panel A entering the Mississippi River via the bottom channel) carries a sediment load consisting mainly of clay and silt and is a significant source of the sediment that accumulates in Lake Pepin. The other major tributary above Lake Pepin is the St. Croix River (shown at the top of panel B entering the Mississippi River under the bridge), which flows through sandy glacial till and consequently transports little sediment (Source: Long Term Resource Monitoring Program aerial photograph library).

depositional patterns that occur during decades-long periods between major floods (Rogala and Boma 1994), (2) tributaries differ in sediment-delivery characteristics (Figure 7-5), some not yet quantified, and (3) movement of sediment throughout the river has never been examined in detail. Last, future human activity could either accelerate or slow the processes of sediment delivery and sediment deposition within a given reach and time interval.

Turbidity is defined as the loss of water transparency that results from the scattering of light by suspended materials. Many species of aquatic organisms have adapted to moderate turbidity. Moreover, suspended particles are a source of food (or nutrients) for some species. Excessive amounts of suspended sediment, however, are harmful to many aquatic organisms and can degrade

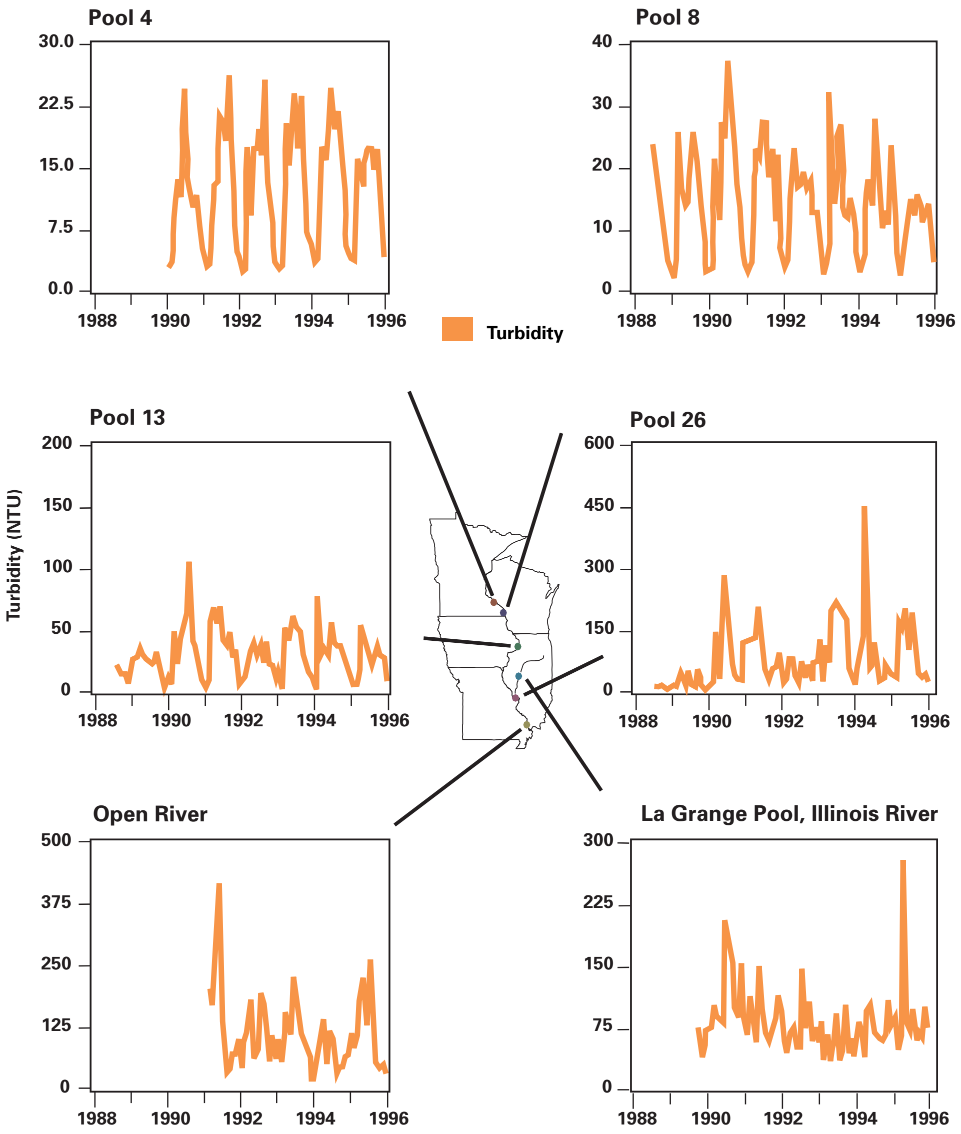

Figure 7-6. Monthly averages of turbidity as measured in nephelometric turbidity, units (NTUs) at impounded or main-channel sites in the six study reaches of the Long Term Resource Monitoring Program. These averages show strong seasonal patterns and longitudinal trends (note differing vertical scales on the graphs).

stream and riverine ecosystems (Castro and Reckendorf 1995; Waters 1995). Data from the LTRMP show a strong seasonal pattern in turbidity (Figure 7-6), as well as annual differences in turbidity and suspended solids among study reaches (Figure 7-7, following page). No consistent long-term trend in turbidity across the entire Upper Mississippi River System has been found in the LTRMP data (Soballe *in press*).

Suspended material—consisting largely of silt, clay, and organic matter—decreases the light available to algae and rooted aquatic plants and can affect organisms that must see to locate prey, avoid predators, or find other members of their species to mate or care for offspring (Waters 1995). Turbidity and suspended solids may have affected the abundance of aquatic plants in certain reaches of the river. Submersed aquatic plants declined abruptly along much of the Upper Mississippi River during the drought years of the late 1980s (Wiener et al. 1998). The cause of this decline is uncertain, but nutrients (Rogers et al. 1995), phytoplankton, and light availability (Kimber et al. 1995; Owens and Crumpton 1995) possibly contributed to the problem.

Suspended material, consisting largely of silt, clay, and organic matter, decreases the light available to algae and rooted aquatic plants.

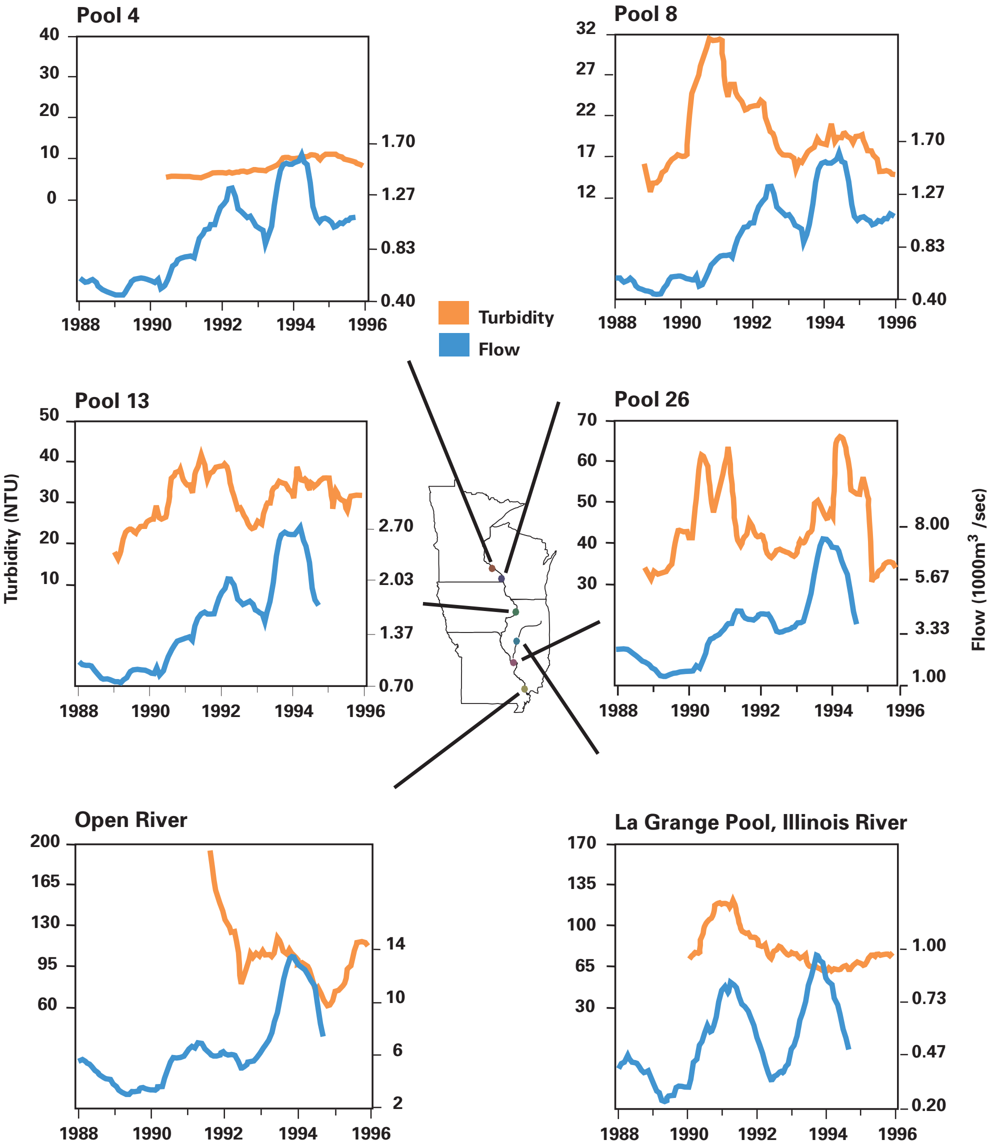

Figure 7-7. This figure illustrates the 12-month moving average of turbidity as measured in nephelometric turbidity units (NTUs) and flow measured in thousands of cubic meters per second at impounded and main-channel sites in the six study reaches of the Long Term Resource Monitoring Program. These averages exhibit long-term patterns in turbidity that differ among regions but suggest peaks in the early and mid-1990s (note the differing vertical scales on graphs).

A recent increase in submersed vegetation in Pool 8 has been accompanied by a steady decline in turbidity in that pool.

It is evident that re-establishment and recovery of aquatic vegetation has been hindered by limited light availability in the turbid backwaters (Kimber et al. 1995; Owens and Crumpton 1995). A recent increase in submersed vegetation in Pool 8 has been accompanied by a steady decline in turbidity in that pool (Figure 7-7).

Environmental Contaminants

Water and sediments in the Upper Mississippi River contain organic and inorganic contaminants that have originated from agricultural, industrial, municipal, and residential sources since European settlement and development of the basin (Meade 1995). These contaminants include heavy metals (such as cadmium, lead, and mercury), pesticides, (herbicides, insecticides, and fungicides), many synthetic organic compounds including polychlorinated biphenyls (PCBs), and numerous other chemicals (Meade 1995). Heavy metals occur naturally in the environment; however, human activity has increased the abundance of certain metals in surface waters and sediments (Foster and Charlesworth 1996). Significant amounts of contaminants enter the Upper Mississippi

River in wastewater effluents and urban runoff from the Twin Cities, Quad Cities, and St. Louis metropolitan areas (Boyer 1984). The Illinois River receives contaminants from Chicago and Peoria.

Recent analyses of contaminants associated with municipal waste waters (Barber et al. 1995) show that sewage effluents affect both water and sediment quality in the river. One mixture found in municipal effluents is linear alkylbenzene sulfonate (LAS), a common anionic surfactant; 88 percent of all LAS manufactured is used in domestic detergents (Malcolm et al. 1995; Tabor and Barber 1996); LAS was ubiquitous in sediments taken from the river during 1991–92; in water, concentrations of dissolved LAS were greatest in samples taken downstream from major metropolitan areas, particularly Minneapolis-St. Paul and St. Louis (Barber et al. 1995; Tabor and Barber 1996).

Coprostanol is a nonionic, nonpolar organic compound present in the fecal matter of higher animals (including humans and livestock) that can be used as an indicator of sewage contamination from municipal effluents and agricultural feedlot runoff (Writer et al. 1995). Like LAS, coprostanol was found in all sediment samples taken from the Upper Mississippi River, indicating widespread sewage contamination. Concentrations of coprostanol were greatest in samples taken downstream from large metropolitan areas, particularly Minneapolis-St. Paul and St. Louis (Writer et al. 1995).

The river also has been contaminated by industrial wastes, although inputs of many industrial pollutants have diminished since stricter national water quality regulations were enacted in the early 1970s (Rostad et al. 1995). The presence of PCBs (a class of stable industrial chemicals) in the river can be attributed largely to industrial sources. Within the Impounded Reach of the Upper Mississippi River, concentrations of PCBs in sediments sampled during 1991–92 and in emergent burrowing mayflies sampled during 1988 (Figure 7-8) were highest in the reach from the Minneapolis-St. Paul metropolitan area through Lake Pepin in Pool 4 (Steingraeber et al. 1994; Rostad et al. 1995). Concentrations of PCBs in sediment and emergent mayflies were much smaller in samples taken downstream from Lake Pepin (Steingraeber et al. 1994; Rostad et al. 1995), which traps particles and associated contaminants from upstream sources. In the reach downstream from Lake Pepin, PCB concentrations were greatest in pools with human communities, particularly the combined Rock Island-Moline, Illinois-Davenport-Bettendorf, Iowa, metropolitan area, where a known point source of PCBs has contaminated Pool 15 (Steingraeber et al. 1994).

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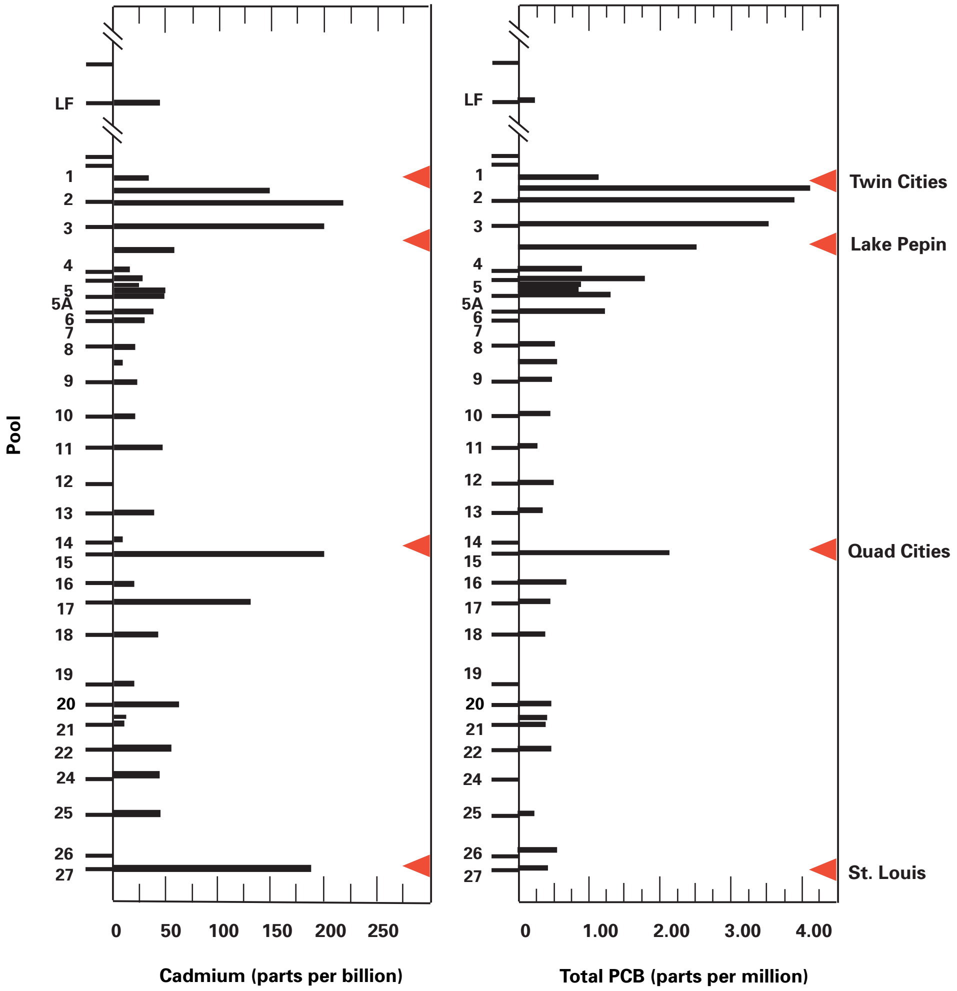
Some environmental contaminants are toxic and can cause stress, injury, or death in aquatic organisms. Thus, the pollution of aquatic ecosystems with toxic contaminants can greatly diminish habitat suitability. Some metals (e.g., copper, zinc) are essential to living organisms but can be toxic at high concentrations, whereas others (e.g., cadmium, lead, mercury) are nonessential and toxic at relatively low concentrations.

Certain contaminants, such as PCBs and methylmercury, readily accumulate in aquatic organisms and can biomagnify to high concentrations in organisms near or at the top of aquatic food webs—with adverse consequences (Rasmussen et al. 1990; Wiener and Spry 1996). Contamination of the riverine food web with PCBs is the probable cause of the precipitous decline in populations of mink on the Upper Mississippi River National Wildlife and Fish Refuge during 1959–65 (Dahlgren 1990; Wiener et al. 1998). The partial recovery of mink populations that began in

Figure 7-8. Contamination of the Upper Mississippi River with polychlorinated biphenyls (PCBs) and cadmium exhibits a pronounced spatial gradient downstream from the Minneapolis-St. Paul metropolitan area. Concentrations of these contaminants in emergent mayflies, which inhabit burrows in soft bottom sediment as nymphs, are generally greater in Pools 2, 3, and 4 (Lake Pepin) than in pools downstream from Lake Pepin. Reprinted with permission from Steingraeber and Wiener (1995).



Distribution and transport of certain environmental contaminants are linked closely to suspended material.

the late 1970s coincided with a period of declining PCB levels in fish (Hora 1984; Sullivan 1988; Biedron and Helwig 1991). In 1989–91, PCB concentrations in carcasses of mink from the Upper Mississippi River in Minnesota averaged 0.26 parts per million (microgram per gram) wet weight, exceeding concentrations in mink from all other areas of Minnesota except Lake Superior (Ensor et al. 1993). This and other recent studies (Steingraeber et al. 1994; Rostad et al. 1995) indicate that PCBs continue to enter into or cycle within the river and its aquatic food web.

Contaminant-Sediment Interactions

Distribution and transport of certain environmental contaminants are linked closely to suspended material (Rostad et al. 1995; Foster and Charlesworth 1996; Balogh et al. 1996; Rostad 1997). Many toxic contaminants do not dissolve readily in water, but adhere to small sediment particles that can be transported far downstream before depositing into quiescent riverine lakes, backwaters, and pools. A detailed study of PCB congeners in emergent mayflies sampled in 1988, for example, indicated that PCBs were transported more than 200 miles (320 km) downstream from sources along Navigation Pool 2 (Steingraeber and Wiener 1995).

Lake Pepin, situated in Pool 4 of the Upper Mississippi River about 45 to 75 miles (75 to 110 km) downstream from the Twin Cities metropolitan area, traps sediment and associated contaminants

(McHenry et al. 1980; Rada et al. 1990; Maurer et al. 1995). This decreases the transport of potentially harmful pollutants from the Twin Cities, the Minnesota River Basin and other upstream sources into the reach of the river downstream from Lake Pepin. Indeed, concentrations of PCBs and certain metals in fish, burrowing mayflies (Figure 7-8) and fine-grained sediment generally are greater in the reach from the Twin Cities through Lake Pepin than in the reach downstream from the lake (Bailey and Rada 1984; Dukerschein et al. 1992; Steingraeber et al. 1994; Beauvais et al. 1995; Meade 1995; Rostad et al. 1995; Sullivan 1995).

Aquatic organisms can be exposed to adsorbed contaminants through contact with sediment resuspended in the water column or deposited on the bottom. Use of bottom sediment as spawning substrate by fish, for example, may expose sensitive young to potentially toxic substances in the sediment. Bottom sediments in extensive reaches of the Upper Mississippi are contaminated with cadmium, copper, chromium, lead, mercury, zinc, and PCBs (Rada et al. 1990; Beauvais et al. 1995; Garbarino et al. 1995; Rostad et al. 1995). For example, cadmium concentrations in sediment from 12 sites extending from Pools 2 through 16 ranged from 1.2 to 3.2 ppm (µg/g) dry weight, 4 to 10 times greater than the estimated natural abundance of 0.2 to 0.3 ppm (µg/g) (Beauvais et al. 1995). No specific guidelines have yet been established by the EPA for heavy metals associated with bed or suspended sediments (Garbarino et al. 1995). It is evident, however, that sediment toxicity can persist for years or decades, greatly hampering ecological recovery or restoration (see Chapter 14).

Pesticides

Much of the Upper Mississippi River Basin is intensively cultivated (Antweiler et al. 1995; see Chapter 5) and the entire navigable reach of river receives a complex mixture of agricultural chemicals and their degradation products (Pereira and Hostettler 1993). Most pesticides used in the upper basin are herbicides used for weed control, particularly in the production of corn and soybeans. The Upper Mississippi River Basin upstream of the confluence with the Missouri River contributes 40 to 50 percent or more of the load of many pesticides found in the Mississippi River, even though it represents only 22 percent of the flow from the entire Mississippi River Basin (Goolsby and Pereira 1995). These chemicals enter tributary streams in both contaminated surface runoff and groundwater (Pereira and Hostettler 1993). The tributary streams act as point sources of agricultural chemicals to the main stem Mississippi River (Pereira and Hostettler 1993; Goolsby and Pereira 1995). The Minnesota and Des Moines rivers, for example, are the primary contributors of the herbicides alachlor, cyanazine, and metolachlor to the entire Mississippi River main stem (Pereira and Hostettler 1993).

Concentrations of the three major triazine herbicides (atrazine, cyanazine, and simazine) in the Upper Mississippi River are greatest near the confluences of the Iowa, Des Moines, Illinois, and Missouri Rivers (Pereira and Hostettler 1993; Figure 7-9, following page). Average concentrations of herbicides in water from the main stem Mississippi River during 1987–92 did not exceed the maximum contaminant levels of drinking-water standards established by the EPA (Goolsby and Pereira 1995). After herbicide application in early summer 1990 and 1991, however, periodic maximum concentrations of atrazine temporarily exceeded maximum concentration levels (Figure 7-9). Estimated total quantities (loads) of herbicides transported in waters of the Upper Mississippi River and its

Much of the Upper Mississippi River Basin is intensively cultivated and the entire navigable reach of river receives a complex mixture of agricultural chemicals and their degradation products.

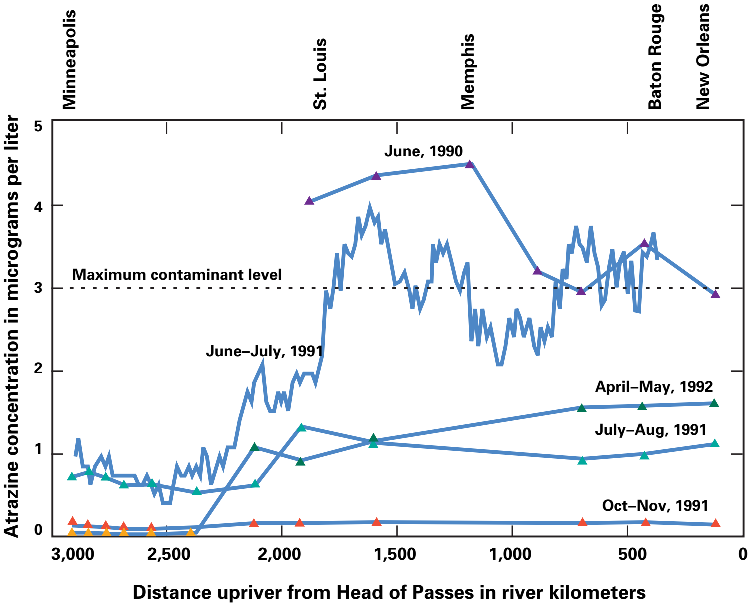


Figure 7-9. Concentrations of the herbicide atrazine (micrograms per liter) in water sampled from the Mississippi River during five different cruises by the U.S. Geological Survey. Atrazine concentrations in the river increased downriver because of inflows from tributaries draining watersheds in the corn belt. Discrete points connected by straight-line segments represent samples taken in downstream sequences. The continuous line labeled "June-July 1991" represents samples collected at 10-mile (16 km) intervals in upriver sequence. Concentrations were greatest in samples collected during June and July, soon after the application of atrazine in the basin. Reprinted from Goolsby and Pereira (1995).

tributaries during April 1991 through March 1992 were generally less than 3 percent of the total quantities of herbicides applied annually in the basin (Goolsby and Pereira 1995).

Discussion

In some ways water quality in the Upper Mississippi River has improved in recent decades. Gross pollution by domestic sewage, for example, has been reduced since passage of the Federal Water Pollution Control Act of 1972 mandated secondary treatment of sewage effluents. However, the river continues to receive an array of contaminants from agricultural, industrial, municipal, and residential sources. The risks and threats of many of these contaminants to the biota of this riverine ecosystem are largely unknown.

All reaches of the Upper Mississippi River are contaminated with a complex mixture of agricultural chemicals and their degradation products (Pereira and Hostettler 1993; Goolsby and Pereira 1995). Mean concentrations of herbicides in water from the main stem Mississippi River during 1987–92 did not exceed maximum contaminant level values for drinking water (Goolsby and Pereira 1995). However, it is unclear whether agricultural chemicals and their degradation products adversely affect biological communities in the river. For example, the responses of submersed aquatic plants to inflows of herbicides after spring and summer storms are unknown.

The riverine ecosystem seems to be threatened by nutrients from nonpoint and point sources. It is possible that toxic conditions in the sediment have contributed to recent widespread declines of fingernail clams in the Upper Mississippi River (Wilson et al. 1995). Fingernail clams are sensitive to un-ionized ammonia (Sparks 1984), which may reach toxic concentrations in the sediments during low-flow conditions in summer (Frazier et al. 1996). Changes in nutrient and sediment exported from the Upper Mississippi River Basin to the Gulf of Mexico may be having an adverse affect on the Gulf ecosystem.

Concentrations of dissolved heavy metals in the Upper Mississippi River are considerably less than U.S. Environmental Protection Agency's guidelines for maximum concentrations in drinking water and in water supporting aquatic life (Garbarino et al. 1995). However, concentrations in suspended and deposited sediments often exceed maximum contaminants levels (Garbarino et al. 1995), and toxic substances accumulated in the bed sediments could remain a potential problem for decades. In particular, contaminated fine-grained sediments deposited during the past century into Lake Pepin and other depositional sites downstream from metropolitan areas along the river represent a huge reservoir of potentially available toxic substances, posing a continuing hazard to riverine biota. Juvenile bluegills exposed for 28 days to 1 g/L of resuspended sediment from Lake Pepin suffered 24 percent mortality, but the toxic agent in the sediments was not identified (Cope et al. 1994).

Lack of suitable winter habitat is a potential threat to many popular backwater sport fishes (e.g., bluegill, crappies, largemouth bass) in ice-covered, northern reaches of the Upper Mississippi River. Continued exposure to water temperatures near 32° F (0° C) can be stressful or lethal to many backwater fishes (Sheehan et al. 1990; Bodensteiner and Lewis 1992). Knights et al. (1995) found that bluegills and black crappies require areas with a water temperature that exceeds 34° F (1° C), current velocity below 0.4 inches per second (1 cm per second), and dissolved oxygen above 2 ppm (mg/L). Sites meeting these requirements are few, based on analysis of LTRMP water-quality data taken during winter; for example, less than 5 percent of the total area in Pools 4, 8, and 13 seem to provide tolerable habitat for fish during some winters (Figure 7-10, following page). Whether this small amount of winter habitat is limiting for certain fishes is not known.

Human activity has increased the rates of sediment delivery and deposition within the Impounded Reach of the Upper Mississippi River (Knox et al. 1975; Knox 1977; Demessie et al. 1992), and suspended and deposited sediments have affected this ecosystem in various ways. Many areas supported dense beds of aquatic plants before an abrupt decline in the late 1980s. Reestablishment and recovery of submersed aquatic vegetation in these areas has been hindered by inadequate light penetration caused by turbidity and suspended solids (Kimber et al. 1995; Owens and Crumpton 1995; Wiener et al. 1998). A variety of water depths and current velocities support a more diverse biological community by providing suitable habitats for an array of fish and wildlife species with differing habitat requirements (Littlejohn et al. 1985; Korschgen et al. 1988; Fremling et al. 1989; Korschgen 1989). Over time, however, the combined processes of erosion and sedimentation have diminished the diversity of water depths in the Upper Mississippi River (LTRMP bathymetric database). The conversion of backwater lakes and marshes to shallow, turbid mud flats in the Illinois River has caused the loss and ecological degradation of many backwater lakes and adversely affected habitat quality and quantity for many fish and wildlife species (see Chapter 14).

Reduction in sediment inputs to the impounded Upper Mississippi River could retain fertile soil in agricultural fields and reduce entry of sediment and associated contaminants (e.g., Balogh et al. 1996) into the river.

Water quality in the Upper Mississippi River has improved in recent decades. However, the river continues to receive an array of contaminants from agricultural, industrial, municipal, and residential sources.

Information Needs

Decision makers and resource managers attempting to enhance, maintain, or restore aquatic habitats within the river require information on water and sediment quality. In the short term, managers need information on problems and problem areas and the capability to predict whether improvements can be achieved through remedial or regulatory actions. Large-scale management of aquatic habitat will require information and long-term forecasts on the physical structure (morphometry) of the riverine ecosystem, along with information on the habitat requirements of plants and animals. Development of models capable of predicting responses of water quality and sediment to potential management actions will

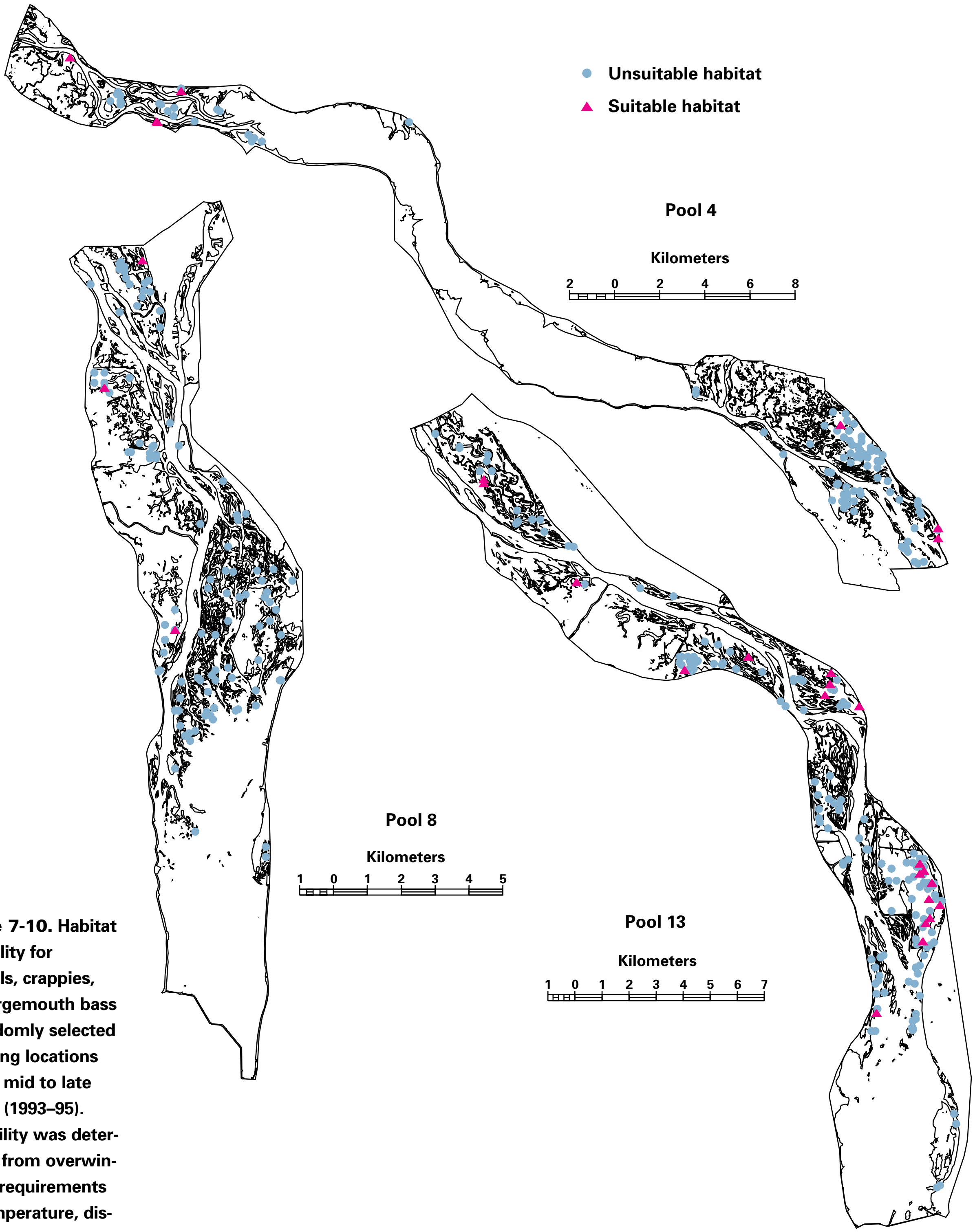


Figure 7-10. Habitat suitability for bluegills, crappies, and largemouth bass at randomly selected sampling locations during mid to late winter (1993–95). Suitability was determined from overwintering requirements for temperature, dissolved oxygen, and water velocity published for these species (Source: Long Term Resource Monitoring Program database).

require accurate information on sediment dynamics and geomorphological processes, as well as focused communication and collaboration between scientists and resource managers.

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