The Ecological State of the UMRS 2

INTRODUCTION

The purpose of this chapter is to describe the ecological state of the UMRS.[1] In the context of the EMP, this description is necessary to evaluate the current program's monitoring, research, and habitat restoration activities, as well as the identification of future system needs. From a broader perspective, an assessment of the UMR ecosystem should inform the river community, in a scientifically objective and responsible way, about the system's condition.

Describing the river's ecological status requires a scientific understanding of how the river should function as an ecosystem and as a part of its basin. This understanding helps to select a working set of ecosystem features or criteria that function like "subjects" on a student's report card.

The process requires consistent observations of the river's habitats and species, how they vary over time, and how they are impacted by natural processes and human activity. The following description is heavily dependent on results of the LTRMP, although other relevant data also have been used in its development.

The river reaches of the UMRS and their basins have been extensively altered by human use (Yin *et al*., 1997; Nelson *et al*., 1994; Yin and Nelson, 1996). As a result, none of the reaches support the same species or habitats, in the same proportions that they did in their natural state (Theiling, 1996; Duyvejonck, 1996). Defining the status or "health" of such altered systems is made more difficult by the fact that different river users value different ecosystem related conditions.

[1] Due to its significantly modified condition, the highly urbanized upper reach of the Illinois River is not considered in the context of this report chapter.

At least one of the major alterations, impoundment for navigation, increased aquatic habitats and habitat diversity that were and still are considered from certain perspectives to be beneficial. In the eyes of many river users, the first few decades after impoundment represented an optimal river state that now should be used as a gage against which to measure river health. Altered geomorphic conditions resulting from impoundment, however, prevent this "optimal river state" from being maintained.

Much of the upper impounded river reach of the Mississippi River still retains many important river species and habitats and, for the time being, is considered to be ecologically healthy. However, conditions at even the most healthy sites within the UMRS are at least partially artificial, non-sustainable, and in a recognized state of degradation. Continued and progressively increasing human energy and resources will be needed to maintain current or restore past levels of ecological health to "acceptable" levels. Ultimately, the river community collectively defines what an acceptable level of ecological health is, relative to the commercial, recreational, and cultural river uses that the community also values.

RIVER REACHES OF THE UMRS

The Illinois River and Upper Mississippi River make up about 94% (by linear mile) of the UMRS.[2] We refer to separate reaches of the rivers because of their distinctive floodplain structures and because the ecological health of each reach has been impacted differently by human activities. One defining river modification, alignment and maintenance of the navigation channel, has been uniform along the entire length of the Illinois and Upper Mississippi Rivers. The fluvial dynamics once responsible for channel migration across the floodplain, for alternating terrestrial and aquatic phases on the floodplain surface, and for sustaining a diverse array of aquatic habitat types and alluvial forest successional stages have been largely arrested along the entire length of the two rivers. Three reaches of the UMR and the Lower Reach of the Illinois will be the focus of this chapter (Figure 2-1).

The Upper Impounded Reach of the UMR extends from Minneapolis, Minnesota, through Pool 13 at Clinton, Iowa. It is characterized by a narrow floodplain terminating at steep bluffs. Variable floodplain topography created by hydraulic, glacial, and geologic processes, combined with seasonal flooding and dam impacts, create many off-channel permanent and ephemeral aquatic habitats. A unique feature of this reach is that approximately 50% of the floodplain environment is contained within the Upper Mississippi River National Wildlife and Fish Refuge. Land-cover analyses (Laustrup and Lowenberg, 1994) indicate this reach supports higher proportions of non-channel aquatic and marsh area and lower proportions of agriculture and channel area than the two lower reaches. Less than 3% of the floodplain has been isolated by levees.

The Lower Impounded Reach of the UMR lies between Clinton, Iowa, and Pool 26 at Alton, Illinois. Between Clarksville, Missouri, and Alton, Illinois, the average width of the valley floor is 5.6 miles with an average slope of 0.5 foot/mile. Floodplain land use is diverse, including urban areas, conservation lands, and agricultural fields that are protected from moderate floods by levees. Smaller percentages of marsh and backwater habitats occur in this reach. Fifty-three percent of the floodplain has been isolated by levees.

The Unimpounded Reach of the UMR between St. Louis and the river's confluence with the Ohio is structurally different from the upper reaches as a result of both natural and human activities. Missouri River flows have historically contributed significant water and sediment inputs that, before levee construction, sculpted a more dynamic floodplain physiography. In this reach, except for Lock and Dam 27 which includes a diversion canal and a submerged rock weir

[2] See Attachment 1, Water Resources Development Act of 1986, Section 1103(b)(1) for the definition of the UMRS.

at the Chain-of-Rocks Rapids, the 9-foot navigation channel is maintained entirely with channel training structures, side channel closures, and dredging. Much of this reach is isolated (82%) from the river by agricultural levees. Unlike upstream reaches, there is virtually no land contained in the National Refuge System in the Unimpounded Reach.

The Illinois River can also be divided into floodplain reaches based on geomorphic and ecological criteria. The Upper Illinois Reach lies above Starved Rock Lock and Dam. This reach has a steep gradient, narrow floodplain, and is mostly urbanized. It has been greatly impacted by industrial and municipal pollution following the diversion of water from Lake Michigan. Opportunities for habitat rehabilitation along this reach are limited.

The Lower Illinois River reach extends downstream from Starved Rock Lock and Dam to its confluence with the Mississippi River. The Lower Reach is more characteristic of floodplain ecosystems in both form and function than is the Upper reach. The Lower Illinois has a shallow gradient and a wide floodplain. Before recent glacial processes changed the course of the Mississippi River, the Lower Reach of the Illinois River carried the flow of the Mississippi River. Over 60% of the floodplain has been isolated behind levees.

WHAT IS RIVER ECOLOGICAL HEALTH?

Scientists have only recently begun to bridge the gap between the concept of ecosystem "health" and its application to practical natural resource management. Three general ecosystem features, or criteria, have most commonly been recognized for their value in characterizing ecosystem health (Cairns, 1977; Rapport, 1989; Grumbine 1994):

1. The presence of habitats and viable, native animal and plant populations that the ecosystem, if undisturbed, would support;

2. The ability of the ecosystem to return to its pre-existing condition after a disturbance (whether natural or human-induced); and

3. The ability of the ecosystem to sustain itself.

A meaningful discussion of ecological integrity or "health" must be tempered by the realization that the concept does not exist outside of human value judgment. Measurements of integrity or health by scientific means are therefore limited to criteria that are subjectively selected (Serafin and Steedman, 1991). Unique features and processes of floodplain river ecosystems can also be used as criteria for evaluating the health of the UMRS reaches. The following reach-specific ecosystem health criteria were synthesized by a team of river scientists at an LTRMP-sponsored international conference on river ecology in 1994:

4. The reach's capacity to function as part of a healthy basin;

5. The degree to which the annual flood pulse "connects" the main channel to its floodplain; and

6. The ability of infrequent natural events (floods and droughts) to maintain ecological structure and processes within the reach.

The sixth criterion may seem to be at odds with the second. The second refers to an innate ability of a healthy ecosystem to adjust to external factors without permanently changing its overall character. The sixth refers to the presence of infrequent but important external factors that help structure an ecosystem's character over a long period of time. This criterion is less related to the ecosystem *per se* than it is to the external factors that affect the ecosystem.

RIVER REACH ECOLOGICAL HEALTH

This section synthesizes ecological status and trend information from the UMRS according to the six criteria listed above. By far the greatest amount of available information relates to the first criterion, presence of native species and habitats.

Criterion 1. The presence of habitats and viable, native animal and plant populations that the ecosystem, if undisturbed, would support.

Habitats

The development of the commercial navigation system and the construction of agricultural levees represent two river and floodplain modifications that have extensively altered aquatic and terrestrial floodplain habitats within the UMRS. These activities have had varying impacts among the different river reaches.

- **Navigation Channel Training Structures and Impoundments.** Prior to engineering improvements, the floodplains of the UMR were dominated by terrestrial habitats, primarily bottomland forests intersected with braided channels (Figure 2-7). Channel training structures built to create and maintain the 4.5-foot (in 1878) and the 6-foot (in 1907) navigation channel, while not changing the position of the main channel (Chen and Simons, 1986), reduced the river's ability to reshape itself, a dynamic process that, in part, kept its bottomland forests in early successional stages. Closing structures in the Unimpounded Reach of the UMR have substantially reduced available side channel habitat which, while still providing most of the off-channel habitat, now represents less than 5% of the total aquatic area (Figure 2-8).

After the navigation dams were built, low-lying floodplain areas were permanently inundated (Figure 2-2). Floodplains in the lower reaches of the pools were transformed to wide, open water areas in which higher points of land remained as islands. The middle sections of the pools were not as deeply flooded. Old channels and floodplain depressions were flooded to form networks of interconnected side channels and backwaters. Depth diversity resulted in the formation of wetland communities that range from deep water to emergent marsh and floodplain forest communities.

Impoundment initially resulted in an increase in aquatic productivity and species diversity. Aquatic plant species and backwater fisheries flourished. In much of the Upper Impounded Reach of the UMR, these conditions still persist and are indicators of ecological health. However, long term, persistent river forces are changing these conditions.

Two of the most important structural indicators of what is referred to as the "aging pool" response are sedimentation and island loss. Impounded areas and backwaters contiguous with the river have been subject to the effects of impoundment and sedimentation. Physical consequences of these processes include the loss of water depth, island surface area, sediment quality, and bathymetric diversity (Figure 2-3).

Additional studies have suggested that sedimentation rates are lower now than they were immediately after impoundment. The process of sedimentation will continue in impounded areas until they reach a state of sediment equilibrium. As a result of sedimentation analyses, the life spans of many backwaters, critical to the productivity and diversity of the post-impoundment UMRS floodplain ecosystems, have been estimated at less than 100-200 years (Belrose *et al*., 1983; Chen and Simons, 1986).

Post-impoundment river forces have impacted terrestrial habitats within the floodplain. Many islands were created by impoundment, especially in the Upper Impounded Reach of the UMR. Over time, these islands have eroded away. For instance, 624 acres of islands existed in the middle section of Pool 8 in 1939, two years after impoundment. In 1995, only 129 acres remained (Figure 2-3). Such island loss impacts hydrological patterns within the pool, allows wind to resuspend bottom

sediments, and reduces the diversity of habitats available for a variety of wildlife species.

In the Unimpounded Reach of the UMR, the required navigation channel depth has been maintained by dredging and the construction of wing dams that have reduced flows into side channels. The latter was accomplished by constructing closing dams across 23 side channels. An example of the long term habitat change associated with one of these closures is shown in Figure 2-4 **.**

▪ **Levee Construction and Ecological Consequences.** Levee construction began in the UMRS in the late 1800s, first by individual farmers, cooperative levee districts, and local governments. Federal levee construction began on a large scale after World War II. Now, approximately 530,000 acres (53% of the total floodplain) in the lower impounded reach and 543,000 acres (82% of total floodplain) in the Unimpounded Reach of the UMR are located behind the levees. Figure 2-5 provides an example of long term land cover change associated with floodplain agricultural development in the Unimpounded Reach of the UMR. Levee construction along the Lower Illinois River reach sequestered more than 61% (334,000 acres) of the floodplain (Laustrup and Lowenberg, 1994; Figure 2-6).

Agriculture use of the floodplain reduces available bottomland forest and wet meadow habitat; and the levees effectively reduce the flow cross-sectional area (i.e., width of a river reach's flood zone), thereby increasing the heights of flood stages.

▪ **Water and Sediment Quality.** Physical and chemical conditions of UMRS water are generally good now, but there have been periods in which the rivers, especially the Illinois River, were severely degraded by municipal and industrial waste. Recognition of the pollution problem and risk to human health led to interventions by local governments in the early 1900s which continue today under Federal guidelines. Gross pollution by domestic organic waste has been almost entirely eliminated since passage of the Federal Water Pollution Control Act of 1972[3] that limited the quantity or concentration of all sewage effluent discharges. However, the rivers continue to receive a host of agricultural, industrial, and municipal contaminants that threaten their biota.

Concentrations of toxic heavy metals dissolved in river water are well below U.S. EPA guidelines for human consumption and aquatic life (Garbarino *et al.*, 1995). However, concentrations in suspended and deposited sediments often exceed pollution guidelines, and contaminants accumulated in the river's sediments will be a potential problem for decades. Lake Pepin, a natural river lake impounded by alluvial deposits from the Chippewa River, traps sediment, contaminants, and nutrients, and thus reduces the downstream levels of pollutants such as polychlorinated biphenyls, or PCBs, and cadmium. It appears that rates of deposition of toxic metals (e.g., cadmium) to lower Lake Pepin have not diminished. The fine-grained sediments deposited during the past century in Lake Pepin, and presumably into other depositional sites nearer the Twin Cities, are a reservoir of potentially toxic metals, posing a continuing hazard to riverine biota. In the Illinois River, there is evidence that some of the more toxic sediments deposited in the past are being buried by cleaner sediments deposited more recently (Sparks, 1984).

Nutrient enrichment of the river results from soil and fertilizer runoff and sewage discharge. Moderate levels of nutrients are required for normal system function, but excessive levels can be detrimental. For example, high levels of nitrate can be toxic to humans, and ammonia from the decomposition of organic waste can be hazardous to aquatic biota. High ammonia concentrations have been implicated in the loss of most of the benthic community in upper and middle reaches of the Illinois River during the 1950s (Sparks, 1984). Nutrients exported to the Gulf of Mexico are also considered a likely causal factor contributing to the Hypoxic Zone in the Gulf of Mexico. Prudent agricultural practices have reduced the use of fertilizer and

[3] This statute is also referred to as the Clean Water Act.

pesticides in recent years, but it is unknown if these reductions will have a widespread or lasting effect on the water quality of the UMRS.

Native Plant and Animal Species

▪ **Submersed Aquatic Vascular Plants (SAV).** Before the lock and dam system was built, submersed aquatic vegetation (SAV) was present in the UMR, but not greatly abundant (Green, 1960). SAV was never very common in the Open River reach. Because of its lower gradient and more numerous backwaters, the Lower Reach of the Illinois River supported an abundance of SAV. SAV is an important indicator of the health of the now impounded river reaches of the UMRS because it provides food and structure for invertebrates, fish and waterfowl. Its presence suggests that physical conditions have not declined past viable ecological levels.

Pollution and sediment-related factors caused a dramatic decline in SAV in the Lower Reach of the Illinois River during the mid-1950s. Subsequent impacts to the river's fish and waterfowl have been extensively reported. SAV on the Lower Illinois River is currently restricted to isolated waterfowl management areas, but it is now common in the upper reach.

In the late 1980s, declines in the abundance of SAV were observed in the Upper Impounded Reach of the Mississippi River (Rogers *et al.*, 1995). The observations, supported by Landsat images[4] consistently suggested that the declines occurred primarily during a drought period between 1987 and 1989. The great Midwestern flood of 1993 also triggered declines in SAV. However, SAV in the Upper Impounded Reach is slowly recovering from both the drought and the flood.

There is little quantifiable information on aquatic plant communities south of Pool 19, but anecdotal information suggests that plants were initially abundant in shallow lakes created by the dams. Through time, sediment accumulation, reduced water clarity, and greater water level fluctuations led to reduced plant abundance in most pools in the Lower Impounded Reach of the Mississippi River. Currently, SAV is not abundant in aquatic areas connected to the river in this reach, but sometimes flourishes in isolated backwaters managed as waterfowl refuges and hunting areas.

▪ **Forests.** Modern UMRS forests represent only a small portion of the presettlement floodplain forests. For example, floodplain forests covered 56% of the landscape at the confluence of the Illinois and Mississippi Rivers in 1817 but they were reduced to 35% of the landscape by 1975 (Nelson *et al.*, 1994). Floodplain forests covered 71.4% of the landscape in a 102-km stretch in the Unimpounded Reach of the Mississippi in 1809, but their cover was reduced to 18.3% of the landscape by 1989 (Yin *et al.*, 1997). Mast producing oaks, hickories, beech, and walnuts have been drastically reduced in much of the Lower Impounded Reach and the Lower Reach of the Illinois River, and these species have virtually disappeared from the unleveed portions of the Unimpounded Reach of the UMRS. Land clearing for agriculture, steamboat fuel wood cutting, and lumber production was responsible for most of the changes to the forests, although modified hydrology may also be impacting forest community structure and species composition.

Large portions of the floodplain forests in the UMRS, especially in the lower impounded and unimpounded reaches, were impacted by the major disturbance caused by the flood of 1993. Floodplain forests are capable of enduring brief inundation; however, prolonged inundation during the growing season can be deadly to many tree species. Although the flood only slightly affected the floodplain forests above Pool 13, its impact increased sharply in the downstream reaches. In Pool 26, 37.2% of

[4] Landsat is a satellite-based, passive remote sensing system that provides medium resolution land use/land cover information.

the trees 10 cm or greater in diameter and 80% of the trees between 2.2 and 9.9 cm in diameter were killed. Mortality rates were positively correlated with flood duration and negatively correlated with the diameter of the trees. Hackberry and pin oak were two of the most severely impacted species (Yin *et al*., 1994).

▪ **Macroinvertebrates.** Fingernail clams and mayflies are important food sources for many species of waterfowl and fishes. They are widely distributed throughout the UMRS. Shifts in diving duck migration patterns and fish condition (Sparks, 1984) have been linked to the decline of fingernail clams and mayflies along the middle and lower reaches of the Illinois River in the 1950s.

Fingernail clam collections in the Impounded Reaches of the UMR have produced mixed results. In Mississippi River Pool 19, population densities of fingernail clams exceeding 100,000/m^2 were observed in the late 1960s. Their numbers gradually declined until none were found in the early 1990s. However, the Pool 19 population appears to have fluctuated with flood and drought years, and the community has recovered since the flood of 1993. Several site-specific studies conducted in Mississippi River Pools 2-9 documented declines in fingernail clam populations. A variety of potential causes was investigated, but the decline was ultimately attributed to pollution from the Twin Cities. Metal contaminated sediments and ammonia were suspected causal agents. A different study in Pool 9 found substantial population increases and densities more typical of the mid-1970s.

LTRMP data collected between 1992 and 1995 revealed patchy distributions of fingernail clams. Pool 13, the lowermost pool in the Upper Impounded Reach, has consistently supported the highest densities of fingernail clams among the six LTRMP trend analysis reaches. The LTRMP data suggest that low densities of fingernail clams are common in the river, and that high densities are rare. Non-channel (primarily impounded) habitats typically support higher densities of fingernail clams than channels. These spatial patterns may explain, in part, some of the mixed results of previous studies.

Mayflies are subject to many of the same perturbations as fingernail clams. Among the LTRMP trend analysis areas, they presently occur in the greatest abundance in Pools 4, 8, and 13. In Pool 19, the population appears stable since 1984 after increasing from lower earlier levels. In the Pool 2 to 4 reach, mayflies were eradicated between 1957 and 1976 due to pollution from the Twin Cities. Sampling conducted in 1986 and observations of mass emergences revealed a strong recovery in response to improved sewage treatment. This recovery has been faster than that of fingernail clams, possibly because mayflies filter more surface water while fingernail clams filter more heavily contaminated sediment pore water (Wilson *et al.,* 1995).

▪ **Fishes.** Long Term Resource Monitoring Program standardized monitoring has documented the existence of 127 fish species in the UMRS during its first five years. River wide, there is no evidence that the number of fish species has declined since the construction of the locks and dams. Fish species richness tends to be greater in the northern reaches of the UMR than in the more southerly reaches. The greater physical complexity of the northern-most reaches may explain their higher species richness.

Dam 19 blocks fish migrations because it is a high head dam of 38 feet and its main purpose is hydropower. However, this effect was at least temporarily reduced during the flood of 1993. The other dams are low head and their main purpose is navigation. Although these dams restrict upriver fish movements, they do not completely block it. For example, skipjack herring returned to the uppermost pools of the Mississippi River during the flood. The migration blocking effect of the dam therefore is not permanent. Species can recolonize upstream reaches given the appropriate opportunity.

Many fish species of the UMRS, like black basses, crappies and sunfishes, are ecologically and economically important and generally known to be dependent on healthy

backwaters. Backwaters provide suitable conditions for aquatic vegetation, and thus refuge from predation for these species and substrates for invertebrate food sources. Backwaters also provide spawning areas and refuges necessary for overwinter survival.

Local variables have traditionally made it difficult to quantify the relationship between habitat and fish community structure. Centrarchids (bluegills, sunfishes, crappies, etc.) exemplify backwater species. Differences in their abundance among the six LTRMP study reaches are now beginning to reveal "how much habitat is enough." Centrarchid relative abundance in the open river study reach is typically less than one-third of its value in other study reaches. These results suggest that the abundance of centrarchids in some areas of the UMR may presently be limited by the availability of suitable backwater habitat. They also provide initial estimates of how much backwater habitat may be needed in a given reach to achieve target management levels.

▪ **Mussels.** Under natural conditions, the river reaches of the UMRS supported one of the most diverse and abundant mussel faunas of the world. Consistent, long term mussel monitoring has not been conducted within the UMRS, but multiple study results from a variety of sites indicate that the number of mussels species has declined from 48 to 37 (a 23% decline), and from 45 to 25 (a 44% decline) in the Upper Mississippi and Illinois Rivers, respectively. Starrett (1971) documented widespread declines in both species and their abundance on the Illinois River. These declines have been variously attributed to high substrate ammonia concentrations, sedimentation, impoundment, and commercial navigation. Fuller (1974) attributed many of the effects of impoundment on UMR mussels to alterations in fish faunas that follow impoundment, further underscoring the interaction between native mussel reproduction and human alterations of habitat. Tucker *et al*. (1996) suggested that impoundment of backwaters reduced mussel diversity by interfering with energy transfer from the river to the backwater.

Mussel diversity consists of two components. The first is the actual number of native mussel species that occur in an area such as the UMRS (species richness). The second and equally important factor is the relative abundance of each native mussel species (species evenness). Maximum mussel diversity results when many native mussel species that are all fairly abundant occur in a particular region. This is important because changes in mussel diversity in native mussel faunas of the UMRS are only in part due to loss of species richness. Other species have become rare though they still occur at reduced population levels. Hornbach *et al*. (1992) compared surveys from 1930 and 1977 to those they conducted. They found three fewer species than the 36 species that had been previously reported. However, they found a significant increase in the abundance of the threeridge mussel (a species tolerant of impounded conditions) with a concomitant decrease in abundance of other species less tolerant of the habitat conditions created by dam construction.

The introduction of the exotic zebra mussel significantly complicates conservation of mussel faunas in the UMRS. Zebra mussels can form dense aggregations on native mussels. These aggregations lead to decreased native mussel density and have even been blamed for the complete extirpation of native mussel faunas in some portions of the Great Lakes. Initial surveys in Pool 26 suggest that the absolute number of native mussels decreases where zebra mussels become and remain abundant. At one location in Pool 26, the mussel fauna contained 18 species with three co-dominant species and a density of 18.6 mussels per square meter in 1993 (Tucker, 1994). However, one year later, a survey at this same site which was heavily colonized by zebra mussels, found 10 species, and densities were reduced to 6.6 mussels per square meter.

▪ **Birds.** The ecological value of the Mississippi and Illinois Rivers as migration

corridors for waterfowl has historically been great. On Pool 19, fall waterfowl censuses during 1948-1984 made by the Illinois Natural History Survey revealed a yearly mean peak of 345,000 diving ducks. A maximum of 875,000 divers was reported for Pool 19 in 1969. The percent composition of peak numbers was lesser scaup 71%; canvasback 18%; and ring-necked ducks 10%. Peak population counts of these three species on Pool 19 have been much lower during the past 10 years (S. Havera and M. Georgi, Illinois Natural History Survey, unpubl. data). During the 1978-1994 period, a peak of 195,000 canvasbacks was observed on Pools 7, 8, and 9 (C. E. Korschgen *et al*., 1989 and unpubl. data); significant numbers of ring-necked ducks and lesser scaup used these pools during this time period.

Waterfowl use of the Illinois River has declined dramatically (Mills *et al.*, 1966; Havera and Bellrose, 1985). Dabbling duck populations have declined steadily since the late 1940s, when annual fall surveys indicated that peak mallard numbers during the fall migration exceeded 1.5 million birds on the Illinois River alone. Environmental degradation and subsequent loss of food resources on the Illinois River caused a shift in migration routes of both dabblers and divers from the Illinois River to the central portion of the Upper Mississippi River (Pools 19-26). The populations converged after 1960 due to increased use of Mississippi River habitats and declining use of Illinois River habitats. Today, the combined populations barely exceed 500,000 birds, a full two-thirds reduction from pre-1950 counts from the Illinois River alone.

Bald eagle numbers began to decline nation-wide due to loss of prey and habitat prior to 1940, when the Bald Eagle Protection Act was passed (USFWS, 1996). While they were in a recovery stage, the use of DDT as an insecticide expanded. Its breakdown product (DDE) caused reproductive failure in bald eagles and other predatory birds. After DDT was banned in 1973, eagle populations began to recover (USFWS, 1996). Numbers of breeding bald eagles along the UMR have increased from 2 to 5 pairs in the 1970s to 43 to 44 pairs in 1993 and 1994.

Populations of great blue heron, great egret, and double-crested cormorant appear to have declined in the Upper Impounded Reach of the UMR (Graber *et al*., 1978; Thompson, 1977 and 1978; Upper Mississippi River National Wildlife and Fish Refuge, unpublished data; Kirsch in review). The Illinois Department of Natural Resources aerial surveys of Illinois rookeries since 1983 revealed a substantial increase in the number of active heron nests on the Mississippi River bordering Illinois, from 2,111 nests in 21 colonies in 1987 to 5,045 nests in 20 colonies in 1991. Active egret nests also increased, from 351 nests in 14 colonies in 1987 to 1,099 nests in 18 colonies in 1991. Ground surveys of colonies in Pool 26 indicated that both species occur mostly in tall cottonwood and sycamore trees on islands (Browning-Hayden *et al*., 1994). They select live trees and thus may have been impacted by tree mortality resulting from the flood in 1993. Colonies in the Upper Mississippi River National Wildlife and Fish Refuge have decreased from 31 in 1977 to 18 in 1992.

Double-crested cormorants were common breeders and abundant migrants on the UMR from St. Paul, Minnesota, to St. Louis, Missouri, during the 1940s and 1950s. Their numbers declined from about 40,000 in the 1940s to almost none in the 1960s and 1970s due to effects of contaminants and human disturbance on productivity. Populations have been increasing within the last decade. Populations of endangered least terns, which occur on the lower portion of the Mississippi River, appear to be increasing (Rumancik, 1985-1995).

Swan use on the UMR has increased in recent years, principally on Pools 7, 8, and 9 where counts during 1992-1993 were an order of magnitude higher than those observed in the early 1980s.

Criterion 2. The ability of the ecosystem to return to its pre-existing condition after a disturbance (whether natural or human-induced).

Although it is not yet possible to directly measure or model the ability of an ecosystem to return to its pre-existing condition after a disturbance, we can evaluate recent events on the UMRS and retroactively observe how the river reaches have responded.

The Lower Reach of the Illinois River has yet to recover from the combination of factors that caused widespread declines in its aquatic plant and invertebrate communities. This observation is a clear indication that these reaches are ecologically unhealthy.

In the Upper Impounded Reach of UMR, aquatic plants have recently shown the capacity to recover from both a drought and a flood. Mayflies have recovered from earlier declines that were related to pollution from the Twin Cities. Both observations suggest that this river reach meets this criterion of health.

The trends of succession before and after the 1993 flood indicate different futures for early-successional willow and cottonwood communities in the impounded and unimpounded reaches. Willow and cottonwood seedlings abundantly occurred after the flood in the open river reach. Patches of willow and cottonwood seedlings are colonizing the openings created by the flood and show rapid growth. In response to the flood disturbance in 1993, the aerial extent of willow and cottonwood communities is not expected to decrease in the next 50 years in the unimpounded river reach. The observations suggest that this component of the unimpounded reach ecosystem has shown the healthy ability to recover after a disturbance.

In contrast, in the Lower Impounded Reach where water levels are regulated by navigation dams, the 1993 flood did not change the trend of a willow and cottonwood decline, because willow and cottonwood did not regenerate vigorously in the aftermath of the flood. It is unclear why willow and cottonwood regenerated well in the Unimpounded Reach of the Mississippi River, but poorly in Pool 26, despite the fact that both reaches were equally disturbed by the flood. It is clear, however, that willow and cottonwood in the impounded reaches will continue an unhealthy decline in the future unless other management actions are taken.

Criterion 3. The ability of the ecosystem to sustain itself.

Two important long term trends within the reaches of the UMRS suggest that current conditions are non-sustainable. These trends relate to the pool aging and sedimentation processes that are occurring within impounded reaches, and changes in river discharges and elevations in the Unimpounded Reach of the UMR.

- **Pool Aging and Sedimentation.** Sedimentation is one of the most critical resource problems affecting impounded areas within the UMRS. As the navigation pools age, sedimentation will continue to degrade the quantity and quality of non-channel aquatic habitats. Sediments originating from both basin and floodplain sources settle in the deepest portions of the off-channel impounded river first (Bellrose *et al.*, 1983; Robert Gaugush, USGS-BRD, personal communication). The result will be a transformation of the diverse impounded aquatic habitats toward pre-impoundment geometry, which was primarily channel habitat.

Studies indicate sediment accumulation in aquatic areas is probably slower now than it was in the earlier years following dam construction. This pattern is consistent with other perturbed systems; change is greatest following the initial disturbance (i.e., impoundment) and tapers off as a new equilibrium is approached.

The rate of sediment delivery from the basin and erosion of floodplain soils will affect the time it takes to achieve equilibrium. A complicating factor is the considerable amount of sediment stored in tributary streams. DeMissie, *et al*. (1993) predicted that it would take more than 100 years for sediments in Illinois River

tributaries to be flushed if all basin runoff were eliminated. Stored sediments may also be delivered at different rates than sediments associated with runoff. Sediments stored in tributary valleys may mobilize more slowly to the main stem rivers of the UMRS and may be deposited in different spatial patterns than sediment originating in upland areas of the basin. Improvements to land-use practices and reduced soil erosion rates will likely slow the pool aging process, but the impacts of these measures will be dependent on climate and runoff patterns.

Anticipated ecological responses to pool aging include poorer water quality (i.e., more frequent dissolved oxygen problems, higher turbidity levels), poorer substrate quality, reductions of submerged aquatic plants and benthic invertebrates, shifts in fish communities to less desirable species, and fewer areas that are able to support migratory waterfowl.

Some of these responses have already been observed on the Lower Reach of the Illinois River (Starrett, 1972; Sparks, 1984; Sparks *et al*., 1990). However, the Illinois River has been subjected to a much higher level of municipal and industrial pollution and greater loads of sediment runoff than the reaches of the UMR and, therefore, comparisons between the two rivers, especially rates of expected change, should be made cautiously.

There appear to be certain thresholds of environmental conditions that determine biotic community development in the UMRS. Changes were rapid on the Illinois River in the mid-1950s. Because many of the pools of the UMR receive less sediment and other pollutants than those of the middle and lower Illinois River, future changes on the UMR may well be more gradual than those observed on the Illinois River.

Perhaps the most important point to be made about the navigation pools is that they are still responding to the effects of impoundment and are changing toward a less diverse mix of habitats that will resemble pre-impoundment conditions. In order to maintain the ecosystem quality that currently exists in the navigation pools, or to reduce its rate of decline, active management, such as habitat restoration, is necessary.

▪ **Discharge and Elevation in the Unimpounded Reach of the UMR.** Water surface elevation and discharge data, measured daily, are available for over 130 years at St. Louis, Missouri, and for over 60 years at Chester and Thebes, Illinois. Analyses of data from these three stations show a disturbing trend. At equivalent low discharges, water surface elevations are now lower than they were in the past. At equivalent high discharges, water surface elevations are now significantly higher than they were in the past. Thus, at low river discharges, habitats that were previously aquatic are now significantly dried, while at high discharges greater land areas that previously would have been dry are now inundated during floods.

The number of days an area is above flood stage is also increasing. Water levels were above flood stage for 217 days in a 38-year period from 1880 to 1917 at St. Louis. That figure rose to 312 days for the 38 years between 1918 and 1955, and to 485 days for the 38 years between 1956 and 1993. Without the influence of the Missouri River, the change is even more significant. In Pool 24, the number of days above flood stage for the same three periods was 295, 470, and 1,166, respectively.

The annual flood is one of the most important factors that controls a river reach's annual productivity. Many river animals and plants are well adapted to floods and readily occupy and use flood zones to reproduce, feed, and grow. However, if flood waters rise or fall too rapidly, or the flood zone shifts too much from one year to the next, much of the ecological value associated with a flood is lost.

Criterion 4. The reach's capacity to function as part of a healthy basin.

From an ecological basin perspective, rivers provide several functions. They carry surface water and materials out of the basin and are therefore vital elements of continental water and nutrient cycles. Floodplains, when

connected to their river channels, provide opportunities for nutrients and organic material to be recycled and used to the greatest extent possible. Because of its position in the basin, the ecological state of a river is also dependent on the health of the basin itself.

Basin land cover and use control a variety of physical and biological conditions within the UMRS. They affect the distribution and rate of snow melt and rainwater runoff and therefore the delivery of materials (sediments, nutrients, and contaminants) to the floodplain river reaches. Before European colonization, the stream network delivered these materials to the rivers at rates to which river plant and animal populations were adapted. The materials originated in undisturbed sub-basins with riparian forests, prairies, and wetlands that stored water during wet periods and slowly released it during dry periods (Figure 2-6). High and low flows were additionally buffered by the storage capacities of the stream network.

Today, much of the UMRS basin landscape is dominated by agricultural practices, especially corn and soybean production (Figure 2-7). These landscapes typically release greater amounts of sediments, nutrients and contaminants, and concentrate flows in both space and time (DeMissie and Kahn, 1993, Hey and Philippi, 1995) because modern urban and rural drainage networks deliver runoff to the rivers more quickly, with greater velocity, and at higher stages than in the past (Belt, 1975; Bellrose *et al*., 1983; LTRMP data [see previous section]). Agricultural and urban land uses also generate a variety of contaminants not present in the past. Fertilizers and herbicides can be delivered in concentrated pulses if application occurs just before a heavy rainfall.

A unique, basin-scale feature of the UMRS, its interbasin connection with the Great Lakes through the Illinois Waterway, has exposed the stream network to exotic, and potential nuisance, species. Zebra mussels, the European Ruffe, and the Round Goby are recent examples.

Another unique basin-scale feature of the UMRS is the influence of the Missouri River on the Unimpounded Reach. Regulation of water levels in large impoundments of the Missouri River for flood control and recreation has altered the natural hydrograph downstream. The impoundments also trap sediments, and have been implicated in the reduction of coastal wetlands at the mouth of the Mississippi River.

The above observations indicate that the ecological health of the UMRS reaches has been constrained by declines in the more general health of their basins. Further, their ability to perform basin-level ecological functions, such as the floodplain processing of nutrients or the transport of sediment loads, has been also been altered.

Criterion 5. The degree to which the annual flood pulse "connects" the main channel to its floodplain.

Under natural conditions, spring high flows resulting from snow melt and rainfall within the UMRS basin would overflow UMRS channels and inundate low areas of the floodplain. From year to year, the size and duration of the inundated area, or flood zone, would vary depending on the magnitude and length of the flood.

A growing body of ecological information has recently indicated how important the extent and annual duration of the flood zone inundation is to river species and several important ecological processes. The successful spawning of many fish species and annual recruitment, nutrient recycling, and emergent plant growth and distribution are all intimately dependent on the timing, duration, and extent of the annual flood pulse.

The construction of navigation dams and levees and subsequent reductions in the size of the potential flood zones of the UMRS are among the most significant human-induced changes. Dams permanently flooded areas that previously drained and became exposed during a considerable portion of the annual discharge cycle, whereas levees have effectively eliminated a

large portion of the floodplain from high water inundation.

LTRMP spatial analyses in Pools 8 and 25 and the Unimpounded Reach of the UMR documented how these alterations have changed the extent of the flood zone. The areal extent of the flood zone, both as it is now and as it would be if the dams and levees were not present, was calculated for the 50-year average high and low flow for each of seven different locations. The areal extent of the flood zone in Pool 8 has decreased due to the impounding action of the dam, which keeps much of the pre-existing flood zone permanently inundated. In Pool 25, changes were attributable to the combined presence of levees and the navigation dam, with levees restricting high flows and the dam impounding low flows. The smaller flood zone in the Open River is attributable to the presence of levees that prevent flood water from reaching the floodplain.

Criterion 6. The ability of infrequent natural events (floods and droughts) to maintain ecological structure and processes within the reach.

Under natural conditions, floods that occurred every 100 to 500 years within the UMRS shaped the floodplain by re-routing channels through its bottomland forests and marshes and depositing sand and sediment on different land surfaces.

Long term overbank impacts associated with 100- to 500-year floods have been largely eliminated by development of the levee system. The most notable ecological effect of this change has been in the forest community, which is now less diverse both in terms of species and the age-structure of the trees that remain. Each of these variables is indicative of poor ecosystem health.

FINDINGS AND CONCLUSIONS

- Presented together in a river reach report card demonstration (Figure 2-9), the criteria discussed above indicate that ecological health of the three UMR reaches decreases from upstream to downstream. The Lower Illinois River is the least healthy reach within the UMRS.

- The abundance and distribution of plant and animal populations within the UMRS change from year to year in response to weather conditions and river flows. These changes are as difficult to predict as the weather patterns that control them.

- Hydrodynamic variability and consequent population responses are part of the natural dynamics of river ecosystems and are important to sustaining their long term diversity.

- Long term habitat changes, especially those that create permanent conditions that are beyond the suitability range of river species, are of great concern. It is now possible to forecast the direction and some of the likely future ecosystem conditions

associated with pool aging. However, it is not yet possible to predict the rate of change, or how soon a shift to a different, potentially less desirable, stable ecological state, as occurred on the Illinois River, might occur.

- The Upper Impounded Reach of the UMR is the relatively healthiest reach within the system. Habitats in this reach are degrading primarily because of long term changes in dynamic river physical processes associated with channel training and impoundment. Floodplain development has not been a major problem,[5] except where tributaries enter the floodplain.

- The Lower Impounded Reach of the UMR supports fewer backwaters and marsh habitats and their associated species. In this reach, suspended sediment loads increase, and therefore sedimentation problems are typically greater here. Floodplain development has isolated much of the floodplain. In combination with greater flood flows, this produces more rapid water level fluctuations that are atypical of large, floodplain rivers and less suitable for aquatic plants. The larger islands in this reach are commonly protected from bank erosion by rock revetment, and therefore are not as much of a concern from the perspective of reduced habitat diversity.

- Most of the floodplain in the Unimpounded Reach of the UMR is isolated from the river; water level fluctuations are extreme; and suspended sediment loads are high. The reach does support a range of river species, and its forests are demonstrating the ability to recover from the flood of 1993.

- The Lower Reach of the Illinois River remains ecologically unhealthy. In addition to sedimentation problems typical of the whole system, the plant and invertebrate communities of these reaches have not recovered from the disturbance event of the 1950s. Habitat rehabilitation within this reach will continue to be difficult, because it will likely need to address multiple limiting factors (sedimentation, altered water level regimes, contamination) at the same time.

[5] This is in part due to more than 200,000 acres of floodplain lands along the mainstem of the Upper Mississippi River having been acquired for the Corps of Engineers 9-Foot Channel Navigation Project and subsequently transferred to the USFWS for management as part of the national refuge system.

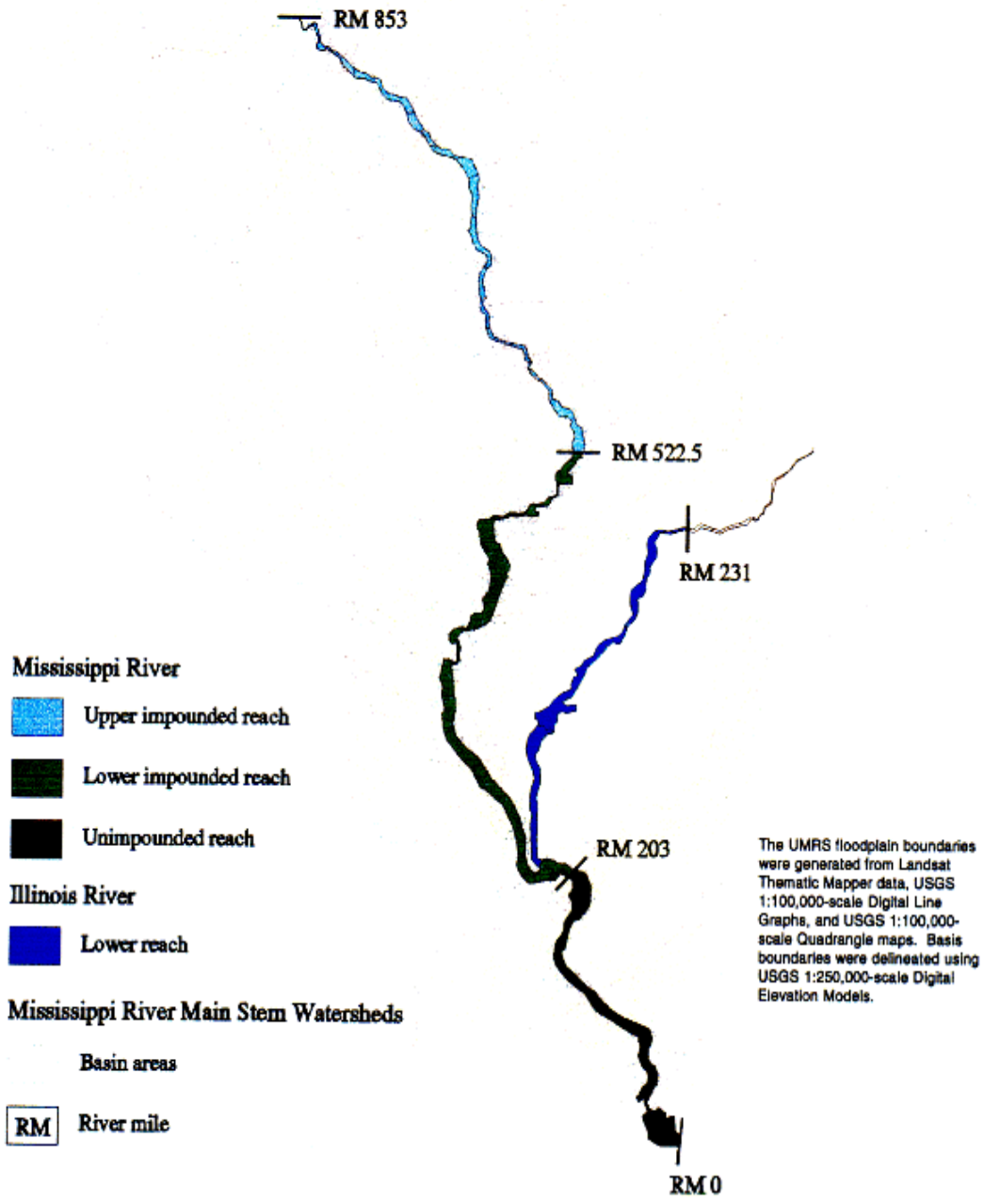

Figure 2-1. Four floodplain reaches of the Upper Mississippi River System.

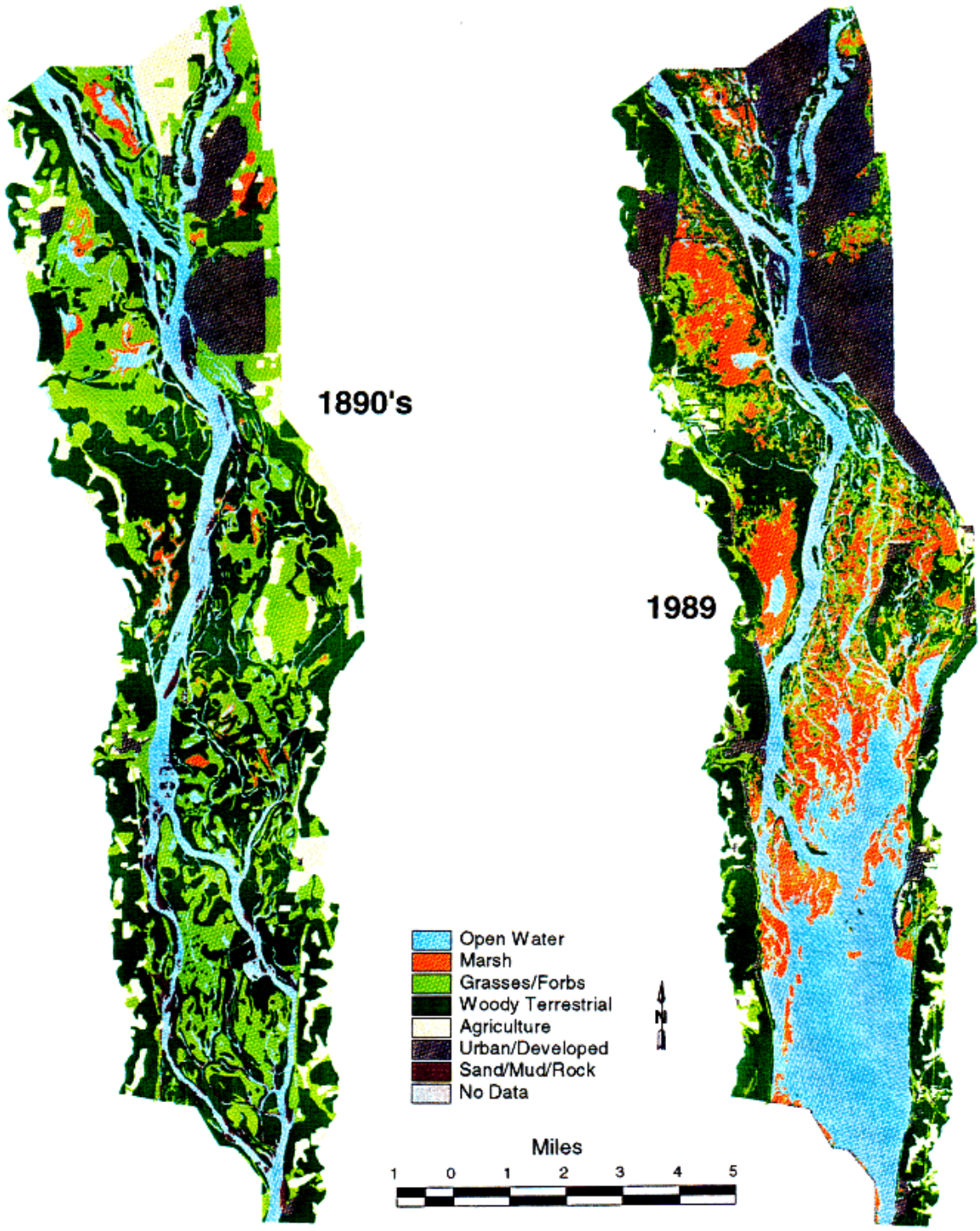

Figure 2-2. Land cover change in Navigation Pool 8, Upper Mississippi River, 1898-1989. Pool 8 is typical of other pools in the Upper Impounded Reach in terms of the degree to which impoundment increased the open water area above the dam. Source: Environmental Management Technical Center.

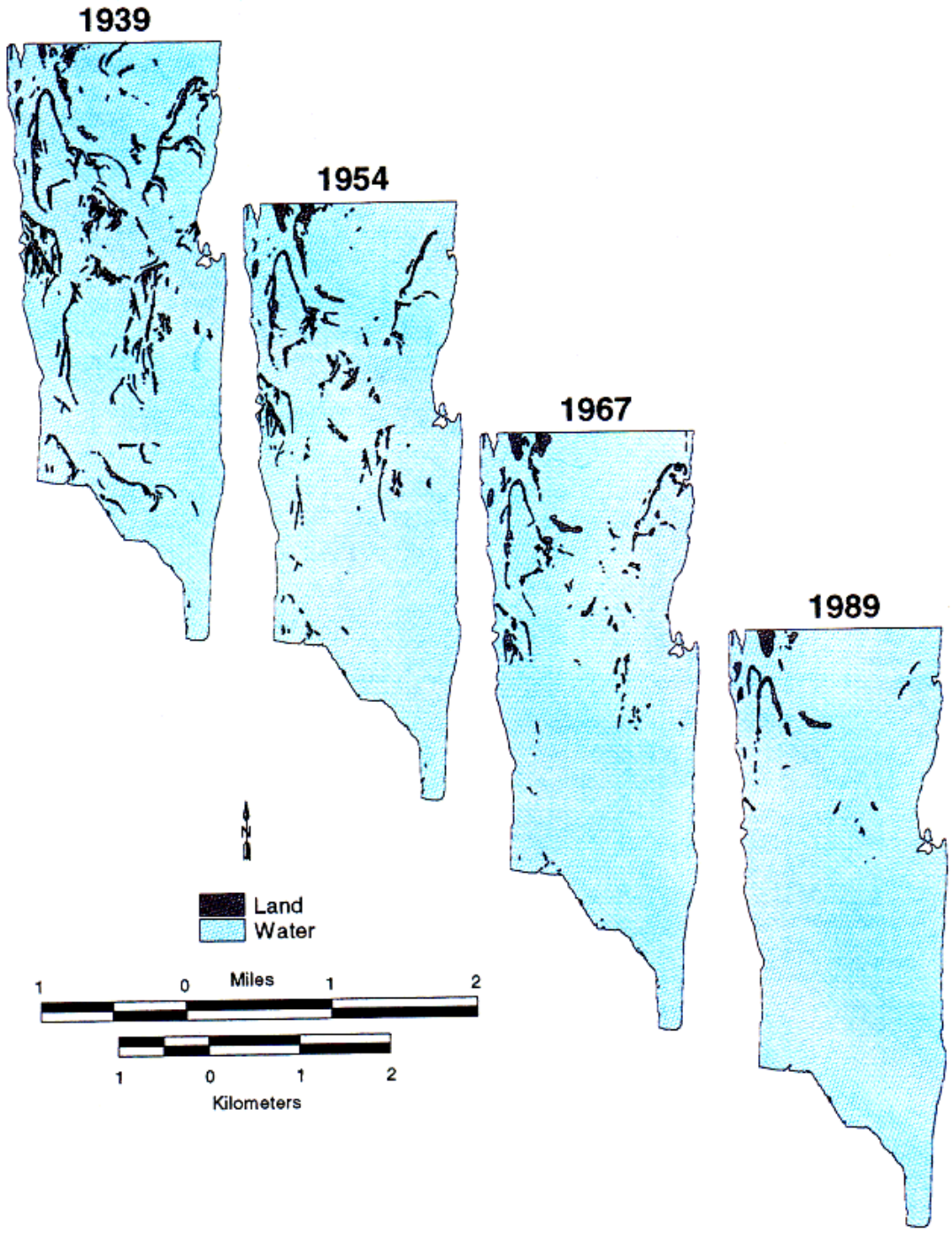

Figure 2-3. Island loss in Pool 8, Upper Impounded Reach, since impoundment. Source: Environmental Management Technical Center.

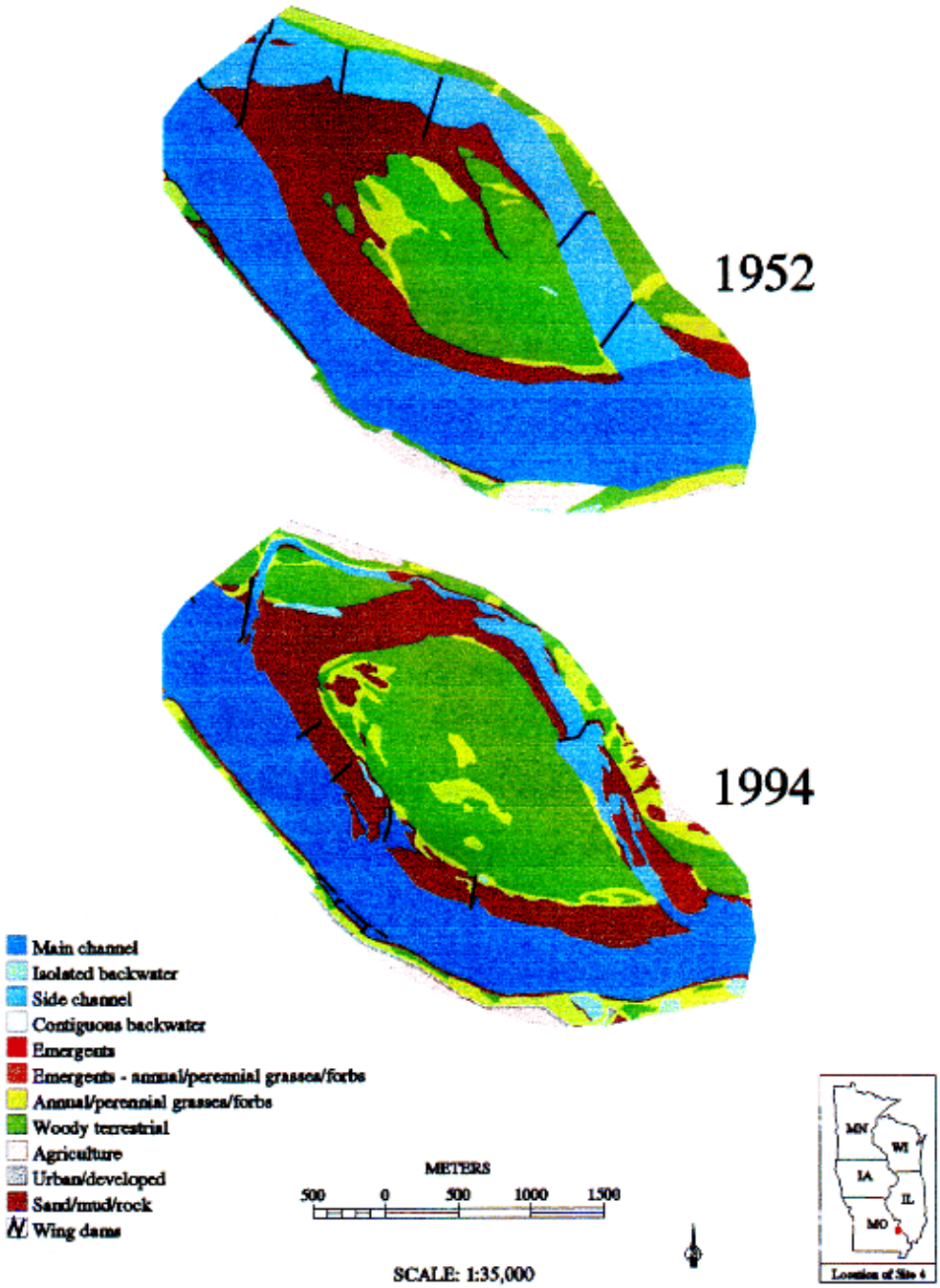

Figure 2-4. Physiographic changes near a side channel in the Unimpounded reach of the Upper Mississippi River, 1952-1994. The site typifies the loss of side channel aquatic habitat that has occurred at more than 20 such sites in this river reach. The changes resulted from the construction of closing dams to restrict river flows to the main navigation channel. Source: Environmental Management Technical Center.

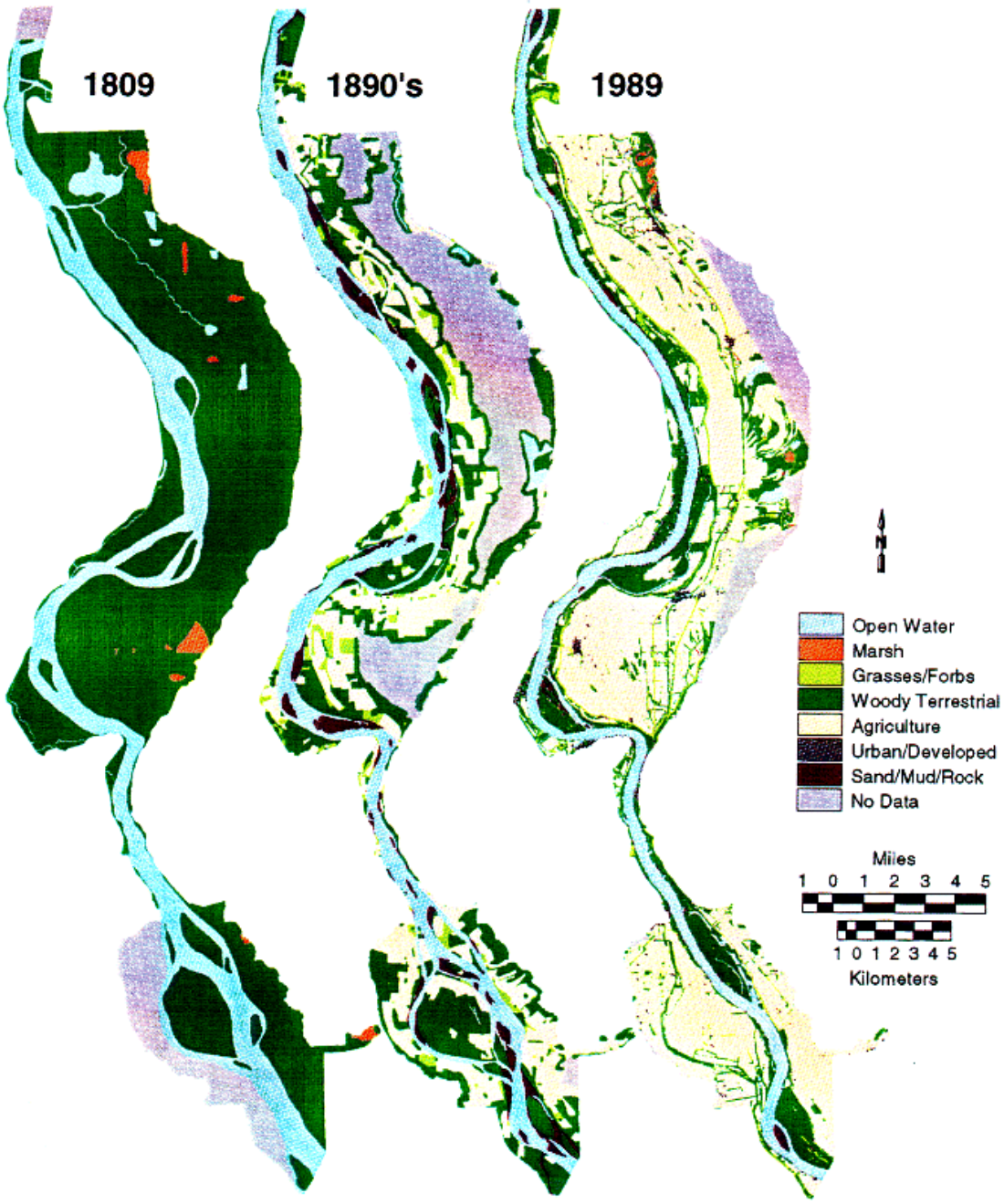

Figure 2-5. Long term land cover change in the Unimpounded Reach of the Upper Mississippi River, 1809-1989. Source: Environmental Management Technical Center.

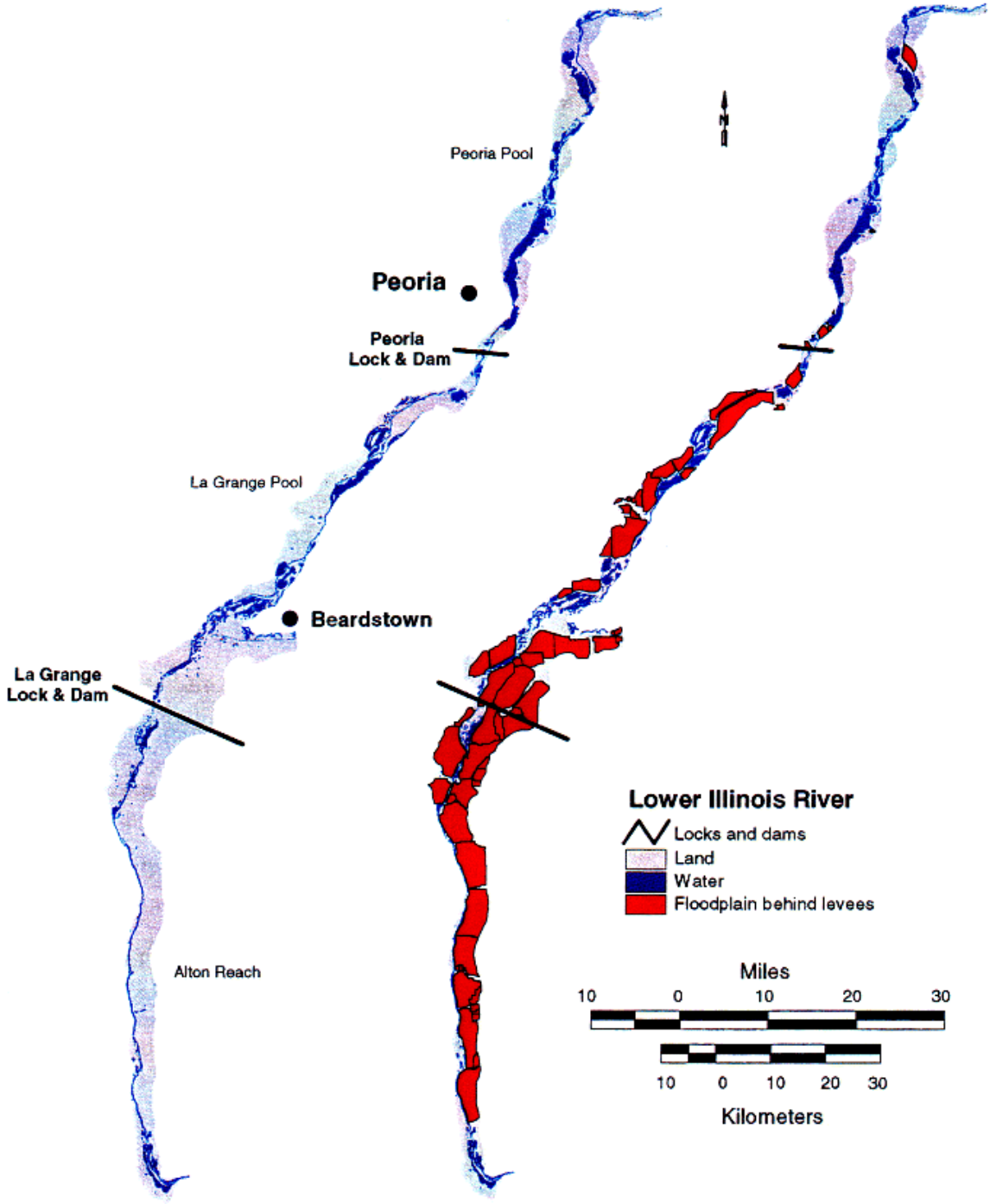

Figure 2-6. The Lower Reach of the Illinois River, showing the floodplain (left) and current agricultural levee districts. The levee information was produced by the Rock Island District, Corps of Engineers, for the Scientific Assessment and Strategy Team following the 1993 Midwest flood. Source: Environmental Management Technical Center.

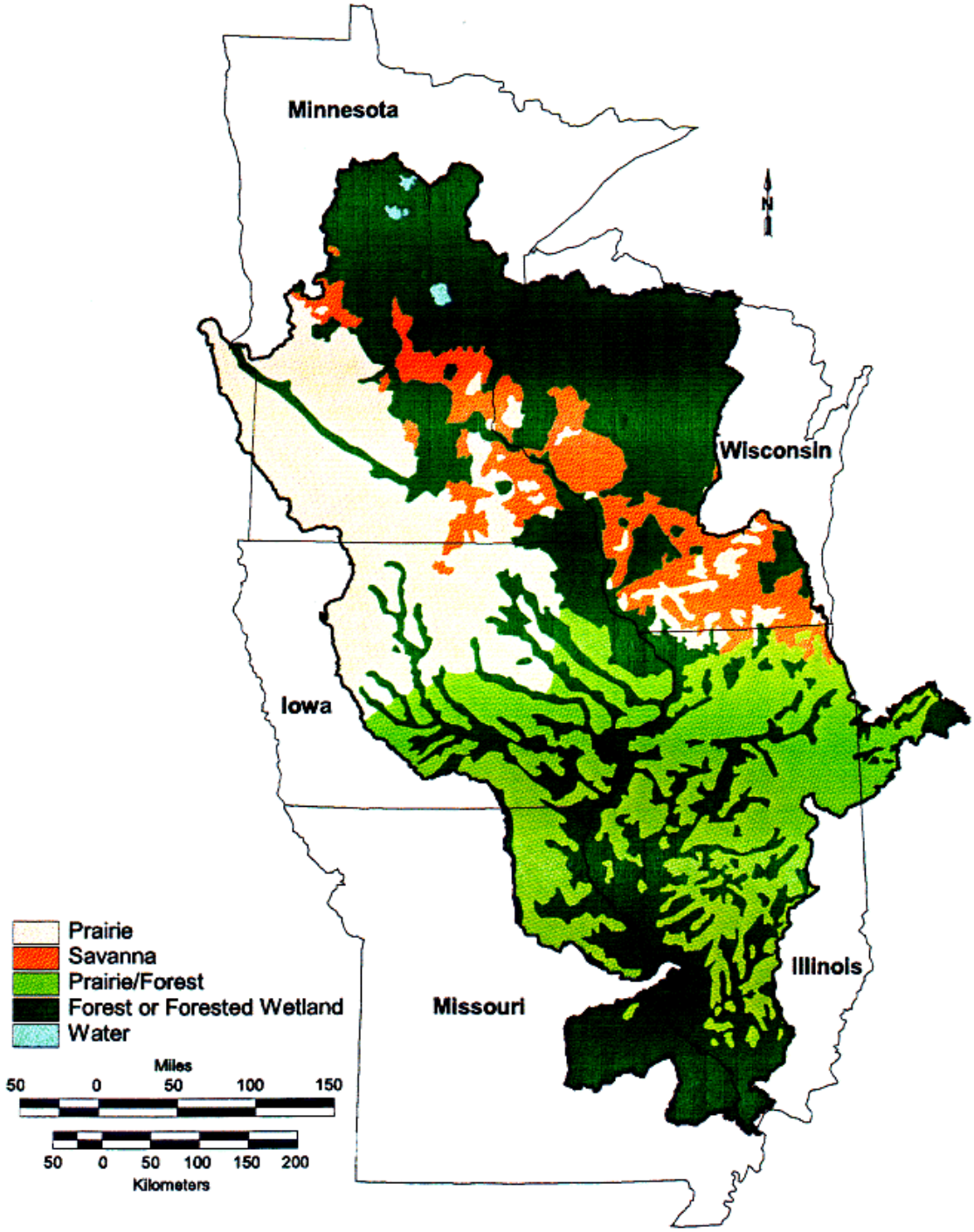

Figure 2-7. The potential natural vegetation of the Upper Mississippi River Basin (based on Kuchler (1964); source of map: Environmental Management Technical Center).

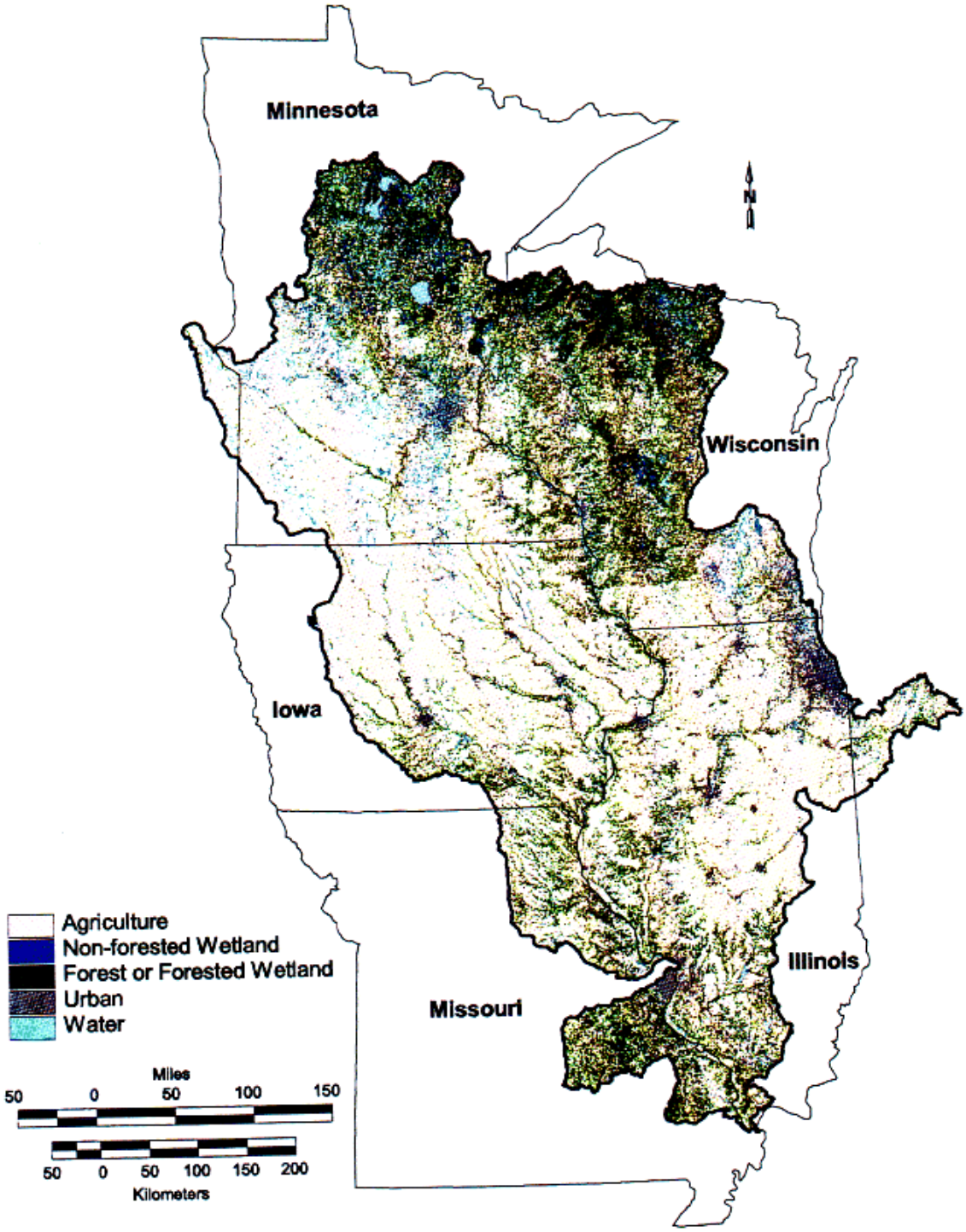

Figure 2-8. Current Land Cover and Land Use within the Upper Mississippi River Basin (based on USGS GIRAS data; source of map: Environmental Management Technical Center).

An Ecological Report Card for Four Floodplain Reaches of the Upper Mississippi River System.

Criteria for Evaluating Reach Ecosystem Health	Upper Mississippi River Upper Impounded Reach (Pools 1-13) Rating	Explanation	Upper Mississippi River Lower Impounded Reach (Pools 14-26) Rating	Explanation	Upper Mississippi River Unimpounded Reach Rating	Explanation	Illinois River Lower Reach Rating	Explanation
General Ecosystem Criteria								
1. Presence of habitats and viable native animal and plant populations that the reach, if undisturbed, would support	++	Although gradually declining in structural diversity, the wetlands created after impoundment still support viable river populations. Mussel diversity has declined. Zebra mussels are latest exotic to threaten native species.	++	Similar to Upper Impounded Reach, but greater encroachment of levees into floodplain. Forests are less diverse and have a simpler age structure. Zebra mussels are latest exotic to threaten native species.	+	Limited off channel habitats, and wide, rapid water level fluctuations. Zebra mussels are latest exotic to threaten native species.	+	Aquatic vegetation and native invertebrates still limited. Zebra mussels are latest exotic to threaten native species.
2. Ability to recover from disturbances	++	Invertebrates and aquatic vegetation recently have demonstrated continuing capacity to recover from floods, droughts and pollution.	+	Similar to Upper Impounded Reach, regeneration of willows and cottonwoods limited.	++	Similar to Upper Impounded Reach, willows and cottonwoods regenerating adequately.	-	Aquatic vegetation and invertebrates have not recovered after major declines in the 1950's.
3. Ability of ecosystem to sustain itself	+	Habitat quality and diversity continues to decline as pools fill and age. Some pools may be near a sediment transport equilibrium.	-	Similar to Upper Impounded Reach, suspended sediment loads and sedimentation rates are greater.	-	Suspended sediment loads are high. Increasing trend to greater flood peaks and longer flood durations.	-	Suspended sediment and nutrient loads are high. Point source pollution control in Upper Reach may gradually help cleanse this reach.
Floodplain River Criteria								
4. The reach's capacity to function as part of a healthy basin	++	Reach with least basin land cover change, but elevated suspended sediment and nutrient loads.	+	Major land cover changes, from forests and prairies to agriculture and urban, have altered the volume, rates, and kinds of materials carried by tributaries in this reach.	+	Major land cover changes, from forests and prairies to agriculture and urban, have altered the volume, rates, and kinds of materials carried by tributaries in this reach. Sediment and water discharge altered by large reservoirs on upper Missouri River.	-	Major land cover change in basins drained by tributaries in this reach. Elevated suspended sediment, and nutrient loads.
5. Annual channel/floodplain connectivity and exchange	++	Channel/floodplain connectivity enhanced by lack of levees.	+	Greater isolation of floodplain by levees.	-	Almost all of the floodplain is levied. Value of floodpulse lowered as a result of water level fluctuations that are too rapid.	-	Much of the floodplain is leveed. Long term filling of backwaters and sediment deposition in terrestrial habitats has reduced flood storage capacity of floodplain and increased flood peaks.
6. Ability of infrequent natural events to maintain ecosystem structure and processes	-	Channel-forming ability of infrequent floods almost eliminated by channel training structures and dams	-	Channel-forming ability of infrequent floods almost eliminated by channel training structures, dams, and levees.	-	Channel-forming ability of infrequent floods almost eliminated by channel training structures and levees.	-	Channel-forming ability of infrequent floods almost eliminated by channel training structures, dams, and levees

Legend:

+++ No ecological constraints associated with this criterion exist.
++ Some ecological constraints exist.
+ Many constraints, or constraints with broad spatial coverage, exist.
- Constraints associated with this criterion currently are considered ecologically unhealthy.

Figure 2-9. An Ecological Report Card for Four Floodplain Reaches of the Upper Mississippi River System.