CHAPTER 2

Floodplain River Ecology and the Concept of River Ecological Health

Kenneth Lubinski

The Upper Mississippi River System (UMRS), as defined by Public Law 99–662, includes the commercially navigable reaches of six Midwest rivers. The U.S. Army Corps of Engineers is responsible for building, operating and maintaining channel training structures (i.e., revetments, wing dams, closing dams); locks and dams; and dredging on the UMRS (Figure 2-1). These activities provide a continuous and permanent 9-foot (2.7-m) channel through which barges move between such cities as St. Louis, Missouri; Minneapolis-St. Paul, Minnesota; Chicago, Illinois; Memphis, Tennessee; and New Orleans, Louisiana. The driving need for commercial barge traffic on the UMRS is to move Midwest grain to international markets. Upstream transport of coal, petroleum, and fertilizer takes advantage of the bulk transport capacity presented by returning barges. Occasional reference is made in this report to the Upper Mississippi River (UMR) without the word “system” attached. The UMR is the upper portion of the Mississippi River not including tributary rivers.

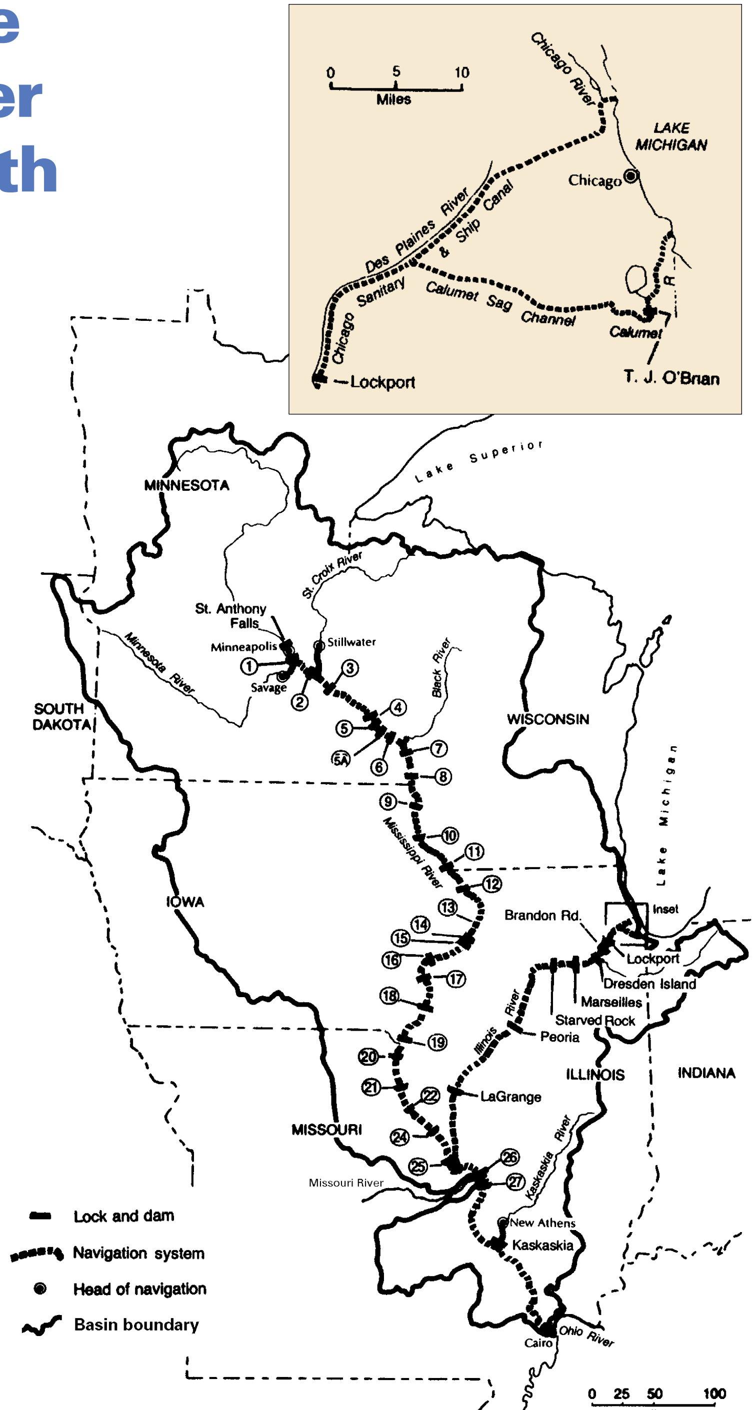

Figure 2-1. The Upper Mississippi River Navigation System with locks and dams numbered and the Upper Illinois Waterway inset to show detail.

By linear measure, the Upper Mississippi and Illinois Rivers make up 93 percent of the UMRS. These two rivers are the focus of the Long Term Resource Monitoring Program (LTRMP) and most of the information in this report.

Floodplain River Ecosystems

The reaches of the UMRS fit into a category of ecosystems called floodplain rivers. Floodplains are relatively flat land surfaces created when alluvial material (mud, sand, gravel) carried by surface water deposited in old valleys over many centuries. This material has filled the valleys of the UMRS for thousands of years. The valleys themselves were formed by flood waters from melting glaciers. Now, except during extreme events like the Flood of 1993, only a fraction of the original valley-forming flows occur each spring. Some floodplain areas are dry every year.

Floodplain ecosystems are unique in providing conditions necessary to support a third, intermediate habitat—the flood zone.

The structure of a floodplain river reach is determined over a long period of time. The positions of the primary channels can be remnants from glacial periods. However, small-scale features such as individual islands, side channels, and backwaters change more frequently. Extreme floods (100- to 500-year events) and more typical spring floods (1.5- to 10-year events) shape river habitats, but the relative importance and rates of habitat change associated with each have not been determined. Channel migrations and consequent habitat changes are slow processes that occur over hundreds or thousands of years.

Many ecosystems support either terrestrial or aquatic habitats; some support both. Terrestrial habitats occupy high elevations within the floodplain. Aquatic habitats are wet all though the year. Floodplain ecosystems are unique in providing conditions necessary to support a third, intermediate habitat—the flood zone. The flood zone includes areas alternately wet during high (usually spring) flows and dry during low (usually summer and early fall) flows. The regularity of annual floods on many floodplain rivers, including most in the Midwest, has led some ecologists to label them "pulsed" ecosystems (Dunne and Leopold 1978).

Under natural summer conditions, the aquatic habitats of the UMRS floodplains were limited mostly to narrow channels that carried water through bottomland forests and prairies and, in varying degrees of isolation from the primary channels, linear backwaters. The major exceptions include Peoria Lake on the Illinois River and Lake Pepin on the Upper Mississippi River. These are natural floodplain lakes caused by the impounding action of tributary deltas, as well as large rapids at Rock Island, Illinois; Keokuk, Iowa; and above the confluence of the Missouri River.

Over many years, the lateral limits of the flood zone are defined by the frequency, predictability, amplitude, and duration of the spring floods. Flood waters rise out of the channels and spread across the floodplain land surface. The hydrologic variability of the flood zone contributes substantially to plant diversity in a river reach and is vital to nutrient-cycling processes, the spawning success of many fish species, and a complex sequence of life history and foraging patterns.

Ecological Spatial Scales Relevant to the UMRS River Reaches

Natural resource problems within the UMRS are caused by many natural and human-related factors or events. These factors operate at spatial scales as small as an industrial waste pipe and as large as the Midwest grain belt. Legal or political boundaries have no inherent ecological relevance. For example, the Missouri

River plays a great role in controlling ecological conditions on the Mississippi River below St. Louis, yet it is omitted from the legal definition of the UMRS. An assessment of the ecological status of the UMRS and its problems requires special attention to and a working understanding of ecological spatial scales relevant to rivers and basins.

Natural resource problems exist at each of the five spatial scales included in the framework listed below—basin, stream network, floodplain reach, navigation pool, and habitat (Lubinski 1993). Solutions are most effective if they can be applied at the spatial scale appropriate to the problem.

Basin

The basin (or watershed) includes the land area that drains to a stream and is the accepted fundamental land unit for studies of river ecology (Petts 1989). Geology, climate, and vegetative cover regulate ecosystem processes in river basins (Resh et al. 1988; Bhowmik et al. 1994). Glacial events prior to 12,000 years ago were natural-basin disturbances that leveled the topography of much of the UMRS basin. Loess, a soil blown by postglacial winds, now forms a mantle over half the Upper Mississippi and Illinois sub-basins and serves as a major source of silt to the UMRS (Nielsen et al. 1984). Storms and droughts now act as natural climatic disturbances in river basins. Human-induced disturbances to ecosystem processes in the UMRS basin include agricultural and urban development. Figure 2-2 identifies the sub-basins (excluding the Missouri River Basin) that feed directly into the Upper Mississippi River.

Stream Network

Runoff, and to a lesser extent groundwater flow, point source discharges, and inter-basin diversions of water link a basin to its stream network. The stream network includes all water-carrying channels that lie above a selected point in a basin (Figure 2-3). Average stream flow, flow variability, velocity, stream morphology, and water quality gradually change along longitudinal stream gradients (Leopold et al. 1964; Vannote et al. 1980; Minshall et al. 1985; Ward 1989). Under natural conditions, these are primary controlling physical variables that, along with the biological variables of riparian vegetation and organic material processing, control stream ecosystems.

The most important natural ecosystem disturbances at the stream network scale

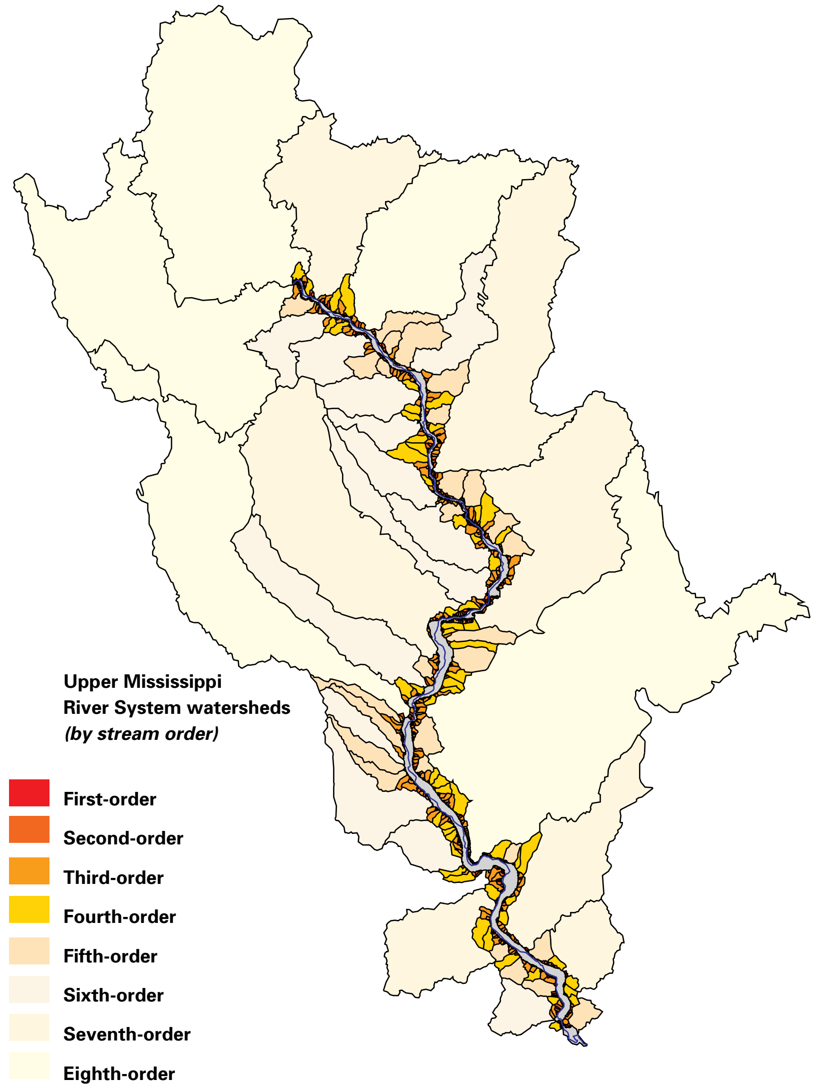

Figure 2-2. Upper Mississippi River Basin and sub-basin maps help identify how land use throughout the basin can affect the main stem rivers (Source: USGS Environmental Management Technical Center, Onalaska, Wisconsin).

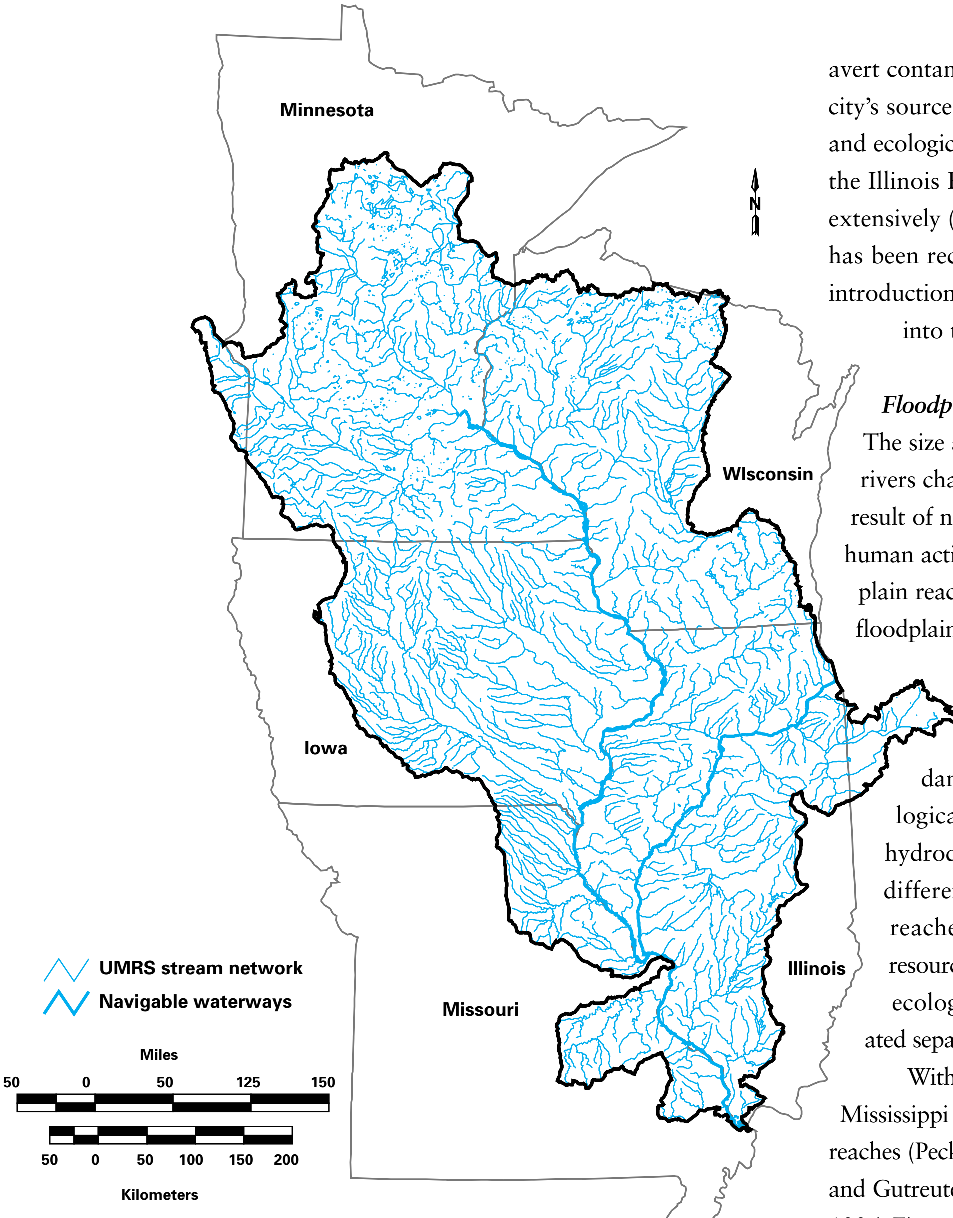

Figure 2-3. The Upper Mississippi River System stream network delivers a variety of materials from the basin landscape to the river system (Source: USGS Environmental Management Technical Center, Onalaska Wisconsin).

are infrequent hydrologic events. These occur on the rivers of the UMRS at intervals of 100 to 500 years. Human-induced disturbances at this scale include dams, water diversions, and point and nonpoint discharges of contaminants.

A unique human-induced ecological disturbance to the UMRS stream network occurred in 1900 when the flow of the Chicago River was reversed. This reversed flow allowed the City of Chicago to flush its waste products down a series of canals and tributaries into the Illinois River to avert contamination of Lake Michigan, the city's source of clean water. Water quality and ecological impacts of this diversion on the Illinois River have been reported extensively (see Chapter 14); the diversion has been recognized as a factor in the introduction of exotic nuisance species into the UMRS stream network.

Floodplain Reach

The size and structure of floodplain rivers change along their length as a result of natural fluvial processes and human activity. We use the term "floodplain reach" to refer to a large area of a floodplain that can be distinguished from another by its width, habitat composition, vegetation coverage, the presence of dams or levees, and geomorphological characteristics. Physical, hydrodynamic, and human-use differences between these river reaches create different natural resource problems and require that the ecological health of each be evaluated separately.

Within the UMRS, the Upper Mississippi River has three recognizable reaches (Peck and Smart, 1986; Lubinski and Gutreuter 1993; Delaney and Craig 1996; Figure 2-4). The Upper Impounded Reach between Minneapolis-St. Paul and Rock Island, Illinois, has a relatively narrow floodplain, contains impoundments formed by 13 navigation dams, and has extensive nonchannel aquatic habitats and marshes. The Lower Impounded Reach between Rock Island and St. Louis has a wider floodplain, 12 navigation dams, fewer non-channel aquatic habitats and marshes, and supports a moderate amount of agricultural land behind levees. In the Unimpounded Reach between St. Louis and Cairo, Illinois, the added discharge of the Missouri River contributes enough flow to the Upper Mississippi River to make navigation dams unnecessary. This reach frequently is called the Open River Reach. It contains almost no nonchannel aquatic or marsh habitats and much of the terrestrial portion of the floodplain is leveed for agricultural production.

The Lower Reach of the Illinois River is of particular concern in this report. This reach, geologically much older that the Upper Reach of the Illinois River, begins near Henry, Illinois, and runs southwest to the Upper Mississippi River at Grafton, Illinois. It flows through a broad, flat valley which, before recent glacial activity, was the valley of the Mississippi River. The Lower Reach of the Illinois River contains a combination of broad, nonchannel aquatic habitats and terrestrial areas leveed for agriculture.

Navigation Pool

Navigation dams impound water at low- and moderate-river discharges to create the 9-foot (2.7-m) navigation channel. Gates in the dams are raised out of the water (or lowered to the bottom of the river at Peoria and La Grange Dams on the Illinois River) during high-river discharges so as not to impede floods. An exception is Dam 19 on the Mississippi River, which also is a hydroelectric dam. The areas of water between dams are called navigation pools (or pool), and the pool is given the same designation as the dam that impounds it. Navigation Dam 8, for instance, impounds Navigation Pool 8 (Figure 2-5, see following page).

Many navigation pools exhibit a repetitive longitudinal structure. The lower, more-impounded end of a pool frequently contains an area of open water. These areas are pronounced in the Upper Impounded Reach of the Upper Mississippi River. The upstream, less-impounded end of each pool retains land and water boundaries similar to those that existed before impoundment. A variably sized transition zone between the two ends of each pool is sometimes recognized because it may support species adapted to both the lake-like conditions of the lower pool and the free-flowing conditions of the upper pool.

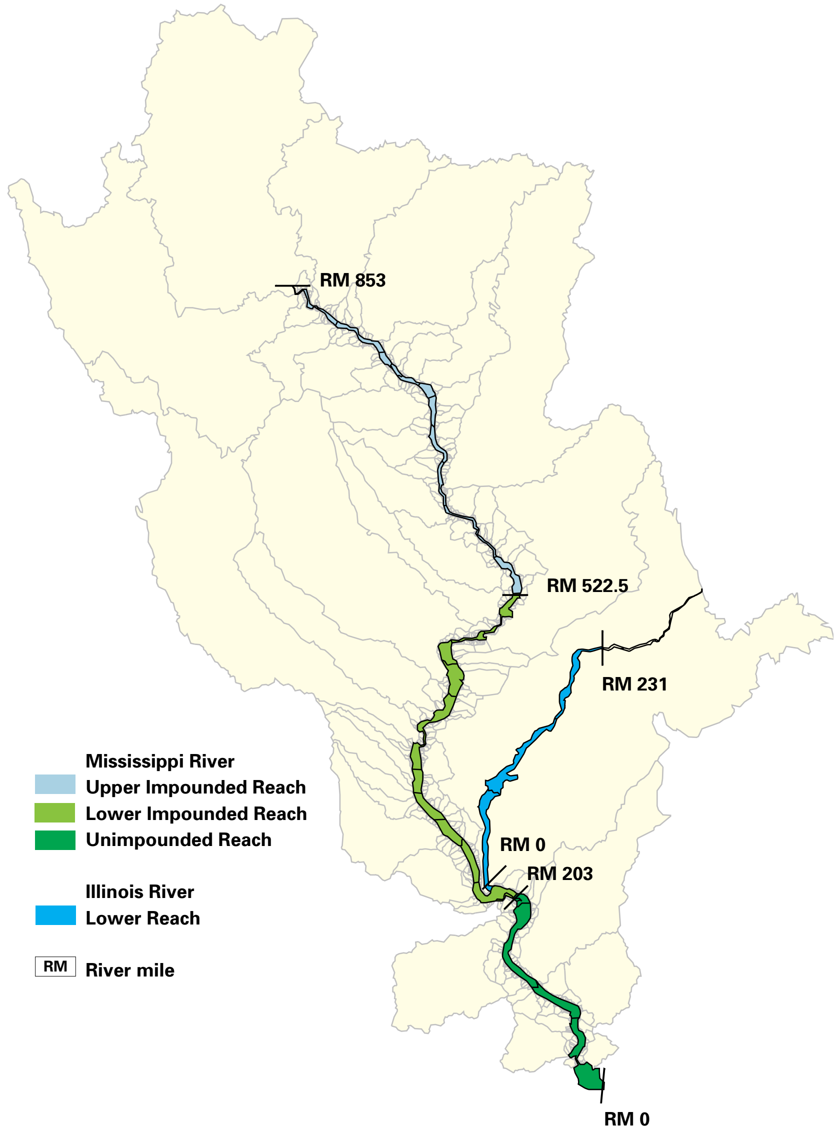

Figure 2-4. The Upper Mississppi River System can be separated into distinct reaches based on physiography and land use. The four reaches include the Upper Impounded Reach, river mile 853 to 522.5 (Pools 1 to 13), the Lower Impounded Reach, river mile 522 to 203 (Pools 14 to 26), the Unimpounded Reach, river mile 203 to 0 (St. Louis to the Ohio River), and the Lower Reach of the Illinois River, river mile 0 to 231 (up to Starved Rock Pool) (Source: USGS Environmental Management Technical Center, Onalaska, Wisconsin).

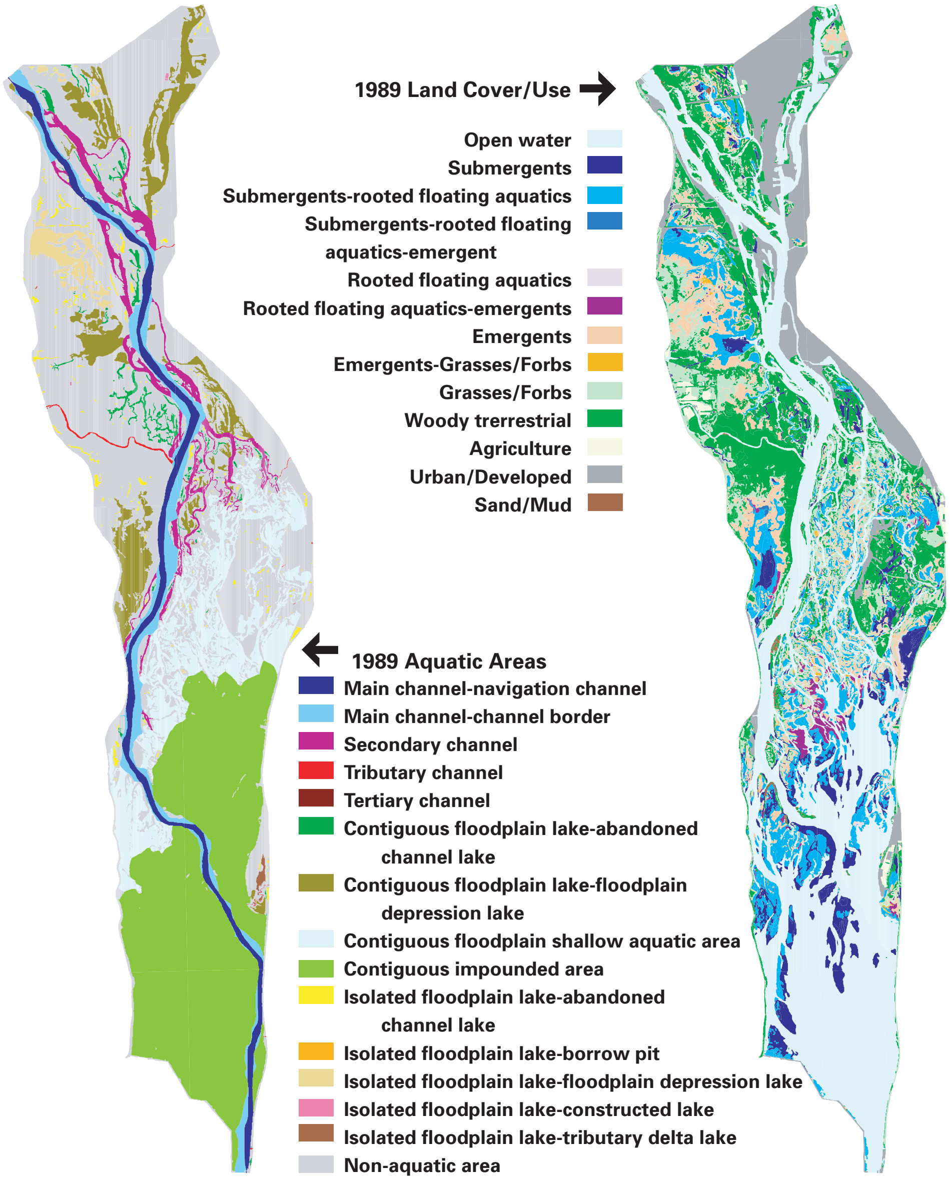

Figure 2-5. Aquatic area and terrestrial landcover/land-use classifications for Pool 8 of the Upper Mississippi River (Source: USGS Environmental Management Technical Center, Onalaska, Wisconsin).

A synthesis approach is logical, valuable, and necessary to reduce the large amount of available ecological data on the UMRS into a brief but relevant assessment.

Habitat

Habitat is the finest scale discussed in this report for distinguishing spatial patterns within the floodplain reaches. It applies to both aquatic and terrestrial habitats and is valuable for evaluating physical and ecological differences between, for instance, channels and backwaters or forests and marshes.

The aquatic areas defined by the LTRMP have different physical and hydrodynamic conditions and species assemblages (Figure 2-5, left image). Table 2-1 summarizes the aquatic area habitat classification scheme (Wilcox 1993).

Land-cover classification can be viewed at various scales of resolution. The 13 classes shown in Figure 2-5 (right image) indicate, at a course scale of resolution, habitat diversity typical of pools in the Upper Impounded Reach.

River Ecological Health

Scientists have begun to bridge the gap between the concept of ecosystem health and its application to practical natural resource management. A synthesis approach is logical, valuable, and necessary to reduce the large amount of available ecological data on the UMRS into a brief but relevant assessment. We use the term "ecological health" as a metaphor familiar to a wide range of river interests.

The following three general ecosystem features are commonly used for their value in characterizing ecosystem health (Cairns 1977; Rappaport 1989; Grumbine 1994):

1. The ecosystem supports habitats and viable native animal and plant populations similar to those present before any disturbance.

2. The ecosystem is able to return to its pre-existing condition after a disturbance, whether natural or human-induced.

3. The ecosystem is able to sustain itself.

Unique features and processes of floodplain river ecosystems also can be used as criteria to evaluate the health of the UMRS. In 1994, a team of river scientists at an LTRMP-sponsored international conference on river ecology synthesized the following guidelines that help in understanding what constitutes health from a scientific perspective (Lubinski 1995):

■ River form and condition are a function of the totality of many actions and processes that occur in the basin, stream network, and floodplain.

■ The degree of connectivity between the main channel and its floodplain is a primary structural attribute of river ecological integrity.

■ Annual flood pulse, channel-forming floods, and infrequent droughts are major driving factors in floodplain river ecosystems.

■ Rivers and their fauna are resilient and measures to improve or rehabilitate them, if taken before critical levels are reached, can produce positive responses within the system.

Table 2-1. Upper Mississippi River System hierarchical aquatic habitat classification system showing four levels of habitat from coarse to fine (Wilcox 1993).

CHANNEL
- **Main channel**
  - Navigation channel
  - Sandbar
  - Channel border
    - Unstructured revetted bank
    - Wing dam
    - Closing dam
  - Tailwater
- **Secondary channel**
  - Navigation channel
  - Sandbar
  - Channel border
    - Unstructured revetted bank
    - Wing dam
    - Closing dam
- **Tertiary channel**
- **Tributary channel**
- **Excavated channel**

BACKWATER
- **Contiguous**
  - Floodplain lakes
    - Abandoned channel lakes
    - Tributary delta lakes
    - Lateral levee lakes
    - Scour channel lakes
    - Floodplain depression lakes
    - Borrow pit lakes
    - Other artificial lakes
  - Floodplain shallow aquatic
  - Impounded
- **Isolated**
  - Floodplain lakes
    - Abandoned channel lakes
    - Tributary delta lakes
    - Lateral levee lakes
    - Scour channel lakes
    - Floodplain depression lakes
    - Borrow pit lakes
    - Other artificial lakes
  - Floodplain shallow aquatic

■ Ecosystem reaction to stress is often expressed catastrophically through critical breakpoints that can only be determined retroactively; that a breakdown in a system is likely to occur can be anticipated, but foretelling when it will occur is more difficult.

Given these five guidelines, the following three criteria specific to floodplain rivers were developed:

1. The reach functions as part of a healthy basin.

2. The annual flood pulse “connects” the main channel to its floodplain.

3. Infrequent natural events—floods and droughts—are able to maintain ecological structure and processes within the reach.

The three general ecosystem features and the three criteria specific to floodplain rivers are used hereafter as the six criteria for assessing the ecosystem health of the floodplain river reaches of the UMRS.

Human-induced disturbances of concern on the UMRS primarily began with European colonization, although the use of fire by Native Americans influenced vegetative communities of the floodplains even earlier.

The Criteria in Detail

Some issues about ecosystem health overlap unavoidably among the six criteria. For the most part, however, each criterion refers to a distinct ecosystem characteristic that, under common circumstances, requires specific and independent management. Specific issues associated with how to apply each criterion to the UMRS are explained in more detail below.

Criterion 1
The ecosystem supports habitats and viable native animal and plant populations similar to those present prior to any disturbance.

Criterion 1 is perhaps the easiest to understand and visualize. An ecosystem that provides habitat and supports the native species present before any disturbance occurred is considered healthy. By definition, this criterion can be assessed at any point in time. Traditionally, ecosystem studies and monitoring programs focus on measuring habitats or counting species. Much data being collected under the LTRMP are directed toward documenting these system attributes.

Several issues complicate application of this criterion to assessing the river’s ecological health. Regularly counting and measuring all habitats and species within a floodplain river ecosystem is cost prohibitive and in many instances comparative data from predisturbance periods do not exist. Rare species attract much attention but are difficult to monitor. Introduced exotic species add to the species richness of an ecosystem but can compete with native species, and consequently exotics are often considered undesirable.

Frequently, it is hard for different interest groups to agree on what should be considered a disturbance and, consequently, to define a predisturbance period. This report defines a disturbance as an event that disrupts biology at the ecosystem, community, or population level (Pickett and White 1985; Resh et al. 1988; Sparks et al. 1990). A disturbance can be temporary or permanent and can result from natural processes or human activity. Human-induced disturbances of concern on the UMRS primarily began with European colonization (e.g., logging floodplain forests to provide fuel for steamboats, clearing snags to improve navigation), although the use of fire by Native Americans influenced vegetative communities of the floodplains even earlier. Each disturbance is a separate event with its own predisturbance period. No single point in time represents ideal river ecosystem conditions.

Infrequent, great channel-forming floods are difficult to categorize using the above definition of disturbance. They disrupt native populations and habitats, but river populations adapt to such events and ecologists have come to believe that floods at infrequent intervals are necessary to maintain floodplain vegetation diversity and age structure. Disturbances, therefore, are not all bad. Some are necessary to maintain river ecological health (see Criterion 6).

Criterion 2
The ecosystem is able to return to its pre-existing condition after a disturbance, whether natural or human-induced.

Criterion 2 is similar to the first in that it pertains primarily to species and habitats. It suggests that ecosystems with the ability to return quickly to an original condition after a disturbance are healthy. However, this ability cannot be measured with a set of observations made over one period of time. It has to be assessed retroactively and, therefore, requires standard and consistent observations through time. Ecosystems typically take time to recover. When recovery does take place, it often results in conditions that may be stable but differ in important ways from the ecosystem's original state. In the case of the UMRS, and depending on the magnitude of the disturbance, recovery may take years or decades. The Lower Reach of the Illinois River has yet to recover from a disturbance that occurred in the 1950s, as discussed in Chapter 14.

Criterion 3
The ecosystem is able to sustain itself

Over long periods of time, many ecosystems tend to remain in a relatively unchanged state. Two factors contribute in part to this unchanged state: (1) predictable and repetitive climate conditions and energy cycles and (2) biological feedback loops or relations that maintain constant conditions and resist change.

Criterion 3 holds that ecosystems are healthy when they can sustain relatively constant conditions by themselves. In the case of floodplain rivers, this constancy refers to conditions sustained over many years, disregarding short-term seasonal or year-to-year variations that are considered to be within the range to which river animal and plant communities have adapted. It also recognizes that long-term habitat change at fine spatial scales results from natural geomorphological processes (see Chapter 4). Natural variations of river flow and structure require that measurement of sustainability be made over an appropriate period of time, at least a decade, and at a suitably large spatial scale, such as a navigation pool.

As noted, over the last 12,000 years the UMRS has slowly filled with sediment, sand, and gravel brought to shallow gradient floodplain reaches by higher velocity tributaries. During this period, river populations and habitats adapted to annual and infrequent flood patterns changed little in spite of of these long-term depositional processes. In the last two centuries, human-induced changes occurred that affect the rates at which water, sediment, and sand are carried to and transported through the navigation system. Selected areas (e.g., impounded areas above dams) are degrading rapidly. Under such artificial conditions, these areas cannot sustain themselves without remedial management action.

When [ecosystem] recovery does take place, it often results in conditions that may be stable but differ in important ways from the ecosystem's original state.

Criterion 4
The river can function as part of a healthy basin.

Criterion 4 treats a river reach not as an ecosystem in itself but as part of a larger ecosystem—its basin. It emphasizes that many water-quality, flow, and habitat conditions existing in a floodplain river are controlled by processes or events that occur within the stream network or basin. It also recognizes that a floodplain river provides important ecological services (water and material transport, nutrient recycling processes, migration routes) that affect the health of the basin and downstream ecosystems.

This criterion provides the opportunity

to discuss river ecological health as it relates to three specific and highly visible problems: increasing flood heights observed in recent decades, high nutrient loading within and downstream from the UMRS, and sediment accumulation within pools.

A common observation in ecology is that "as the system of interest gets larger, the time scale over which that system changes gets longer." Thus, measurements of whether a river reach is functioning as part of a healthy basin need to assess the role of the reach over a suitably long time frame. That time frame should not be too sensitive to extreme high or low flows that might occur in any one year, but long enough to capture broad land-use changes over the entire basin.

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

Although relations between annual flood pulses and floodplain ecological productivity and diversity began to be understood in the late 1800s, they were poorly documented and largely ignored by floodplain developers. **Criterion 5** recognizes the value of annual flood pulses to vegetation diversity and production, fish spawning, and the movement of organic material among floodplain habitats. The size of the flood zone and the timing and duration of the flood pulse all affect different species, habitats, and ecological processes. Summer low-flow water regimes and associated terrestrial drying processes, because of their role in increasing nutrient cycling and plant germination, also are considered important to river ecological health.

Criterion 6
Infrequent natural events—floods and droughts—are able to maintain ecological structure and processes within the reach.

Criterion 6 addresses the dynamic nature over decades and centuries of floodplain reaches. It recognizes infrequent great floods, although considered disturbances (Criterion 1), as important ecosystem resetting events that helped establish habitat and species diversity within floodplain systems. Over time natural selection resulted in occupation of floodplain reaches by plant and animal species adapted to survive and prosper in spite of, or because of, infrequent great floods. Great floods therefore help maintain river ecological health and their absence (or activities that reduce floodplain structure dynamics) serves to lower river health.

This criterion offers the chance to discuss a basic conflict between human activity and river ecological values, and a potential new goal for improving river health. On one hand, floodplain rivers are dynamic by nature. Many primary features (flow, velocity, sediment concentration, temperature, primary production rates) vary over a wide range in the space of a year and even more over many centuries. On the other hand, almost every human use of floodplain rivers requires that one or more of their features be brought under some level of control. One way to consider restoring health to controlled river reaches is to let them regain aspects of variability.

More discussion within the river community is required for these criteria to be accepted and used. Measurable scales of evaluation for each criterion, customized to the circumstances that exist within the UMRS and each separate reach, must be refined. Although these broad criteria are often difficult to quantify, they provide a valuable ecological framework for evaluating the relative health of floodplain reaches. They are specific enough, even now, to help identify appropriate actions needed to improve current conditions.

Kenneth Lubinski is director of the Division of Applied River Sciences, USGS Environmental Management Technical Center, Onalaska, Wisconsin.

Contributors

Hank DeHaan
USGS Environmental Management Technical Center, Onalaska, Wisconsin

Carol Lowenberg
USGS Environmental Management Technical Center, Onalaska, Wisconsin

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