Review of Sedimentation Issues on the Mississippi River

Report Presented to the UNESCO: ISI

Prepared by:

Pierre Y. Julien and
Chad W. Vensel

Department of Civil and Environmental Engineering

Colorado State University

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Executive Summary

Sedimentation on the Mississippi River and its major tributaries, like the Missouri, Ohio, and Illinois Rivers, has long been an issue of serious concern. Major tributaries and the delta area have been susceptible to significant changes in river discharge, cross section, width, mean bed elevation, water surface elevation, and sediment concentration. Additionally, water quality has become an issue of increasing concern throughout the basin due to the vast dependence of life on the river. The sedimentation issues have had broad effects upon several aspects of life, both terrestrial and aquatic, within the Mississippi River Basin. The size and dynamic nature of the Mississippi River Basin, have made the elimination of all sedimentation problems impossible. Several revetments, like dams, locks, levees, and dikes, have been implemented with the intent of mitigating these problems. The success of the revetments has generally been successful, although some negative derivatives have developed over time due to the presence of the revetments. Some problems have been aided by technological and educational advances, resulting in relatively simple solutions, like those associated with upland erosion and land use characteristics, while other issues like wetland subsidence and barrier fragmenting, have been extremely difficult to mitigate and continue to deteriorate with time.

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Background

Sedimentation on the Mississippi River and its major tributaries, like the Missouri, Ohio, and Illinois Rivers, has long been an issue of serious concern (Figure 1). The sedimentation issues have had broad effects upon several aspects of life within the Mississippi River Basin. Recent advances have aided in the understanding and implementation of improvements within the basin. Problems like upland erosion, chemical leaks and spills, and other types of pollution have been prevalent throughout the basin and have been amplified by pollutant/sediment transport, creating environmental problems for humans, wildlife, and especially aquatic life. Several revetments have been implemented with the intent of mitigating these problems. The success of the revetments has generally been initially successful; however, subsequent processes, like aggradation and degradation, have been resultants of these revetments over time. For example, the installation of locks and dams in the upper Mississippi River Basin has reduced sediment discharge to the lower Mississippi River, improved navigation, and also increased flood protection, however, the locks and dams have also reduced channel migration rates, thereby increasing bed slopes and stream power, and been partially responsible for the delta's wetland and marsh loss. Confluences with major tributaries and the delta area have also been susceptible to significant changes in river discharge, cross section, width, mean bed elevation, water surface elevation, and sediment concentration. Additionally, water quality has become an issue of increasing concern throughout the basin due to the vast dependence of life on the river.

Figure 1: Mississippi River drainage basin.
Source: Environmental Protection Agency

Purpose

The primary purpose of this independent study was to gain credits toward the completion of a Masters of Science degree. An additional, underlying purpose was to document sedimentation issues related to some of the world's largest rivers as a reference for United Nations Educational, Scientific and Cultural Organization (UNESCO).

Objective

The objective of this investigation was to document recent sedimentation advances, studies, and occurrences relative to the entire Mississippi River Basin, including its major sources and tributaries.

Methodology

The investigation was completed by utilizing professional publications, like journal articles and conference symposia, to document recent sedimentation issues of the Mississippi River. Publication abstracts were compiled, sorted by topic, and edited to summarize sedimentation issues related to computational and measurement methods, upland erosion, channel dynamics and processes, marsh and wetland impacts, and water quality.

Water and Sediment Measurements

Water and sediment data, in the United States, are collected, organized, and made available to the public by the United States Geological Survey (USGS). Nationally, the USGS surface-water data includes more than 850,000 station years of time-series data that describe stream levels, streamflow (discharge), reservoir and lake levels, surface-water quality, and rainfall. Suspended sediment data may be obtained from the water quality section of the USGS database or from an appurtenant database from the USGS, which focuses primarily on suspended sediment data (http://co.water.usgs.gov/sediment/).

The data, for both databases, are collected by automatic recorders and manual measurements at field installations across the nation. Data are collected by field personnel or relayed through telephones or satellites to offices where it is stored and processed. The data relayed through the Geostationary Operational Environmental Satellite (GOES) system are processed automatically in near real time, and in many cases, real-time data are available online within minutes. Once a complete day of readings are received from a site, daily summary data are generated and stored in the data base (http://waterdata.usgs.gov/nwis/sw). Recent provisional daily data are updated on the web once a day when the computation is completed. Annually, the USGS finalizes and publishes the daily data in a series of water-data reports. Daily streamflow data and peak data are updated annually following publication of the reports. Figures 2, 3, 4, and 5 display examples of gaging station data and graphics, for the state of Missouri and the Mississippi River at St.Louis, Missouri gaging station (#07010000), which may be obtained from both USGS online databases.

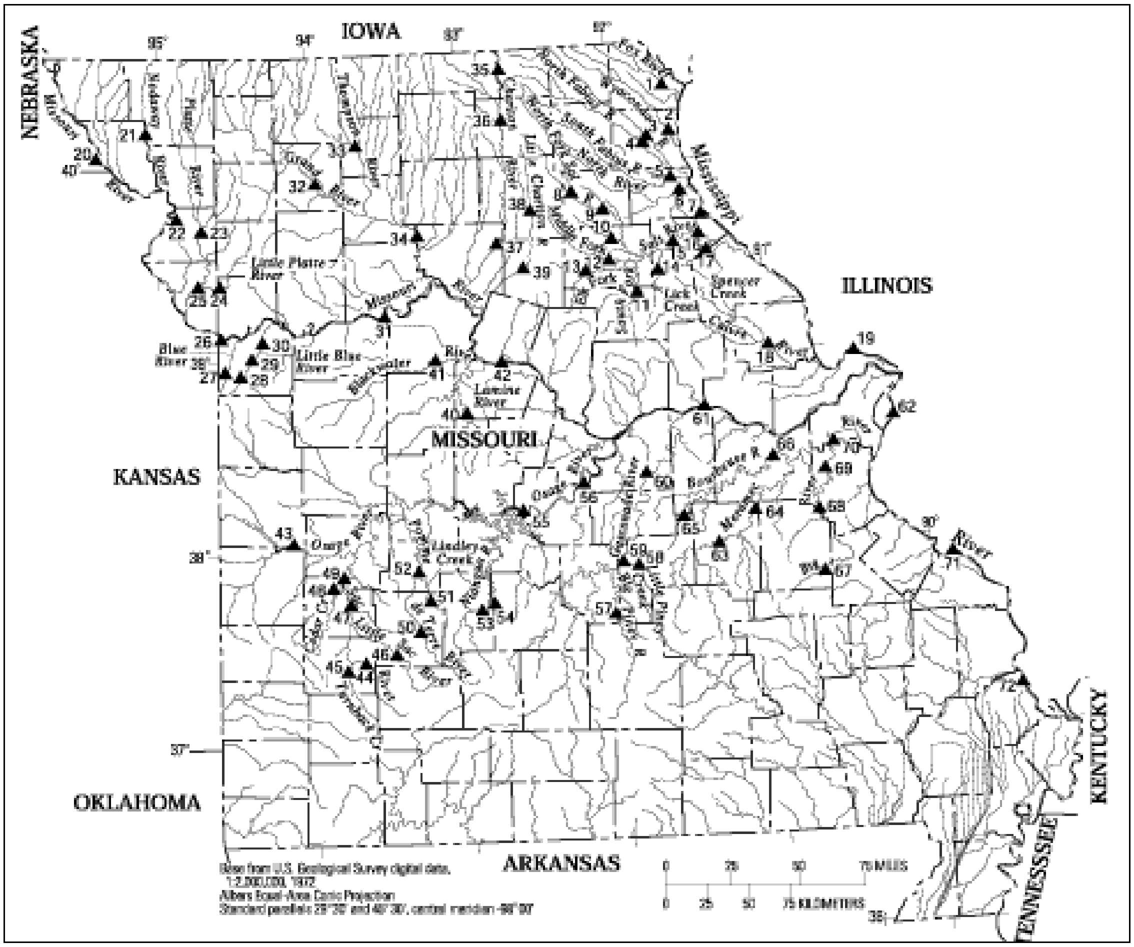

Figure 2: Example of gaging stations, represented by black triangles, located within the state of Missouri. (Note: numbers on figure do not reflect actual gaging station numbers)
Source: U.S. Geological Survey

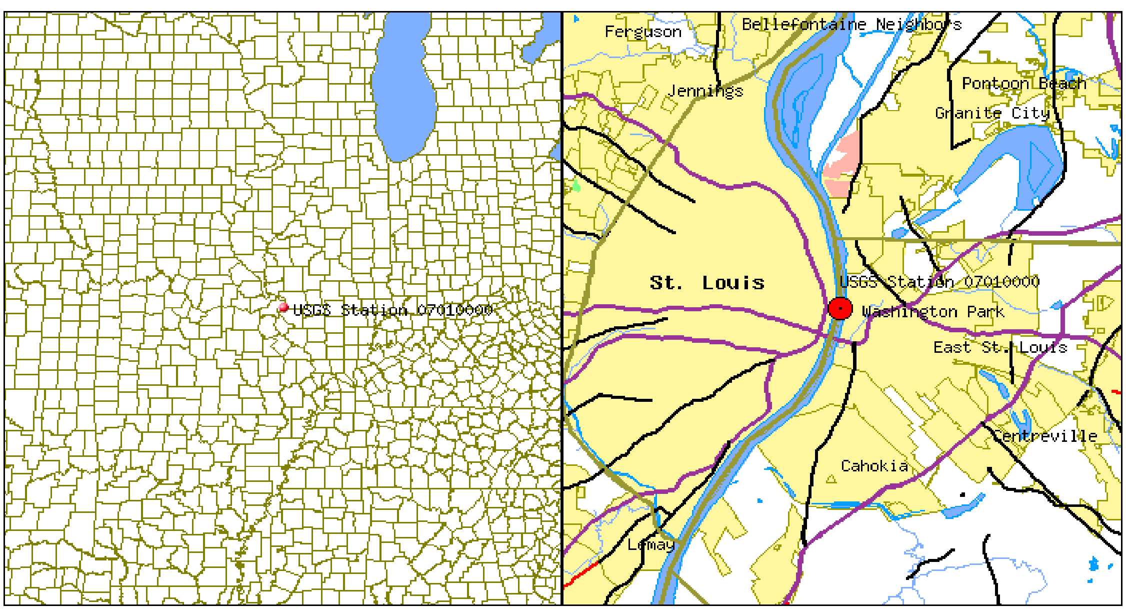

Figure 3: Location maps, from the USGS, for the Mississippi River at St.Louis, MO gaging station.
Source: U.S. Geological Survey

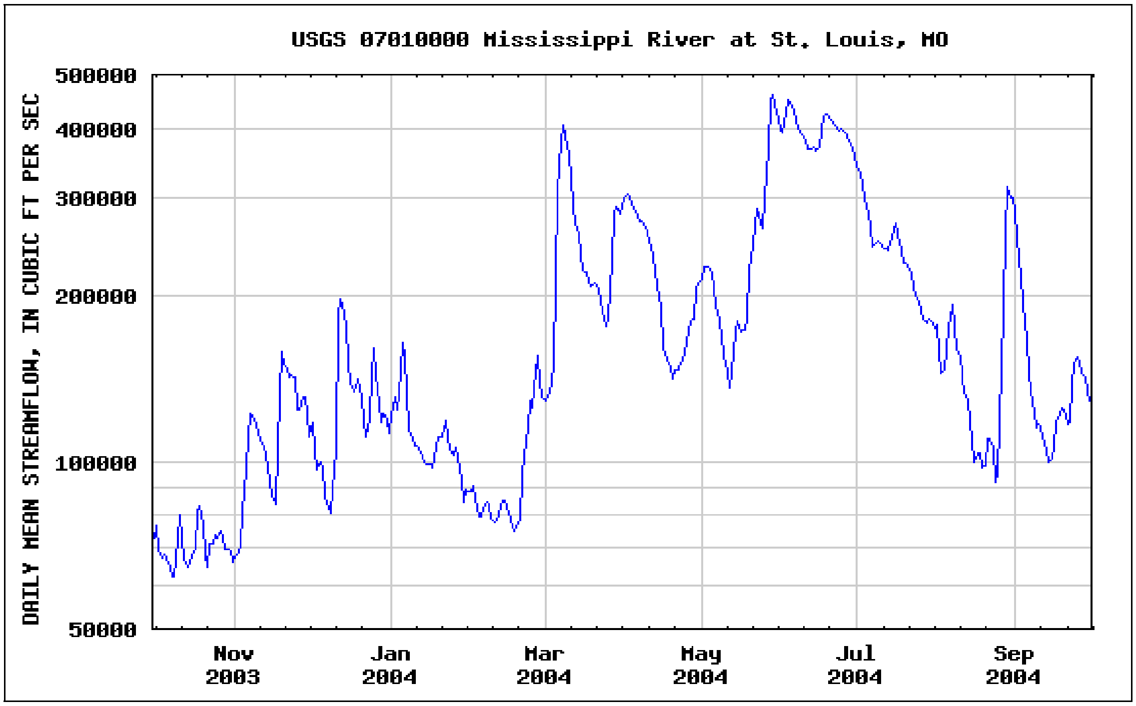

Figure 4: Sample hydrograph, from the USGS, for the Mississippi River at St.Louis, MO gaging station. *Source*: U.S. Geological Survey

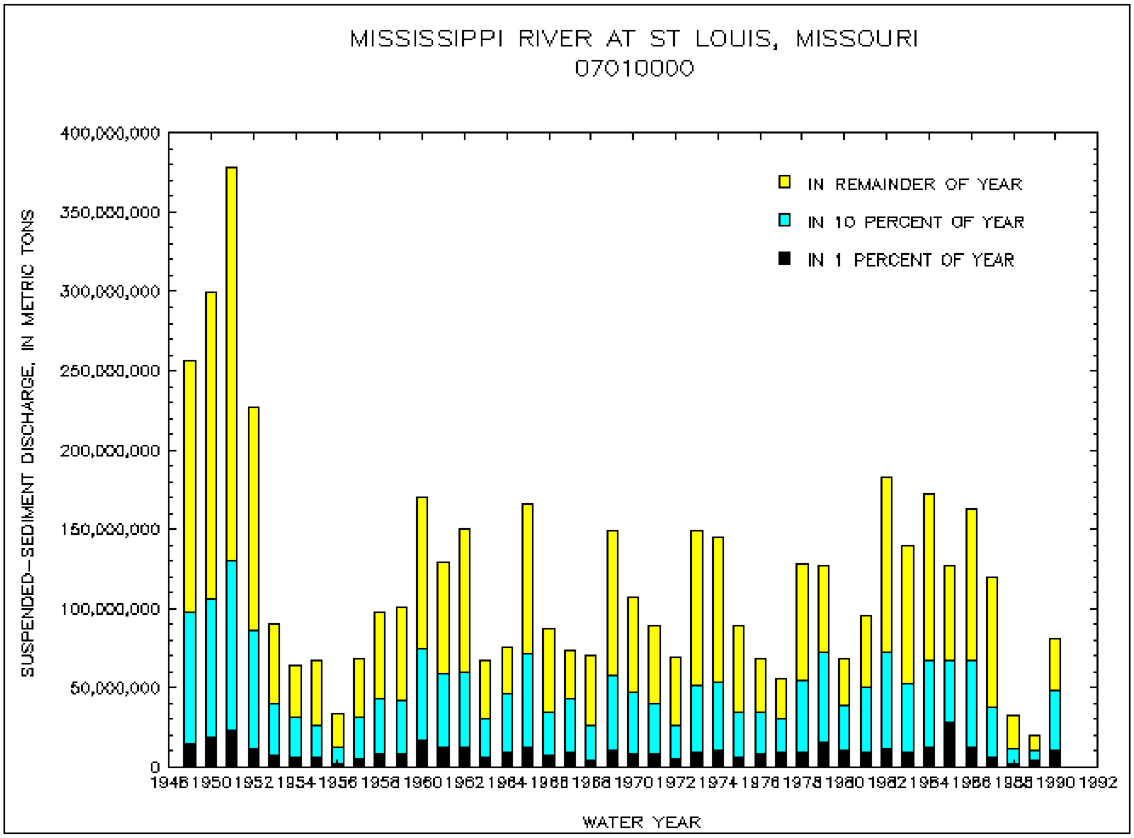

Figure 5: Sample suspended sediment data for the Mississippi River at St.Louis, MO gaging station. *Source*: U.S. Geological Survey

Computational and Measurement Methods

Recent improvements in prediction and measurement have greatly strengthened the accuracy of results. Advanced methods, techniques and technology have been the most significant contributors to the improvements. In particular, the measurement and prediction of particle size, discharge, cross-sectional dimensions (aggradation and degradation), and sediment load and concentration have been vastly enhanced with the advent of these new advances. One such technique, that has been developed to increase accuracy, combines discharge-weighted pumping and a high-speed continuous-flow centrifuge for isolation of particulate-sized material with ultrafiltration for isolation of colloid-sized material. The technique has been field tested, with good results, on the Mississippi River, where colloid particle sizes from twelve sites from Minneapolis to below New Orleans were compared with sizes from four tributaries and three seasons, and from predominantly autochthonous sources upstream to more allochthonous sources downstream (Daniel et al. 1998).

Another improved method has been that of the depth-integration method, which measures water and sediment discharge from the water surface to the bed at 20 to 40 locations across a river. A current meter, which can be lowered or raised at a constant transit velocity, is utilized, so that the velocities at all depths are measured for equal lengths of time. Field calibration measurements have shown that: (1) the mean velocity measured on the upcast (bottom to surface) is within 1% of the standard mean velocity determined by 9-11 point measurements; (2) if the transit velocity is less than 25% of the mean velocity, then average error in the mean velocity is 4% or less. The discharges measured by the depth-integrated method agreed within +/- 5% of those measured simultaneously by the standard two- and eight-tenths, six-tenth and moving boat methods (Moody and Troutman 1992).

Improvements have also been made in equipment via technological advances. The performance, application, and capability of selected waterborne acoustic profiling systems for streambank erosion studies, in fluvial environments, have been evaluated on several rivers including the Mississippi River. The continuous seismic reflection profiling (CSRP) method has allowed detection and identification of stratigraphic and structural geology, while side-scanning sonar systems have been useful in determining overall channel bottom characteristics as well as natural and man-made features. The results from application of CSRP and side-scanning sonar systems reveal that they can be successfully applied to several types of engineering studies, including streambank erosion and hydraulic investigations (May 1982).

Obtaining accurate measurements of flow depth and bed elevation has always been difficult due to the dynamic nature of the bed itself. Traditional survey methods have often been of a low accuracy due to the compressible nature of substrates, and they do not provide measures of accretion or sediment compaction. An approach has been developed to measure these variables in shallow-water, vegetated wetlands. The approach employs simultaneous measures of elevation from temporary benchmarks using a sedimentation-erosion table (SET) and vertical accretion from marker horizons with sediment. The approach has been field tested on the Mississippi River and provided high-resolution measures of vertical accretion and elevation over a 4-year period and also provided rates of compaction of newly deposited sediments and compaction of underlying sediments over a two-year period. Hence, the SET-marker horizon approach has widespread applicability in both emergent wetland and shallow water environments for providing high resolution measures of the processes controlling elevation change (Black et al. 2000).

Accurate estimation of sediment discharge and load is very important for many water resources implications, however, accuracy is often difficult to obtain. Sampling methods and techniques have recently been improved due to the importance of accurate sediment transport estimations. For instance, conventional sediment rating curves have not typically been able to provide sufficiently accurate results. Artificial neural networks (ANNs) have been developed as simplied mathematical representations of the functioning of the human brain. The ANN approach has been used to establish an integrated stage-discharge-sediment concentration relation for two sites on the Mississippi River. Based on the comparison of the results for two gauging sites, it is shown that the ANN results are much closer to the observed values than the conventional technique (Figure 6) (Jain 2001).

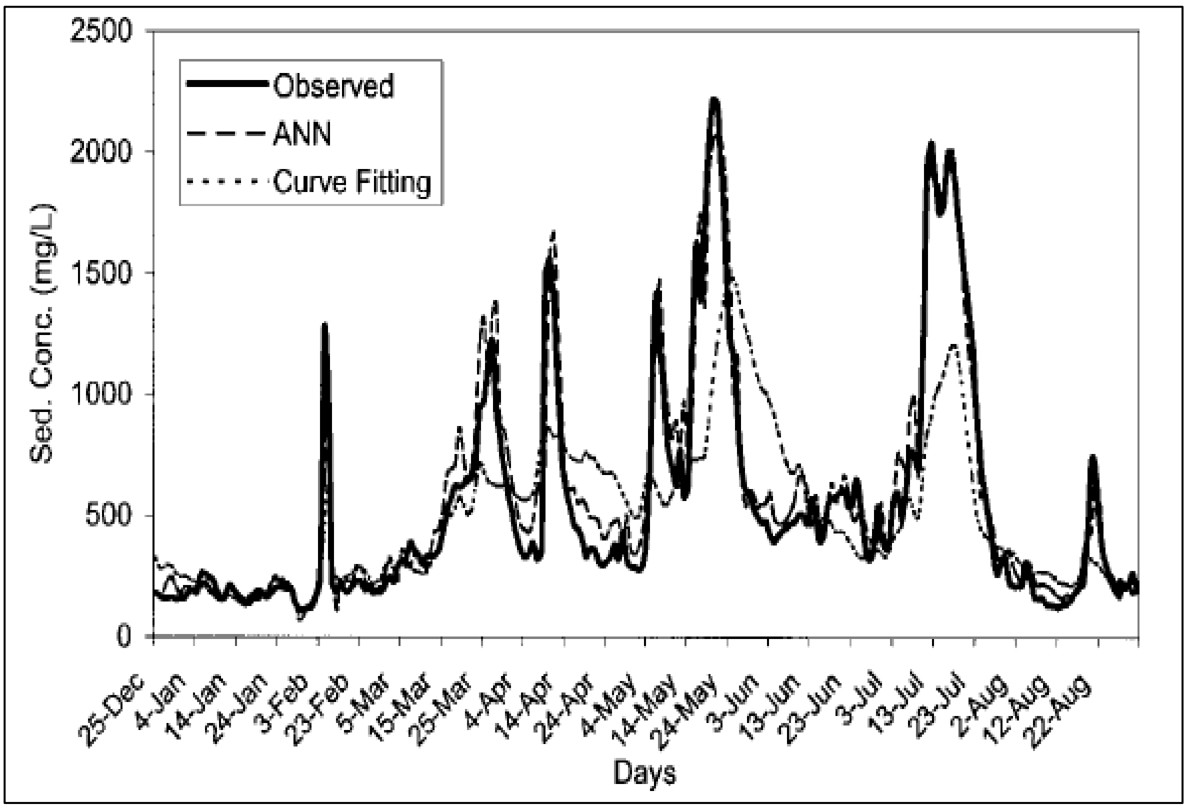

Figure 6: Observed and computed sediment concentration using the ANN approach.
Source: Journal of Hydraulic Engineering

Another improved approach to sediment discharge prediction is that of the use of a phase-space reconstruction. According to this approach, the dynamic changes of the suspended sediment concentration phenomenon are represented by reconstructing (or embedding) the single-dimensional (or variable) suspended sediment concentration series in a multi-dimensional phase-space. After representing the dynamics in the phase-space, a local approximation method is employed for making predictions. The predicted suspended sediment concentrations have been found to be in very good agreement with the observed ones, particularly in the case of bed load dynamics; not only are the major trends well captured but the minor (noisy) fluctuations are reasonably preserved as well (Figure 7). The results have also revealed that bed load dynamics are dominantly influenced by three variables, suggesting that the dynamics could be understood from a low-dimensional chaotic dynamical perspective (Sivakumar 2002, Jayawardena and Sivakumar 2003).

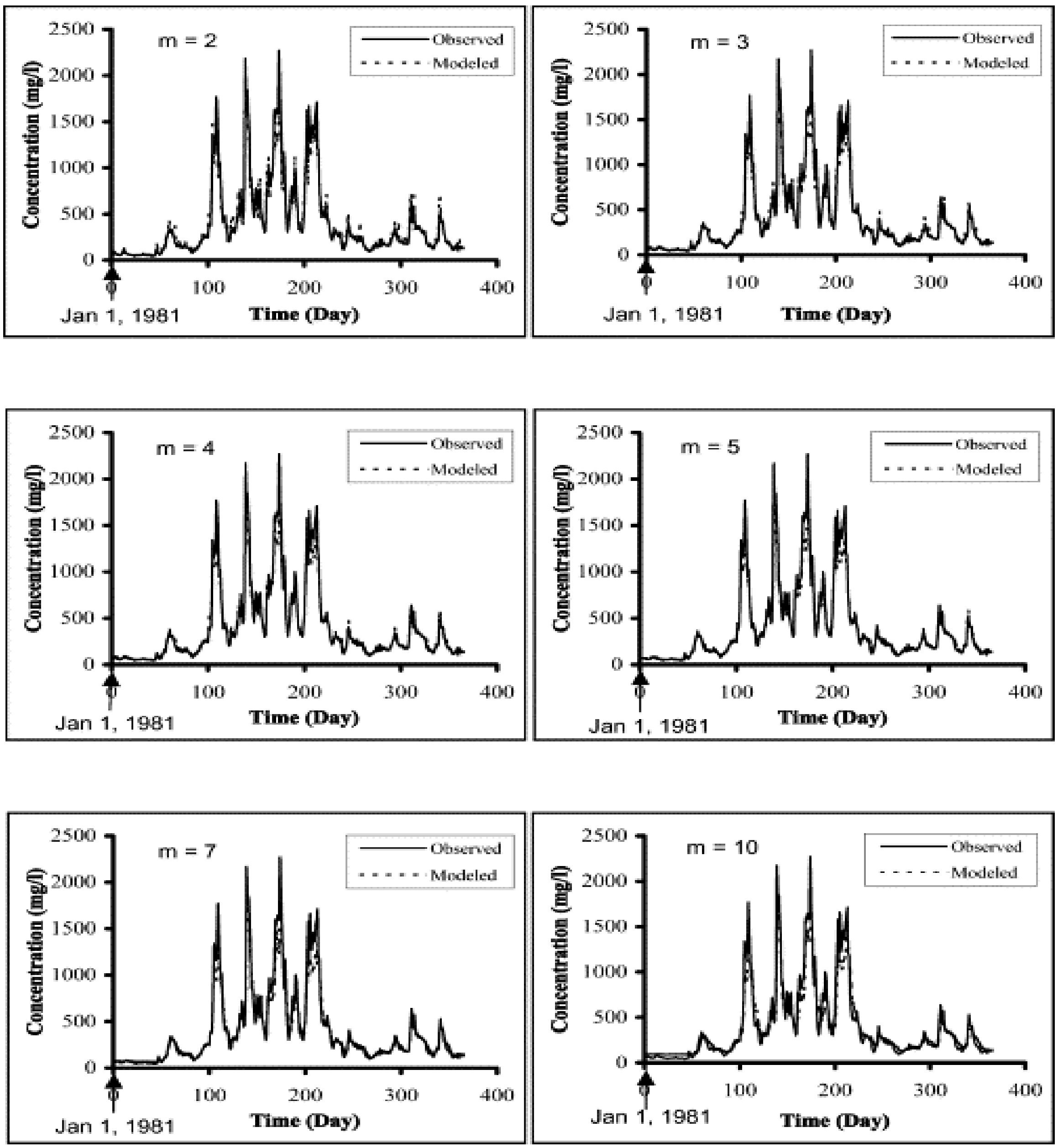

Figure 7: Observed and modeled sediment concentration using a phase-space reconstruction approach
Source: Journal of Hydraulic Engineering

Recent technological advances have also yielded a desktop computational approach, which provided preliminary answers to several questions related to vessel-induced sediment resuspension. Field data has indicated that large vessels generate large drawdown and small wave heights, whereas small vessels such as pleasure craft generate small drawdown and large wave heights. PC-based FORTRAN programs were developed for (1) computation of time series of vessel-induced waves; (2) erosion and deposition of cohesive sediment under waves and nearshore currents; and (3) computation of noncohesive suspended-sediment concentration caused by river current alone. An application to the upper Mississippi River has been completed. The study was completed with various water depths, wave heights, and sediment erodibility and concentrations (McAnally et al. 2001).

A data acquisition program has also been developed, which uses automated data logging systems for data collected with a number of measuring instruments, including current meters, electronic wave gages, wind monitors, turbidity meters, and pressure transducers. Suspended sediment is collected by a series of continually pumped sampling systems. Several fixed-mounting systems have been developed for instream monitoring equipment. Background data collection includes measuring water surface slopes, velocity distributions and water discharges, suspended sediment concentrations and sediment loads, bed material samples, and wind characteristics. Data collection routines can be divided into three categories: ambient, tow passage, and post-passage. Sampling rates were determined from previous field studies, preserving both amplitudes and shapes of ambient and event information (Bogner et al. 1990).

Physical models have also been utilized as arenas in which to test technological advances related to navigation. For instance, time-dependent bed shear stresses, induced by the passage of a barge tow, have been measured with hot film shear stress sensors in a 1:25 scale model. Conditions typical of those observed for upper Mississippi River navigation traffic were simulated in the experimental facility. Two sets of experiments were carried out: the first set consisted of simultaneous shear stress measurements at different locations for a variety of flow depths and boat operating conditions, providing space-time distributions of ensemble averaged wall shear stresses. The second set included a large number of realizations gathered for one particular flow condition at a single position, allowing analysis of the time evolution of the turbulence characteristics (i.e., standard deviation) of the bed shear stresses. The results of the first set of experiments show that for all the experimental conditions the basic patterns of the shear stress are similar, with two regions of high shear stress associated with the passage of the bow and the stem of the barge tow, respectively. Analysis of the second set of experiments showed that as a result of the passage of the barge tow, the bed-shear stress standard deviation departs from the values commonly observed under steady, uniform, open-channel flow conditions (Admiraal et al. 2002).

The advent of advanced personal computers has contributed significantly to the accuracy of prediction, particularly in the case of mathematical models. For example, the lower reaches of tributaries of the Missouri River have been straightened, which has resulted in propagating channel degradation in the upstream direction. Channel deepening and widening have caused problems at stream crossings and have resulted in gully encroachment into cultivated fields. A diffusion model and a hyperbolic model, each describing channel degradation, were solved using a Laplace transform approach. A close-form solution was obtained for the diffusion model, but numerical methods were necessary for evaluation of the inverse transform of the hyperbolic model. A closed-form asymptotic solution was found for the hyperbolic case. Both solutions were found to be in very good agreement with actual results (Hjelmfelt and Lenau 1992).

Upland Erosion

Agricultural landscapes have been more sensitive to climatic variability than natural landscapes because tillage and grazing typically reduce water infiltration and increase rates and magnitudes of surface runoff. Studies have been completed to determine how agricultural land use has influenced the relative responsiveness of floods, erosion, and sedimentation to extreme and nonextreme hydrologic activity occurring in watersheds of the upper Mississippi Valley. The Illinois River Basin has been of particular interest due to its land use characteristics and size. Soil erosion and deposition of sediment into surface waters is a natural process that has been accelerated by land altering changes brought about by man. Intensive agriculture, land clearing, urban construction, drainage of wetlands, levee construction and alteration of stream segments in both the Illinois River Basin and lower Mississippi Valley have significantly increased the rate of erosion and the amount of sediment entering stream tributaries, the Illinois River and its backwater lakes and sloughs (Figure 8).

Figure 8: Sheet erosion in the Upper Mississippi River basin
Source: U.S. Department of Agriculture

High-resolution floodplain stratigraphy of the last two centuries has shown that accelerated runoff associated with agricultural land use has increased the magnitudes of floods across a wide range of recurrence frequencies. The stratigraphic record has also shown that large floods have been particularly important to the movement and storage of sediment in the floodplains of the upper Mississippi Valley. Comparison of floodplain alluvial sequences in watersheds ranging in scale from headwater tributaries to the main valley Mississippi River demonstrates that land use changes triggered hydrologic responses that were transmitted nearly simultaneously to all watershed scales. In turn, flood-driven hydraulic adjustments in channel and floodplain morphologies contributed to feedback effects that caused scale-dependent long-term lag responses (Knox 2001).

In the upper Mississippi Valley, erosion control programs have been targeted to the most critical subwatersheds in order to achieve significant reductions in sediment delivery (Figure 9). An effective sediment reduction program should include both a sediment trapping element, as well as an erosion reduction element. Suggestions for land treatment programs, that have been developed for the upper Mississippi Valley, include: (1) concentrate soil conservation efforts in the watershed areas above the surrounding Peoria Lakes; (2) actively encourage and promote the adoption of cropping systems which reduce tillage and increase crop residues; (3) in priority watersheds, employ large sediment basins and man-made wetlands to trap sediment before it reaches the Lake; (4) utilize a coordinated, multi-county approach to target efforts at the most critical sites; (5) erosion control on some steeper cropland adjacent to streams and near the lake can only be achieved economically by removing that land from production and establishing permanent cover and filter strips on highly-erodible ground; (6) highest priority, for erosion control, should be given to areas with steep slopes and excessive streambank erosion; and (7) organize citizen-based steering committees in each subwater shed to develop an action plan specific to each subwatershed (Parker 1989, Nichols 1989).

In the lower Mississippi Valley, recent sediment accumulation rates have also been an issue of concern. Moon Lake, a large Mississippi River oxbow lake in northwestern Mississippi, has been receiving channeled inflow from an intensively cultivated soybean, rice, and cotton and limited overland flow from surrounding lands, exhibited depositional patterns that were associated with (1) points of inflow, (2) flow patterns, and (3) lake morphology. From 1954 to 1965, 70% of the lake bottom experienced accumulation rates greater than 2 cm/yr. Accumulation rates exceeded 4 cm/yr in areas of delta formation. Changes in cropping systems during the 1960s, from cotton to soybeans and rice, which require less cultivation, resulted in significantly (alpha = 0.01) less sediment accumulation during the period of 1965-1982 when 86% of the lake averaged less than 2 cm/yr sediment deposition. If current sediment accumulation rates continue, open water habitat in the lake will be reduced by only 3 to 7% during the next 50 years (Cooper and McHenry 1989).

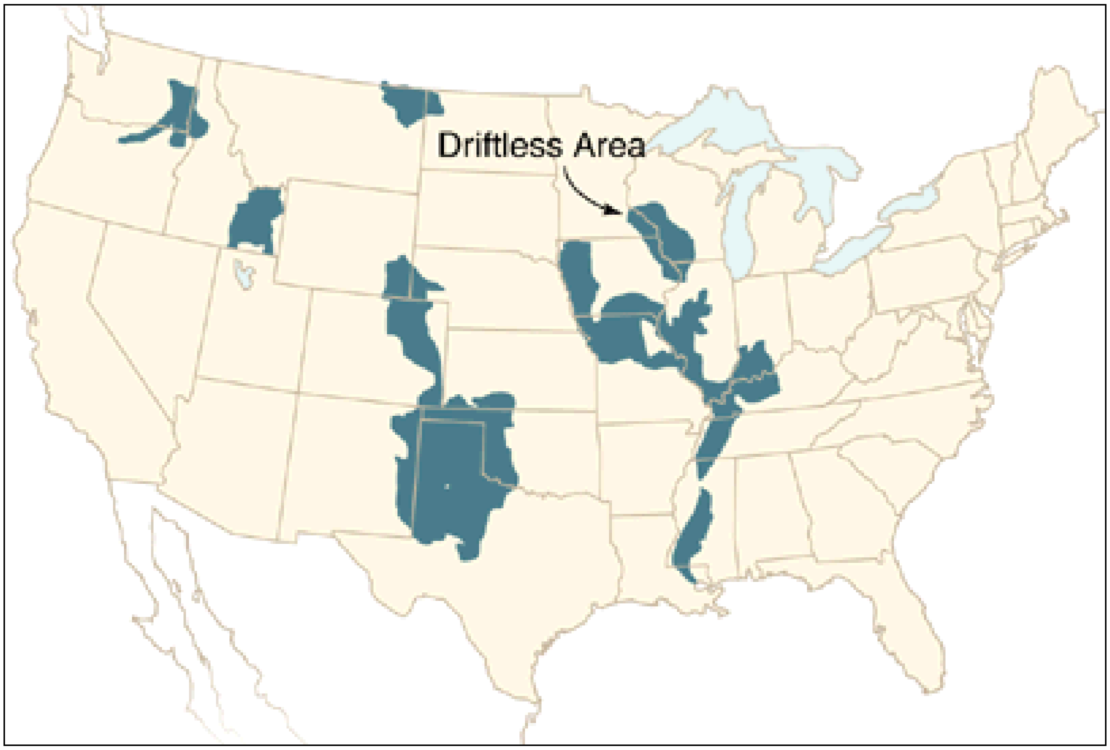

Figure 9: Areas of significant cropland erosion.
Source: Science Magazine

Channel Dynamics and Processes

The dynamics and processes of the channels of the entire Mississippi River Basin have been characterized by channels formations, such as bed forms, sediment transport, morphology and migration, and revetments. Sediment transport, in particular, has had tremendous and widespread effects upon channel dynamics and local ecology. Due to the fact that many of these effects have been undesirable, revetments have also been prevalent throughout the Mississippi River Basin.

Bed Forms

Bed sediments of the lower Mississippi River have been collected to locate deposits of gravel, outcrops of bedrock and aid in the classification of bed forms, or dunes. The size and roughness characteristics of dunes have not been predicted well by experimental and theoretical relations. Although dunes have been found to increase in scale with increasing discharge of water and sediment, the development of multiple dune sizes and nonuniformity have obscured the relationship of dune geometry to synoptic hydraulic variables. Some nonuniformity has been caused by the development of large bed undulations from kinematic waves that can deform into compound dunes, but most of it is related to how convergence and divergence in pools and riffles, varying flow geometry with increasing stage, and reach-controlled relations between flow and energy loss. Even though changes of bedform size have not been found to lag the flow changes because sand transport is large, a considerable volume of sediment is required to initiate and propagate the largest compound dunes (Nordin et al. 1990, Harbor 1998).

Sediment Transport

Average annual rates of erosion and sedimentation have been commonly used to evaluate long-term movement and storage of sediment in watersheds. Average rates often poorly represent actual rates because changing environmental factors may dramatically alter surface runoff, flooding, and channel stability. Dating of historical, Holocene (post-glacial), and late-Wisconsin (late glacial) hillslope and flood plain sediments in southwestern Wisconsin and northwestern Illinois has indicated that rates of sediment erosion, storage, and transportation fluctuated episodically due to changing watershed environmental conditions. In the humid climate of the upper Mississippi Valley, periods of sediment storage tend to be relatively slow and progressive, whereas removal of sediment from storage tends to be episodic with short periods of dramatically high rates separating longer periods of relatively low rates. The replacement of prairie and forest by agricultural land use in the upper Mississippi Valley has resulted in accelerated flood plain sedimentation that averages 30-50 cm deep on tributary flood plains and as much as 3-4 m deep on flood plains in lower reaches of main valleys near the Mississippi River (Knox 1989).

The Illinois River Basin occupies about half of the land area of Illinois. The present-day Illinois River is a remnant of a much larger Mississippi River. The Illinois River serves as the source for public water supply systems through a vast region of the state. The river is also home to a variety of fish populations, and side channels and backwaters serve as nurseries and spawning areas. In addition to fishing and hunting, the activities of boating, water skiing, hiking, and camping and the pleasures of the scenic and historic sites and parks along the river draw thousands of visitors to the banks of the Illinois each year. The most serious consequence to the health and welfare of the Illinois River is the problem of sedimentation. Although sedimentation has been a natural process through the ages, increased row- cropping, and subsequent overland erosion, and the construction of hydraulic structures has exacerbated the problem throughout the river basin (Figure 10). Sedimentation has been responsible for the disappearance of entire backwater lakes, and it has changed many portions of the river from lake-like expanses to narrow incised channels (Witter1990).

Many of the backwater lakes along the Illinois River have lost 30 to 100% of their capacity to sediment deposition. Peoria Lake, a bottomland lake, has lost 68% of its original capacity, and upper Peoria Lake will eventually attain the appearance of an incised river with broad and shallow wetlands on both sides. On the average about 18.7 million metric tons of sediment are deposited annually over the entire river valley, with a deposition rate of 20.5-53.3 mm/yr (Bhowmik and Demissie 1989). The average depth of the lake was reduced from 8 feet in 1903 to 2.6 ft in 1985. The sediment rate in recent years has been higher than in previous years and the annual capacity loss has been 2,000 acre-feet, due in large part to a recent dramatic increase in row crop production (Semonin 1989, Bellrose et al. 1980).

The Mississippi River has also been susceptible to similar sedimentation related problems. Lake Pepin, a natural riverine lake on the upper Mississippi River, has been investigated

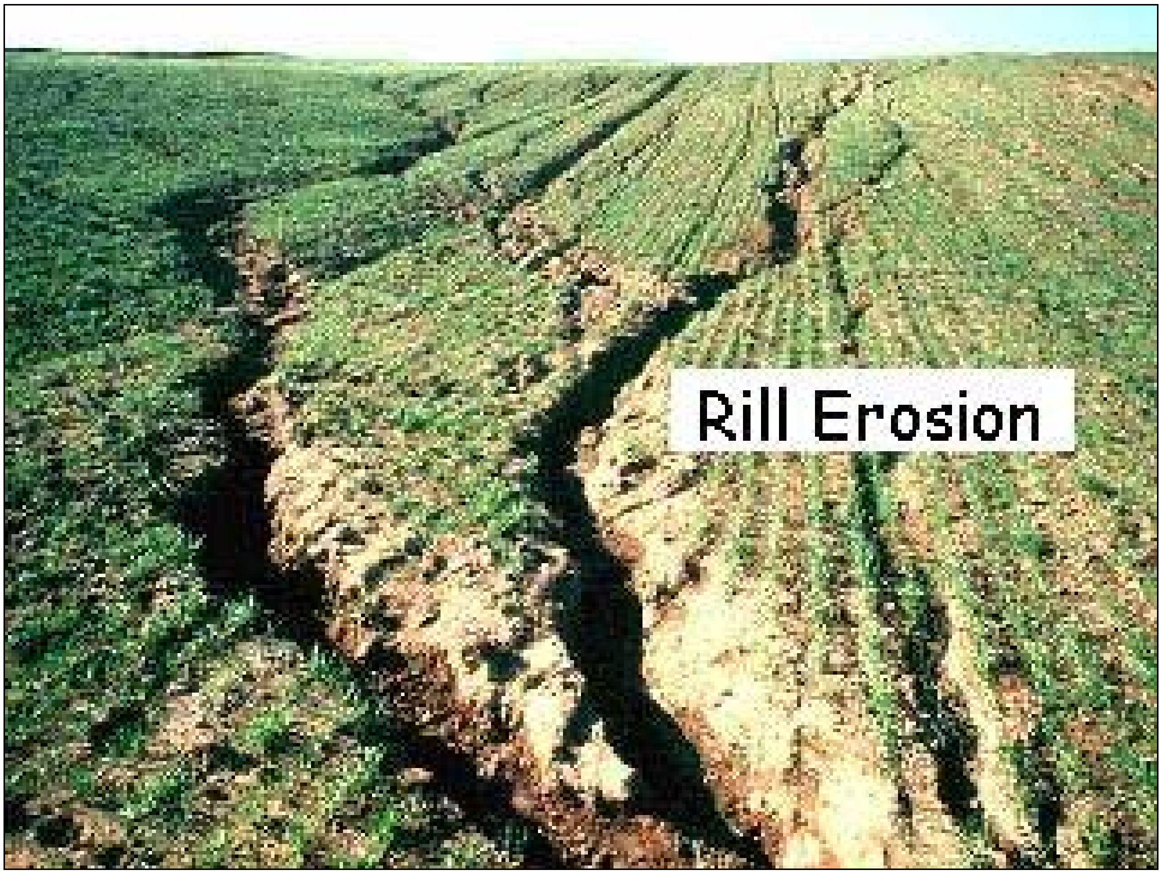

Figure 10: Rill erosion in the Mississippi River Valley
Source: U.S. Department of Agriculture

due to its susceptibility to sedimentation. The modern and historic fluxes of sediments exiting the Mississippi, St. Croix, and Minnesota watersheds and entering Lake Pepin have been examined. The relative apportionment of sediments from the Minnesota River watershed increased since European settlement of the region circa 1830 from 83 to 87% for the upper, 83 to 90% for the middle, and 78 to 87% for the lower reaches of the lake. Sediment loading to the whole lake showed a 12-fold increase from historic levels in the mass of Minnesota River-derived sediments. The amount of sediment currently supplied by this river is more than seven times the amount supplied by the headwater-Mississippi and St. Croix Rivers combined. The causes of these increases have been attributed to intensive agricultural production, especially within the Minnesota River basin. Watershed alterations have also resulted in a decrease in wetlands, riparian zones, and native prairie (Kelley and Nater 2000).

Increased sedimentation has also been present in areas downstream of Lake Pepin on the Mississippi River. Extensive data on sediment input and deposition, including quality and characteristics of the sediment, have been collected from a number of reaches of the Mississippi, downstream of Lake Pepin. The data has indicated similar sedimentation scenarios to those of the Illinois River. Significant sedimentation rates and losses of storage have been prevalent. Pool 19 has lost about 58% of its capacity to sedimentation and may lose about 67% of its capacity by the year 2050, when it will attain a dynamic equilibrium. Pool 21 has also been a significant sediment accumulator (Adams et al. 1988).

In the lower Mississippi Valley, similar sedimentological issues of the upper Mississippi Valley have been present. Areas with high rates of aggradation and degradation, stream deepening and widening and incision have been prevalent. For example, approximately 400 million cubic feet of channel sediments have been delivered to the Mississippi River from the Obion-Forked Deer River system in the last 20 years. The discharge of sediment from these channelized networks in West Tennessee varies systematically with the stage of channel evolution. Variations in yields over time reflect the shifting dominance of fluvial and mass-wasting processes as the networks adjust to lower energy conditions (Simon 1989).

Major influences on rate of stream incision in the Arkansas River basin have been attributed to the arid to semi-arid climate of the region, the type of material being incised by streams, stream captures, and salt dissolution in the bedrock that underlies the region. Rates of incision have exceeded rates of basin filling but significant deposits of unconsolidated late Cenozoic sediments occur in the region. Basins of streams that have incised the slowest since the late Tertiary contain the thickest and most extensive amounts of unconsolidated Quaternary sediments (Carter and Ward 1999).

The Bayou Pierre system in western Mississippi has been experiencing extensive erosion (Figure 11), with pulses of erosion moving from lower to higher stream reaches (e.g., headcutting). This erosion has caused substantial changes to the system, including channel widening and deepening, general loss of downstream riffle habitats, and the creation of new riffle habitats in more upstream locations. There has been an overall trend for erosion to occur in the upper reaches of the Bayou Pierre system, with lower reaches characterized by later, recovery, stages. Between 1940 and 1994, the point of active headcutting moved over 7 km upstream at rates of 48-750 m/yr. Ultimate factors responsible for the rapid headcutting are located downstream of the reaches in question of the Bayou Pierre and the Mississippi River. These factors include natural meander cut-offs, channel avulsion, channelization, and instream gravel mining (Knight et al. 2001).

Magnitude-frequency analysis of gauging station records (1950-1982) on the lower Mississippi has shown that there is a clearly defined dominant flow of about 30,000 m^3/s. This lies within an effective range of channel-forming flows between 17,000 and 40,000 m^3/s, which are responsible for transporting a disproportionately large percentage of the sediment load hydrographic survey data, long-profile records and stage-discharge relationships from calibrated one-dimensional flow models indicated that the dominant discharge corresponds to 'bar-full' discharge on the lower Mississippi and that the effective range of flows occurs between the stage that just tops mid-channel bars and that which significantly overtops the banks. Historical trends in bar growth suggest that bar-top elevations have generally risen to the dominant flow elevation over the last 30 years (Biedenharn and Thorne 1994).

Figure 11: Headcutting in the lower Missisisippi River.
Source: U.S. Army Corps of Engineers

Floodplains contain valuable stratigraphic records of past floods, but these records do not always represent flood magnitudes in a straightforward manner. The depositional record generally reflects the magnitude, frequency, and duration of floods, but is also subject to storm-scale hysteresis effects, flood sequencing effects, and decade-scale trends in sediment load. Many of these effects are evident in the recent stratigraphic record of overbank floods along the upper Mississippi River, where the floodplain has been aggrading for several thousand years. On low-lying floodplain surfaces in Iowa and Wisconsin, Cs-137 profiles suggest average vertical accretion rates of about 10 mm/year since 1954. These rates are slightly less than rates that prevailed earlier in the 20th Century, when agricultural land disturbance was at a maximum, but they are still an order of magnitude greater than long-term average rates for the Holocene. As a result of soil conservation practices, accretion rates have decreased in recent decades despite an increase in the frequency of large floods. The stratigraphic record of the upper Mississippi River floodplain has been dominated by spring snowmelt events, because they are twice as frequent as rainfall floods, last almost twice as long, and are sometimes associated with very high sediment concentrations. The availability of sediment during floods has also been influenced by a strong hysteresis effect. Peak sediment concentrations have generally preceded the peak discharges by 1-4 weeks, and concentrations are usually low (< 50 mg/l) during the peak stages of most floods. The lag between peak concentration and peak discharge has been especially large during spring floods, when much of the runoff is contributed by snowmelt in the far northern reaches of the valley. The great flood of 1993 on the Mississippi River focused attention on the geomorphic effectiveness and stratigraphic signature of large floods. At McGregor, where the peak discharge had a recurrence interval similar to 14 years, the flood was most notable for its long duration, high sediment concentrations (three episodes >180 mg/l), and large suspended load. The flood of 2001, despite its greater magnitude (recurrence interval similar to 70 years), was associated with relatively low sediment concentrations (< 60 mg/l). The 1993 and 2001 floods each left 30-80 mm of silty fine sand on most low-lying floodplain surfaces, but the 2001 flood produced sandy levees near the channel while the 1993 flood did not. The stratigraphic signature of these recent floods is more closely related to the duration and total suspended load of the event than to the magnitude of the peak discharge (Benedetti 2003).

Figure 12: Confluence of the Mississippi and Missouri River in August of 1993.
Source: U.S. Geological Survey

The 1993 flood on the upper Mississippi and Missouri rivers has widely been considered the largest flooding event on these river basins (Figure 12 and Figure 13). Not only were many miles of the rivers flooded, but there was also a significant amount of flooding to the interior of the country. More than 420 counties in all the Midwestern states were declared disaster areas. Stages were exceeded at many locations, hundreds of levees either failed or were overtopped, more than 500 scour holes developed, rivers scoured their beds at numerous locations, sediments were deposited at many other locations, and the rivers attempted to create new channels and/or cutoffs during the peak periods. Field and aerial survey analyses and Landsat 5 Thematic Mapper data were used to appraise the thickness of overbank deposits on leveed and unleveed reaches. Results indicated that minimal (<5 mm) overbank sedimentation occurred at both leveed and unleveed sections, except in the immediate vicinity of a levee break (Bhowmik 1996, Gomez et al. 1998).

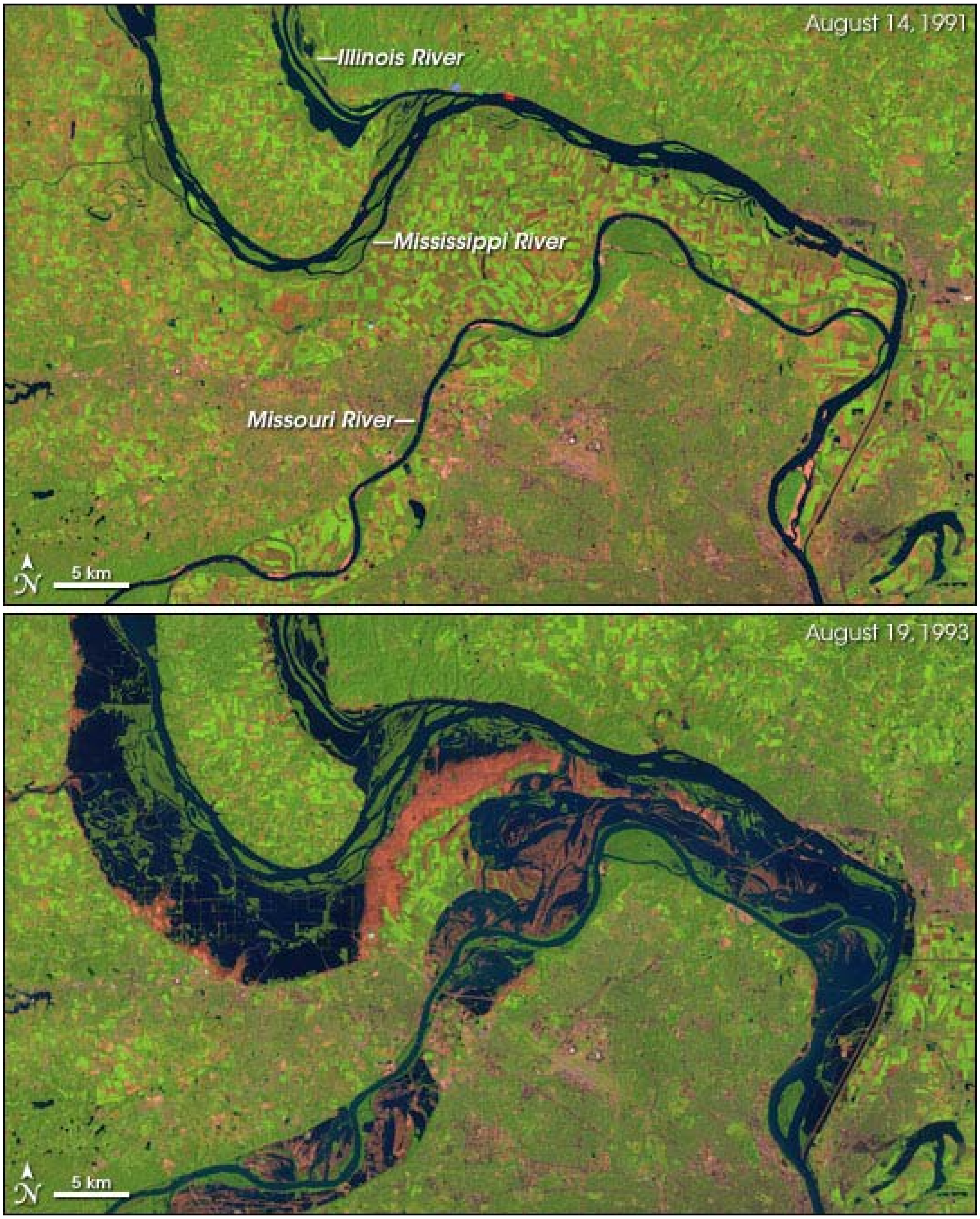

Figure 13: Aerial view of the Mississippi River before (top) and after the flood of 1993 (bottom). *Source:* U.S Geological Survey

Circumjacent sand deposits were a component of the levee break complexes that developed in the immediate vicinity of break sites (Figure 14). As epitomized by the levee break complex at Sny Island, these features consisted of an erosional, scoured and/or stripped zone, together with a horseshoe-shaped, depositional zone. At locales farther removed from the break site, the impact of flooding was exclusively depositional and was attributed to the settling of suspended sediment from the water column. The overall picture was one of modest scour at break sites and minimal suspended sediment deposition at locales farther removed from the breach. Downstream from the confluence with the Missouri River, levee break complexes exhibited a similar morphology, but scour at break sites was greatly enhanced and the excavated sand formed extensive deposits on the floodplain surface. The different erosional response was probably engendered by the higher sand content and reduced aggregate cohesion of the floodplain soils downstream from the confluence with the Missouri River. Little geomorphological or sedimentological evidence of this extreme event is likely to be preserved, which raises questions about the completeness of the stratigraphic record: in situations where wide floodplains with cohesive soils provide effective resistance and dissipate energy so that erosion is minimized, and/or sediment supply is limited by event timing or sequencing, a large flood may leave little or no substantive evidence of its occurrence (Gomez et al. 1997, Gomez et al. 1998).

Figure 14: Levee failure on the Mississippi River during the 1993 flood event
Source: U.S Army Corps of Engineers

Morphology and Migration

Periodic surveys of the upper Mississippi River since 1866 and a discharge record-of nearly equal length have allowed for examination of the magnitudes and rates of geomorphic processes at work. Furthermore, geomorphic and hydrologic adjustments have been evaluated in relation to watershed land use changes, small-scale climate fluctuations, and considerable modifications to the channel and floodplain during the period of record. GIS mapping has been utilized to quantitatively compare historical changes in mapped land and water phenomena in the upper Mississippi River Pool 10, located along southwest Wisconsin's border. Modest channel widening and decreases in island area have been detectable. Flood magnitudes and frequencies also have varied during this time, and stages and low flow discharges have increased since the 1940s. The latter hydrologic change appears to have been related to geomorphic adjustments closely associated with the reach. Results are representative of a valley reach where a major tributary contributes a large sand bedload, forming an alluvial fan of considerable size in the floodplain (Collins and Knox 2003).

Channel migration and meander-bend morphology have also been examined in the lower Mississippi River, specifically between 1877 and 1924, prior to channel cutoffs, revetments, and change in sediment regime. The spatial pattern of meander-bend migration coincided with differences in floodplain deposits. Migration of meander bends averaged 45.2 m/yr in the upper alluvial valley, where there are numerous clay plugs, but increased to 59.1 m/yr in the lower alluvial valley, where there are fewer clay plugs in contact with the channel (Figure 15). The highest migration rates occurred with meander bends having a curvature, r(m)/W-m (ratio between meander-bend radius to channel width) between 1.0 and 2.0, which has been a departure from previous models (Hudson and Kesel 2000).

Figure 15: Evidence of channel migration in the Mississippi River.
Source: U.S. Geological Survey

The soils types of the lower alluvial valley have been particularly susceptible to erosive dynamics, which have lead to increased wood debris on a 400-500 km reach of the Red

River, Louisiana. Sediment and riparian trees from eroded banks formed organic debris dams which blocked the channel and promoted channel aggradation. Over a period > 375 years wood debris dams formed in series. The average rate of channel blockage was 1.3 to 1.6 km/year between1793-1876. Maximum debris accumulation recorded in a single flood was 8.1 km. Exposed wood covered 80-120 km of channel. Wood debris impacted adjacent riparian areas by flooding forests and forming a series of large lakes. Flow reversal in tributaries resulted in channel enlargement and diversion of one half to three quarters of the river's discharge adjacent to riparian lowlands. Wood debris reduced the river's width from about 185 m to approximately 40 m, and aggraded the river bed a maximum of 7 m. Tributary channels were dammed or filled with organic debris, and the river was permanently opened to navigation in 1873. Restoration of full channel flow exposed previously buried logs and eroded forested banks. By 1904, seventy years of debris dams and snag removal, levee projects, dredging and cutting bankside trees resulted in a cleared, wide, meandering channel, which might today be mistaken as typical of a pristine lowland river (Triska 1984).

The changes in slope and stream power of the lower Mississippi River during the pre-cutoff (1880s-1930s), and post-cutoff (1943-1992) periods have been examined. The largest increases have occurred between Fulton, TN, and Lake Providence, LA, where slope and stream power increases ranged from about 27% to 36% and 20% to 38%, respectively. Increases in slope and stream power in reaches upstream and downstream have also occurred, but to a lesser degree. Excess stream power in the sub-reaches, directly affected by cutoffs, resulted in scour that increased downstream bed material load. These elevated sediment loads played a key role in driving morphological adjustments towards equilibrium in the post-cutoff channel. The stability status of the channel in the study reach currently ranges from dynamic equilibrium in the farthest upstream reaches through severe degradation to dynamic equilibrium in the middle reaches, and aggradation in the lowest reaches (Biedenharn et al. 2000).

Human occupation and development of alluvial river floodplains have been adversely affected by river channel lateral migration, which may range as high as several hundred meters per year. Reservoirs that reduce the frequency and duration of high flows typically reduce lateral migration rates by factors of 3 to 6. The ecology of riverine corridors is dependent upon the processes of erosion and sedimentation, which lead to lateral migration. For example, the Fort Peck Dam in Montana on the Missouri River has created downstream ecological problems. Maps and aerial photographs have been analyzed before and after dam construction. This imagery was analysed by digitizing channel centerlines at successive coverages under pre-dam and post-dam conditions, and mean migration rates were computed by bend and by reach. The mean rate of channel centerline migration fell from 6.6 m/yr to 1.8 m/yr after impoundment. Bend-mean channel activity rates were only weakly correlated with variables describing channel form and geometry. Results indicated that flow regulation for flood control and hydropower production have had profound effects on river corridor dynamism, with implications for habitat type distribution and ecosystem integrity (Shields et al. 2000).

Revetments

Levees and dikes have been essential in sustaining the Mississippi River and its banks (Figure 16). Due to the river's size, many innovative revetments have been required to ensure the livelihood of the river, and its surrounding ecology, both terrestrial and aquatic. The purposes and successes of these revetments have been widely varied and in some cases, improvements or alterations have been necessary for already in-place revetments. The Southwest Pass of the Mississippi River is the main navigation outlet to the Gulf of Mexico. As a part of planned efforts to stabilize the banks of the Southwest Pass and reduce maintenance dredging, improvements on the lower part of the river near the entrance were being reviewed. Plan dike fields were developed as a logical progression by consideration of the uniformity of the longitudinal channel velocity and sediment transport capacity. Results have indicated that the most important element of the revetment has been the extension of the dike fields back to the jetty to prevent flow out of the channel and behind the dikes (Berger et al. 1989).

Figure 16: Examples of a levee located in the upper Mississippi River.
Sources: U.S. Geological Survey

In the late 1940s, the principal levees along both sides of the Mississippi River from Alton to Gale, Ill., were raised to a 1-in-50-year flood level--a 500-year frequency in urban areas. In 1950, the St. Louis District initiated an investigation of seepage beneath these levees. As a result of this investigation, 2,480 relief wells were installed along 292 mi of mainline and tributary levees during the 1950s. During the flood of 1993, the stage of the Mississippi River along the mainline levees equaled or exceeded the design stage, the highest river level to which the middle Mississippi River levees had ever been subjected. The relief well systems performed successfully and prevented any significant sand boils or piping for a design river stage. The parameters involved in design and performance of the underseepage control systems were largely confirmed within the normal variations of the parameters involved and field conditions. This investigation has also verified the importance of not only building levees high enough to hold back the design high water of a river, but also the design, construction, and maintenance of relief well systems to prevent failure of levees as a result of sand boils and/or piping for the various subsurface conditions that exist along levees in the alluvial valleys of major rivers (Mansur et al. 2000).

Figure 17: Dike field in the lower Mississippi River
Source: U.S. Geological Survey

Dike fields are intermediate physically, chemically, and biologically to the main channel and backwaters of rivers (Figure 17). Dike fields often support the most diverse fish and macroinvertebrate community of any habitat within the river. But community composition is less stable than backwaters and is dependent upon river stage and water velocity. Long-term effects of river training structures have been detrimental to the biotic integrity of the river. Increased water velocity in the thalweg, as a result of the current being forced into the middle of the channel by dikes, has resulted in riverbed degradation and dewatering of backwater areas during low flow. Stabilization of the channel has prevented the river from meandering and forming new oxbow lakes, secondary channels, and backwater habitats. Deposition of silt in backwaters and on the downstream side of dikes has resulted in the loss of these habitats in extreme cases. The result, as demonstrated in portions of the Missouri River, has been a reduction in water-surface area; loss of island, chutes, and backwater areas; and the constriction of the river to a single, narrow channel. Regions of reduced velocity adjacent to spur dikes along the lower Mississippi River have been valuable aquatic habitats. After many of the dikes were constructed, the aquatic volume and area of associated low-velocity habitats have been reduced by 38% and 17%, respectively. Examination of time series shows that most changes occur shortly after construction, and after initial adjustment, habitat area and volume fluctuate about a condition of dynamic equilibrium. Sedimentation rates have been found to be most rapid for dike fields constructed on the inside of bends to prevent chute development (Atchison and Sandheinrich 1986, Shields 1995).

Figure 18: Fort Peck dam in Montana on the Missouri River
Source: U.S. Army Corps of Engineers

Sedimentation in the upper Mississippi River backwaters has been an issue of concern since the installation of dams (Figure 18) and navigation locks (Figure 19), artificial levees, dikes, concrete revetments and a series of channel cutoffs. The role of the flood plain has also changed. Prior to modifications, the flood plain was the major sediment source as the result of bank caving. Today the flood plain provides only a minor amount of sediment due in part to bank stabilization via revetments like articulated concrete mattresses or ACM's (Figure 20). Significant degradation has occurred within the channel characterized by the growth of channel bars, which have occurred as a result of these engineered modifications (Figure 21 and Figure 22). Many of the pools, formed by the navigation dams, have nearly reached a new equilibrium condition for scour and deposition of sediment. Several pools with extensive backwater or channel border areas are still accumulating sediment at rates similar to those for man-made lakes. The impounded river subjects previously protected aquatic habitat to increased durations of river flow and associated sedimentation. The upper Mississippi River flooding has heavily influenced backwaters adjacent to the main channel, while backwaters more distant from the main channel have the potential to be influenced by small tributary streams (Knox and Theis 2003, Kesel 2003).

Figure 19: Lock and dam structure in the upper Mississippi River.
Sources: U.S. Corps of Engineers

Peoria Lake has been affected by the diversion of Lake Michigan water into the Illinois River in 1900 and the construction of a lock dam in 1939. For the period of 1903 to 1965, the sedimentation rate for Peoria Lake was 0.63%/yr, which was relatively high, but within the range for sedimentation rates for other large lakes and reservoirs in Illinois. The sedimentation rate for the period of 1965-1985 was 1.44%/yr, which was more than double the rate of the previous period and by far the highest sedimentation rate among the large lakes and reservoirs in Illinois. The creation of artificial islands by selective dredging of certain areas has been proposed to attempt to eradicate the problems of Peoria Lake (Adams and Bhowmik 1989, Demissie 1989). Backwater from Lock and Dam 4 on the Mississippi River has inundated the mouth of the Buffalo River valley. Sediment yields from the watershed have persisted at relatively high levels over a period of several decades despite pronounced trends toward less cultivated land and major efforts to control soil erosion from agricultural land. Incision has extended the network of historical incised tributary channels, enhancing the efficient delivery of sediment from upland sources to downstream sites (Faulkner and McIntyre 1996).

Figure 20: Articulated concrete mattress installation in the upper Mississippi River
Source: U.S. Army Corps of Engineers

Figure 21: Example of a channel bar formed as a result of revetments
Source: U.S. Army Corps of Engineers

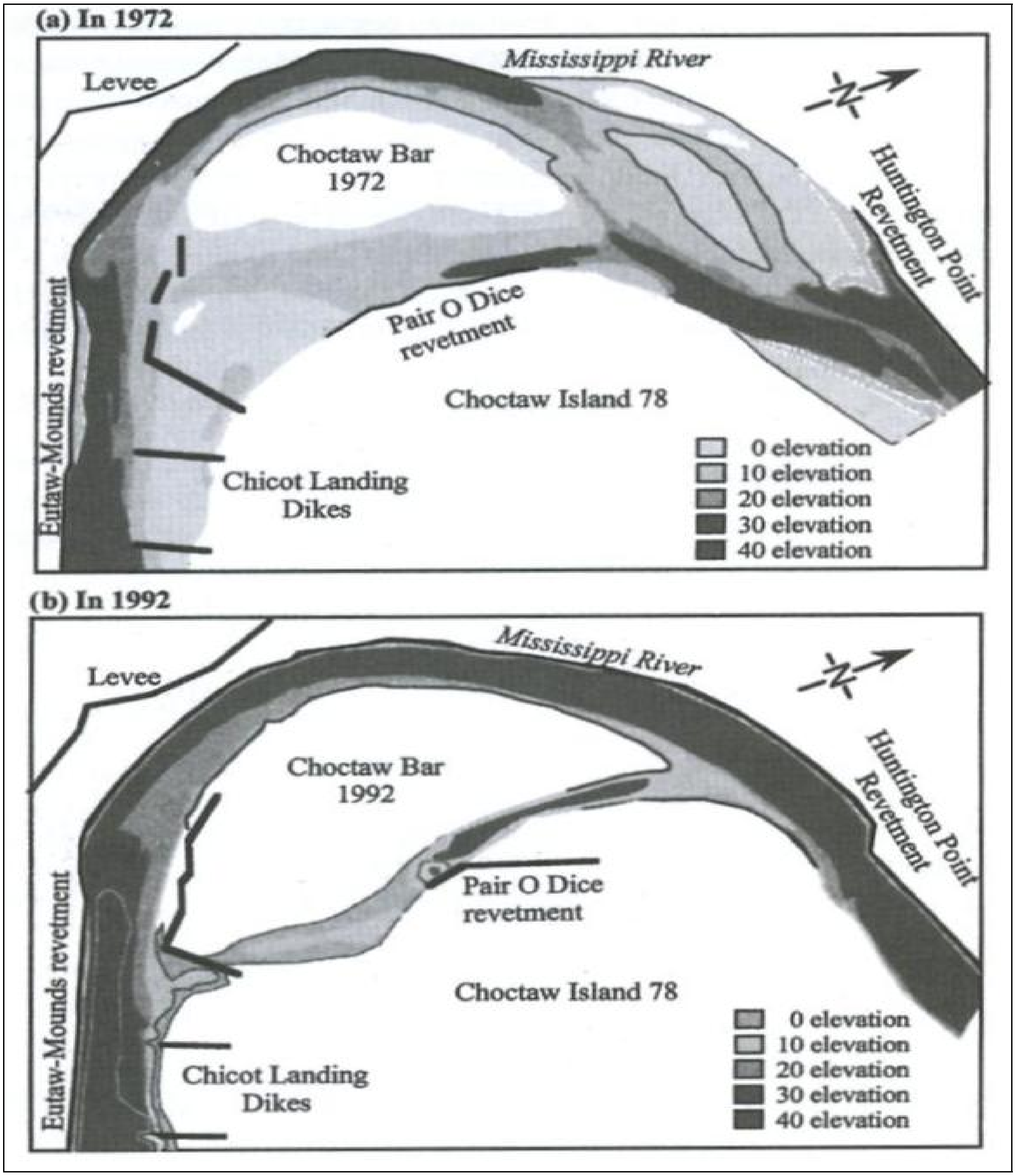

Figure 22: Dredging and revetments at Choctaw bar of the Mississippi River to improve navigation
Source: River Mechanics, Julien 2002.

Sedimentation in cutoff bends along modified, stabilized streams often constitutes a valuable recreational, ecological, and aesthetic resource; however, their resource value rapidly declines as they fill with sediment (Figure 23). Management of cutoff bends should focus on sequencing construction activities and modification of the upstream bend entrance geometry to reduce the quantity of bed material diverted into the bend. Construction of blockage structures to top-bank elevation in upstream entrances of cutoff bends has been recommended for systems with average suspended bed-material concentrations greater than about 50 ppm. Blockage or modification of entrance geometry of longer bends preserves more aquatic habitat longer than similar levels of effort directed toward shorter bends. Maintenance of a hydraulic connection between the river and at least one end of the cutoff bend has also been recommended (Abt and Shields 1989).

Figure 23: Example of a cutoff bend in the lower Mississippi River
Source: U.S. National Park Service

The stage adjustments in the lower Mississippi River during the pre-cut-off and post-cut-off periods have been analyzed. The analysis shows that the majority of the pre-cut-off lower Mississippi River was not undergoing any significant system instability such as channel aggradation or degradation, and, therefore can be considered to have been in a state of dynamic equilibrium during this period. However, the analysis did show that the upper portion of the Mississippi River, in the vicinity of Columbus, was undergoing a significant aggradational trend during this period, displaying the responses of a smaller reach that has experienced a cut-off (Biedenharn and Watson 1997).

Alterations of the Mississippi and Atchafalaya Rivers over the past 140 years have significantly affected the distribution of flow and sediment loads entering the estuaries of south Louisiana. The most significant alterations have been: removal of the Atchafalaya River log raft and subsequent alterations which hastened natural processes; confinement of flood flows by levees limiting discharges to three specific outlets; and those alterations that caused a 50% reduction in average annual suspended sediment loads transported by the Mississippi and Atchafalaya Rivers (Combe and Tuttle 1981). Repeated shifting of the locus of deltaic deposition (delta switching) has been the fundamental process by which the complex delta plain of the Mississippi River has been built. Even though control structures presently limit flow down the Atchafalaya to 30% of the Mississippi plus the Red River contribution (Figure 24), dramatic changes have occurred along the central Louisiana coast since the early 1950s (Roberts 1998).

Figure 24: Atchafalaya control structure in the lower Mississippi River.
Source: U.S. Geological Survey

Sediment control has been an issue of concern related to the influx of bedload sediments near water intakes along the Missouri River. The effectiveness of structural modifications has been investigated via physical hydraulic modeling. The modifications included a series of submerged flow-turning vanes located on the riverward side of the intake, and a sediment-barrier wall between the vanes and intake, which increased the streamwise velocity component, thereby enhancing the effectiveness of flow-turning vanes in maintaining a deep scour trench. Results were found to be highly effective as a means for controlling bedload sediments (Nakato and Ogden 1998).

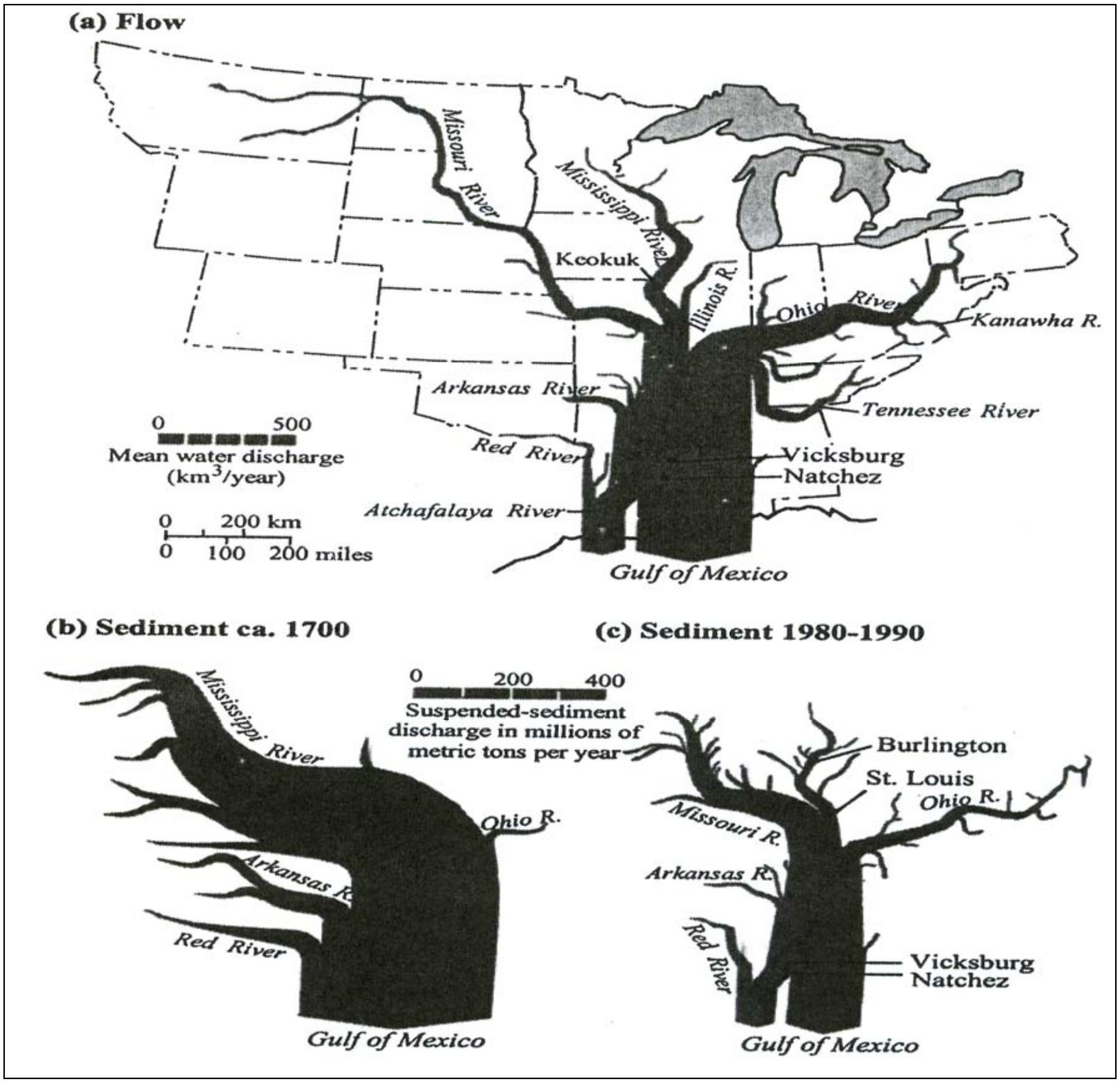

Figure 25: Regime of the Mississippi River
Source: River Mechanics, Julien 2002.

The U.S. Army Corps of Engineers, Missouri River Division, have constructed several large multi-purpose dams in tandem along the upper Missouri River for flood control, power production, irrigation, water supply, augmentation of river discharges for navigation and water quality, recreation, and fish and wildlife benefits. These dams now intercept the sediment from one of the most sediment producing regions in the continental United States, which has had a far-reaching influence, not only within the individual reservoir projects themselves, but also on the open river reaches between the projects and downstream from the lowest dam (Figure 25 and Figure 26). Changes in hydrologic conditions and channel morphology downstream from the dams have impacted channel stability. Impacts have included streambed degradation of up to 3.6 m and substantially altered magnitude, frequency, and temporal distribution of flows (Mellema and Wei 1986, Curini et al. 2002).

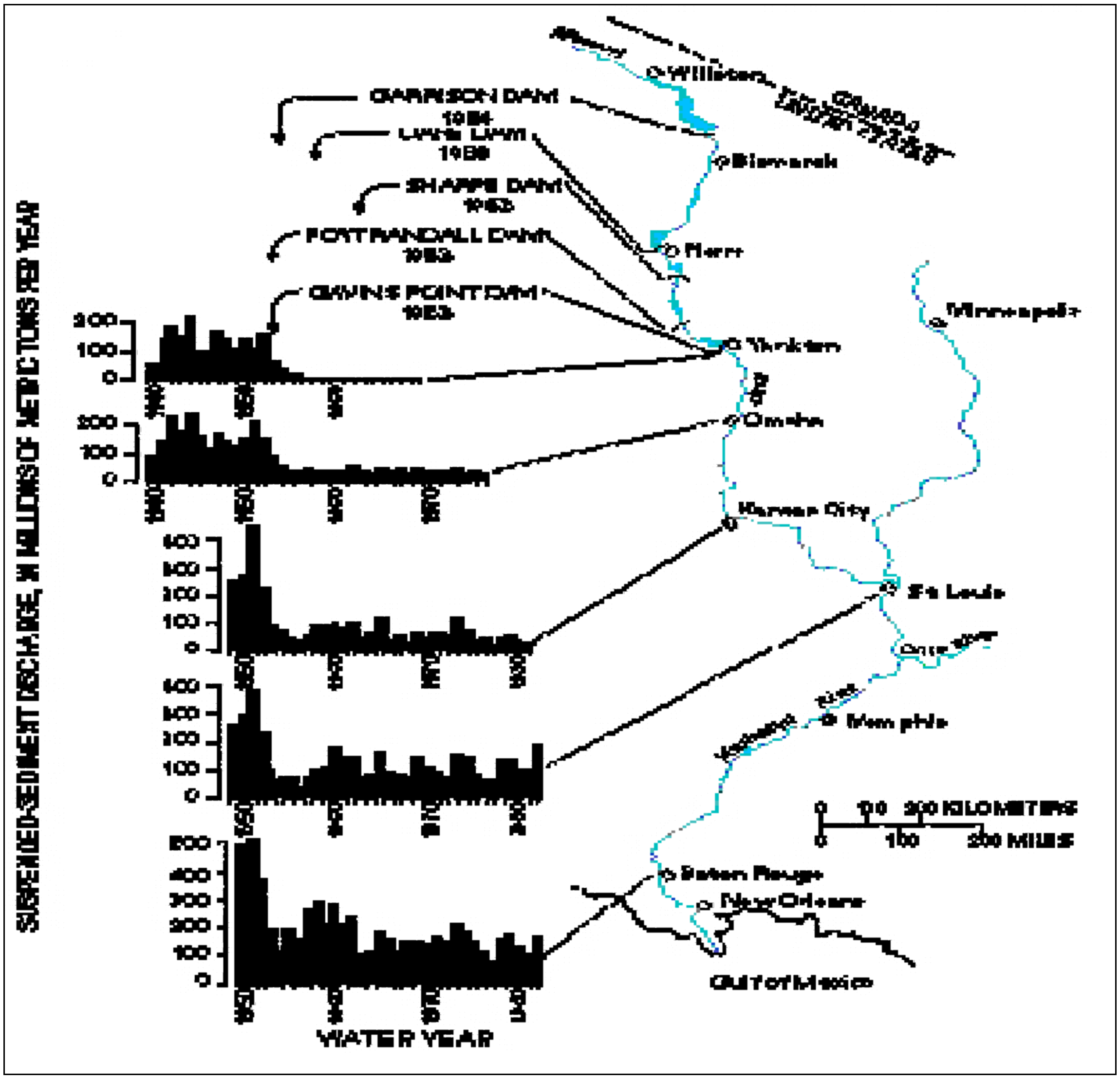

Figure 26: Changes in sediment discharge in the Mississippi River Basin since 1940.
Source: U.S. Geological Survey

Marsh and Wetland Impacts

Since 1850, there has been an overall decrease in excess of 70% in the suspended load transported by the lower Mississippi River. A decrease of 25% between the earliest measurements and 1950 may be partly the result of a decline in discharge and partly the result of a change in land use practices. The largest decrease occurred in 1952-53 following construction of major main-stem reservoirs on the Missouri River. Similar construction on the Arkansas River has resulted in a further decrease in 1962-63. During the pre and post-dam periods, the rate of water level rise exceeded sediment accretion on the marsh surface. Although the elimination of overbank sediment clearly exacerbated the wetlands loss, an accelerated rate of water level rise during the past 25 years has been a dominant factor. The decrease in suspended load, combined with the artificial levee construction program and the overall enhancement of the river channel for navigation has been accompanied by an accelerating decline in land area of the Louisiana coastal zone from 17 sq km/yr in 1913 to 102 sq km/yr in 1980 (Kesel 1988, Kesel 1989).

To counteract the extensive wetland loss, a series of diversion projects have been implemented to introduce freshwater and sediment from the Mississippi River into Louisiana coastal wetlands. To keep pace with increases in water level due to subsidence, Louisiana coastal marshes must vertically accrete through the accumulation of both organic matter and mineral sediment. Vertical accretion and accumulation of mineral sediment organic matter and nutrients in the marsh soil profile have increased at marsh sites receiving freshwater and sediment input. Results demonstrated that freshwater diversion through sediment input and lowering of salinity will enhance marsh accretion and stability, slowing or reversing the rate of wetland loss (DeLaune et al. 2003).

Dredging

The effects of dredging have been well documented and characterized by several problems including those related to cost, channel stability, sediment transport, and surplus sediment masses (as a result of dredging). A 34-year record of dredging in a 484-km reach of the middle and upper Mississippi River documents the spatial and temporal patterns of bed aggradation in the intensively engineered river. Between 1964 and 1997, 183 million cubic meters was removed from the study reach with 112.6 km of the channel undergoing dredging of some kind, 12.1 km requiring greater than or equal to 5 dredgings during this period. 2.6 km requiring greater than or equal to 10 dredgings, and one site requiring 29 dredgings in 34 years. Forty-three sites were identified where dredging volume was exceptionally high and/or were frequently repeated. These sites occur in five settings: (1) where flow is divided through chutes or side channels; (2) at the months of largely unregulated tributary streams; (3) at thalweg crossings in meander bends: (4) in long, straight reaches of the channel; and (5) near problematic engineered structures, like the outlet of the Chain of Rocks Canal (Miller et al. 2004).

Figure 27: Example of dredging on the Lower Mississippi River.
Source: Dredging International

Numerical models have been utilized to examine both the effects of dredging and alternatives to dredging. The long-term effects of dredging due to freshwater diversion have been modeled along the lower Mississippi River to determine the extent of the riverine effects (Figure 27). A HEC-6 model was utilized to predict the changes in river profiles due to deposition and scour (Barbe et al. 2000). Other numerical models have been applied to evaluate the alternatives to dredging along the lower Mississippi River, specifically within the Cubits Gap and Head of Passes reaches. The TABS-1 and TABS-2 models were implemented over a period of several years, utilizing an eleven-year hydrograph. Viable alternatives were found to include: advance maintenance, a sediment trap, and flow reduction. Results from the sedimentation modeling showed that the best nonstructural plan was advanced maintenance, due to the percent of time that project depth could be maintained. The flow reduction alternative also provided for a significant decrease in total dredging requirements (Copeland 1991, Lin et al. 1990).

Dredging sediments from water bodies, in the Mississippi River basin, has typically been completed to preserve reservoir capacity, maintain navigation and recreation channels, and restore habitats, but the fate of the sediments has been an issue. In the past, and less frequently today, material often was placed in bottomland hardwoods in a permanent stockpile. Characteristically, most trees buried to a depth of more than 6 ft died within 1 to 2 years, leaving a sterile, unvegetated sand mound. Natural revegetation (succession) of these sandpiles has been extremely slow or nonexistent. Some sites that were used only once in the 1940's and 1950's still remain mostly devoid of vegetation. Dredged sediment retention ponds have initially supported wetland vegetation. After dewatering, the physical properties of sediments tend to become similar to upland soils and the retention basins have then been able to support conventional agriculture. Results have indicated that properly handled dredge sediments can produce high quality agricultural soils. Corn yields have exceeded 25% from previous years, where lagoons were filled with 3 feet of sediment and utilized for crop production. Test plots showed that 18 inches of sediment increased yields by 40%. The results have also shown that an increase in returns for the test plots with 18-inch sediment treatments, as compared to the zero sediment treatment, could be present. The predicted increase was due to the increased yields and the lower fertilizer requirements of the test plots. In addition, sediment placement on poor soils could improve their productivity (Darmody and Marlin 2002, Duyvejonck 1987, Stout 1989).

Delta and Shelf Processes

Over the last century, the river-dominated Mississippi delta has received increasing attention from geoscientists, biologists, engineers, and environmental planners because of the importance of the river and its deltaic environments to the economic well-being of the state of Louisiana and the nation. Population growth, subsurface resource extraction, and increased land-water use have placed demands on the delta's natural geologic, biologic, and chemical systems, therefore modifying the time and spatial scales of natural processes within the delta and its lower alluvial valley. As a result, the combined effects of natural and human-induced processes, such as subsidence, eustatic sea level rise, salt water intrusion, and wetland loss, have produced a dynamically changing landscape and socioeconomic framework for this complex delta. Under natural conditions, the fundamental changes that result in land-building and land loss in the Holocene Mississippi River delta plain have been rooted in the systematic diversion of water and sediment associated with major shifts in the river's course-the process of delta switching. Research over the last half century has shown that major relocations of the Mississippi's course have resulted in five Holocene delta complexes and a sixth one in an early stage of development as a product of the latest Atchafalaya River diversion. Collectively, these Holocene deltas have produced a delta plain that covers an area of similar to 30,000 km^2 and accounts for 41% of the coastal wetlands in the United States. After a river diversion takes place, the resulting delta evolves through a systematic and semipredictable set of stages generally characterized by: (a) rapid progradation with increasing-to-stable discharge, (b) relative stability during initial stages of waning discharge, (c) abandonment by the river in favor of a higher gradient course to the receiving basin, and (d) marine reworking of a sediment-starved delta as it undergoes progressive submergence by the combined processes of subsidence. Delta switching has taken place every 1000 to 2000 years during Holocene times, and resulting deltas have an average thickness of approximately 35 m. Within a single delta there are subdeltas, bayfills, and crevasse-splays that have higher frequency delta cycles ranging from several hundred years to a few decades. These depositional features are usually less than 10 m thick, and some have produced marshland areas of over 300 km^2. The net result of these delta-building events has been a low-lying landscape with components that are changing (building and deteriorating) at different rates. Geologically, these depositional cycles produce a thick accumulation of coarsening, upward deltaic deposits that have various thicknesses in response to development on a variety of temporal and spatial scales. In this river-dominated delta system, distributaries can prograde seaward at rates of over 100 m/year. The cumulative effect of the Holocene depository has been to depress the underlying Pleistocene surface. In a local setting, e.g., the modern Balize Lobe, differential loading causes the vertical displacement of underlying clay-rich facies (shale diapirs-mudlumps). The delta front of this lobe, which has prograded into deep water of the outer continental shelf, has been characterized by rapid deposition of silt- and clay-rich sediments and slope instability, which results in seaward displacement of sediments by a variety of mass-movement processes. Superimposed on the natural processes and forms of the Mississippi deltaic plain, and its associated estuarine environments, have been human impacts, most of which have been imposed in this century. The most significant impacts have resulted from a decrease in sediment input to the river from its tributaries and the alteration of the river's natural sediment dispersal processes through the construction of levees. Measures are now being taken to reinstate some of the delta's natural processes, thereby mitigating landless so that decline in animal and plant productivity can be mitigated (Coleman et al. 1998b, Roberts 1997).

River avulsions have been commonly considered to be driven by the aggradation and growth of alluvial ridges, and the associated increase in cross-valley slope relative to either the down-channel slope or the down-valley slope. Therefore, spatial patterns of overbank aggradation rate over stratigraphically relevant time scales are critical in avulsion-dominated models of alluvial architecture. New data on long-term overbank aggradation rates, from the Mississippi delta, has demonstrated that the rate of decrease of overbank deposition away from the channel belt has been similar to observations for single overbank floods (Bridge and Tornqvist 2002).

Long-term changes in shoreline position along Louisiana's rapidly deteriorating barrier coastline have been documented from 1855 to 1959. Gulfside rates of change range from -23.1 to +0.9 m/yr, whereas bayside rates range from -5.0 to +24.0 m/yr. Louisiana barrier island systems have also experienced landward migration, area loss (Figure 28), bayside erosion, and island narrowing as a result of complex interactions among subsidence, eustatic sea level rise, wave processes, storm impacts (cold Gents and tropical cyclones), inadequate sediment supply, and intense human disturbance (levees; oil, gas, and sulphur extraction activities; access canals; seawalls; jetties). Consequently, the structural continuity of Louisiana's barriers has been weakening as the barrier shoreline continues to narrow and fragment (Byrnes and McBride 1997).

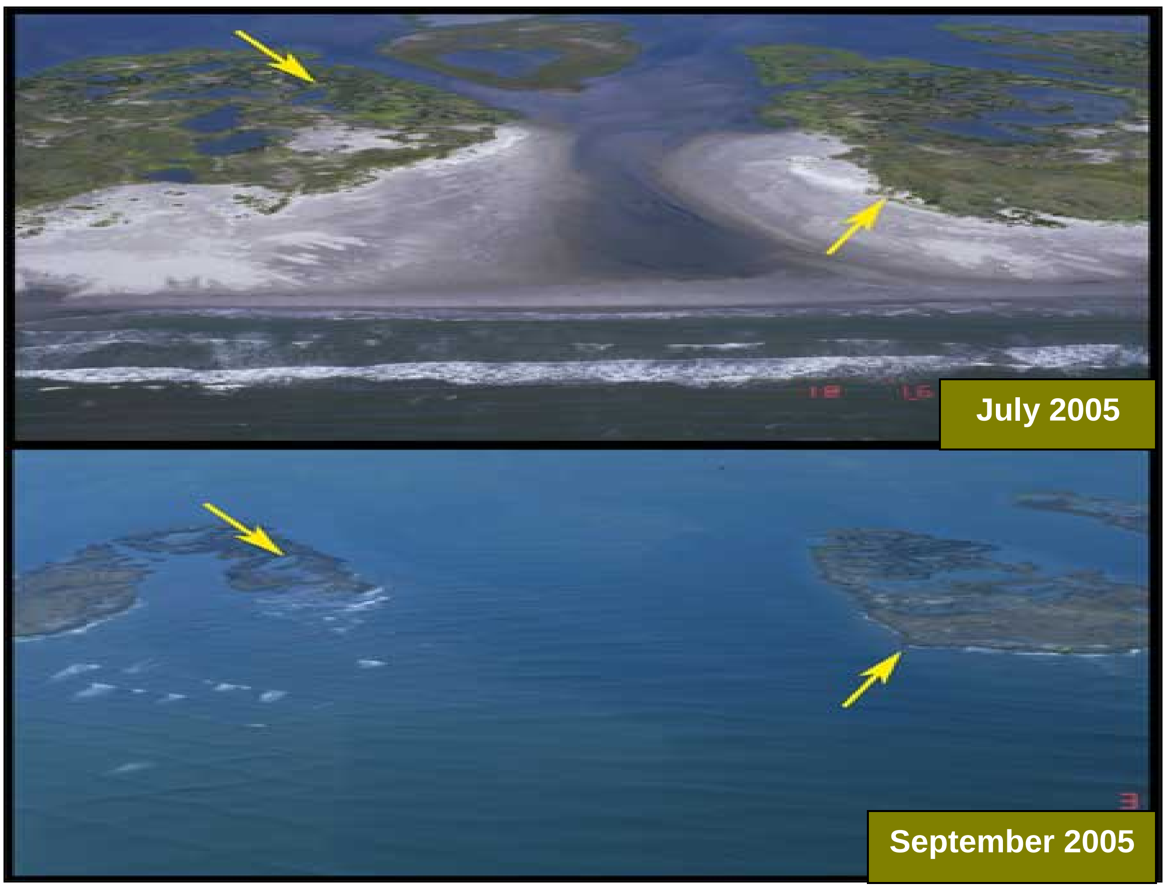

Figure 28: Example of barrier island loss due to hurricane Katrina.
Source: U.S. Geological Survey

The Mississippi River Chenier Plain is a shore parallel landform (down-drift from the Atchafalaya distributary of the Mississippi River) consisting of an alternating series of transgressive sand-shell ridges and regressive, progradational mudflats. The late 1940s shift of 1/3 of the flow of the Mississippi to the newly developing Atchafalaya delta complex to the west has resulted in injection of the river waters and suspended sediment into the westward flowing currents of the coastal current system. This has reactivated the dormant processes of mud accumulation along this coast. The structure, nature, and origin of these “mudlumps” have been determined to be related to small diapers that have resulted from upthrusting of plastic clays in response to overloading by distributary mouth bar sands. Short-lived radiotracers have indicated that river-borne materials are transported less than similar to 30 km from the river mouth before initial deposition. However, seasonal variations indicated significant remobilization of sediment and potential export of sediment during the high energy (e.g., wind/wave) winter months. In addition, depth profiles indicated sediment deposition rates between 0.8 and 3.9 cm/month. These rates are much greater than those observed on decadal time scales (Huh et al. 2001, Corbett et al. 2004, Coleman et al. 1998a).

Surficial sediments consist of a thin unit of sands and muds derived from and reflecting the individual subenvirons of the underlying delta. Holocene inner-shelf development off eastern Louisiana has been controlled by relative sea-level rise and sediment supply. Sediment supply and deposition have been a product of delta progradation and delta lobe switching. The modern shelf configuration and surficial sediment distribution patterns reflect reworking of underlying deltaic deposits. The lack of modern sediment input helps to maintain the imprint of this ancient delta on the modern shelf surface (Brooks et al. 1995). Results have shown that, under the normal tidal inundations, sediment concentrations decreased from bayou bank to marsh interior during flood tides near Terrebonne Bay. During ebb tides, sediment concentrations varied less significantly and only slightly with the distance from the bayou bank and were lower than those during flood tides. These results indicated that marsh surface sedimentation is still an active process in marshes of south Louisiana. During strong southerly winds, inorganic suspended sediment concentrations in the bayou were much higher than those in the marsh. During partial inundation and strong northerly winds, inorganic sediments in the marsh were higher than those in the bayou. This suggests that recently deposited sediment on the marsh may occasionally be resuspended and eroded (Sikora and Wang 1993). Surveys along the Louisiana coast west of the Mississippi River mouth detected a large area of deposition in water depths of 2.0-8.5 m offshore of a 9-km-wide tidal inlet of the Cat Island Pass/Wine Island Pass system. A 59.9 million cubic meter sandy deposit formed from the 1930s-1980s, spanning 27 km in the alongshore direction, delineating the transport pathway for sediment bypassing offshore of the inlet on the shoreface. The processes responsible, for formation of this deposit, have been attributed to sediment that has been transported primarily by wind-driven coastal currents during large storms and hurricanes. Deposition appeared to be related to changes in shoreline orientation, closing of transport pathways into a large bay to the east and the presence of tidal inlets (Jaffe et al. 1997).

Rates of sediment accumulation in coastal marsh communities in the Mississippi River deltaic plain, Louisiana, have been examined (Figure 29). The results indicated that normal riverine flooding contributes relatively little (< 0.1 cm/year) to marsh accretion in the studied area. In contrast, even a minor hurricane can resuspend sediments from shallow bays and deposit more than 2.2 cm of sediments in Phragmites australis dominated communities adjacent to the bayous as far as 7 km inland from the bay shore. Hurricane-induced sedimentation represents at least a partial compensation to prevailing subsidence of marshes in abandoned delta lobes (Peterson et al. 1988). The continental shelf, off the Atchafalaya River, has also been examined to determine the role of deposition related to the annual flood and seasonal changes. Results have indicated that the annual flood deposit thickness ranges from 1-3 cm. Sediment profiles indicated that the seasonal deposit is two to six times the long-term (e.g., decadal) accumulation. Passage of cold fronts interrupts the formation of flood deposits, particularly during the rising to early high discharge period (December-March). No correlation with discharge or long-term accumulation has been made between the Atchafalaya and Mississippi Rivers, indicating a minimal influence from the Mississippi discharge 150 km to the east (Allison et al. 2000).

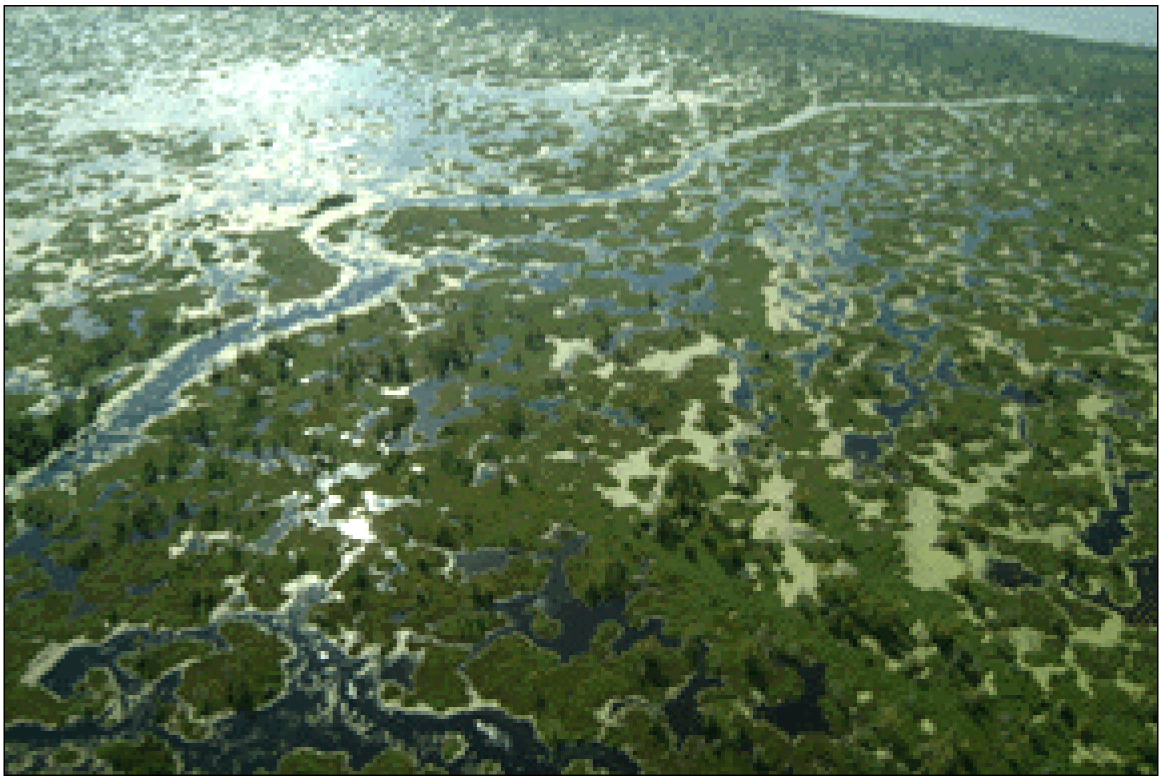

Figure 29: Marsh in the Mississippi River delta region
Source: U.S. Geological Survey

Bottom-boundary-layer velocity profiles, bed stresses and suspended sediment concentration profiles were measured in contrasting shelf and semi-enclosed bay environments that have been accumulating fine sediments. Suspended sediment concentration within the mean current boundary layer was attributable to local resuspension from underlying, very easily eroded pools and to the horizontal advection of near bottom turbid layers (benthic plumes). The presence of density stratification lent itself to simple fits of log profiles to velocity observations over the lowest meter to overestimate bottom stress. Observed semi-log velocity profiles were (1) concave downward, (2) straight, or (3) concave upward depending on whether the density anomaly decreased with height above the bed (1) much more slowly than, (2) at roughly the same rate as, or (3) much more rapidly than z(-1). These patterns were shown to be consistent with analytical relations between velocity and density stratification within the near-bed constant stress layer. Stable stratification was attributable to a combination of locally resuspended sediment and thermohaline effects, with the former and latter dominating under high- and low-energy conditions, respectively. Near-bed thermohaline stratification was observed to increase z, the elevation of the zero intercept of the logarithmic velocity profile (Friedrichs et al. 2000).

Observations from shelf environments have shown that down-slope gravity-driven transport may constitute an important mode of suspended sediment dispersal across shelves and highlight the influence of ambient waves and currents on gravity-induced sediment flux. The phenomena involve high concentrations of suspended sediment mixed with seawater and thus differ in genesis from hyperpycnal plumes released directly from sediment-laden rivers. The fate of sediment seaward of the river mouth involves at least four stages: supply via plumes; initial deposition; resuspension and transport by marine processes; and long-term net accumulation. The processes that operate at each stage, and the relative roles of each stage in governing the long-term accumulation patterns, vary appreciably with river regime and coastal ocean environment. On the Louisiana inner shelf, the down-slope gravity force has been found to be much weaker, but observations suggest that thin gravity flows may still have occurred in the presence of waves. If the supply of easily suspended sediment is less than the capacity of ambient currents (including waves) to carry sediment, then intense turbulence limits gravity-induced sediment transport by increasing the drag at the base of the flow. When ambient currents abruptly cease, rapid down-slope transport can then occur over short distances until the sediment settles. Such flows do not remain intensely turbulent because the slope of the continental shelf is too gentle to induce shear instability within the gravity flow. The maximum sustained rate of gravity-induced sediment transport occurs when ambient currents are strong, but the supply of easily suspended sediment exceeds the resuspension capacity of the ambient currents. Slope failures have been common in many areas of the shelf where down-slope gravity-driven transport is prevalent. A simplified kinematic wave equation model that neglects second-order effects such as diffusion treats the failure mechanism as a sedimentation and slope oversteepening process and sediment motion as a propagating kinematic wave. The model allows estimation of sedimentation rates necessary to initiate slope failures for a range of observed depths of basal shear planes. Model results indicate that slope oversteepening is a viable failure mechanism and a thin surface sediment layer may be moving downslope in a slow, continuous motion (Friedrichs et al. 2001, Nittrouer and Wright 1995, Adams and Roberts 1993).

Satellite data were used to investigate the variability of the Mississippi River sediment plume and the environmental forcing factors responsible for its variability (Figure 30). River discharge and wind forcing have been identifed as the main factors affecting plume variability. Seasonal and interannual variabilities in plume area were similar in magnitude and corresponded closely with large changes in river discharge. However, day-to-day variability in plume size and morphology was more closely associated with changes in the wind field. The plume region was also examined to determine the effects upon aquatic ecology. Photic-zone-integrated primary production varied significantly in both the river plume and shelf regions, with greatest variability observed in the river plume region. In the river plume and the adjacent shelf, highest production occurred during July-August 1990 and lowest during March 1991 (Fahnenstiel et al. 1994, Walker 1996).

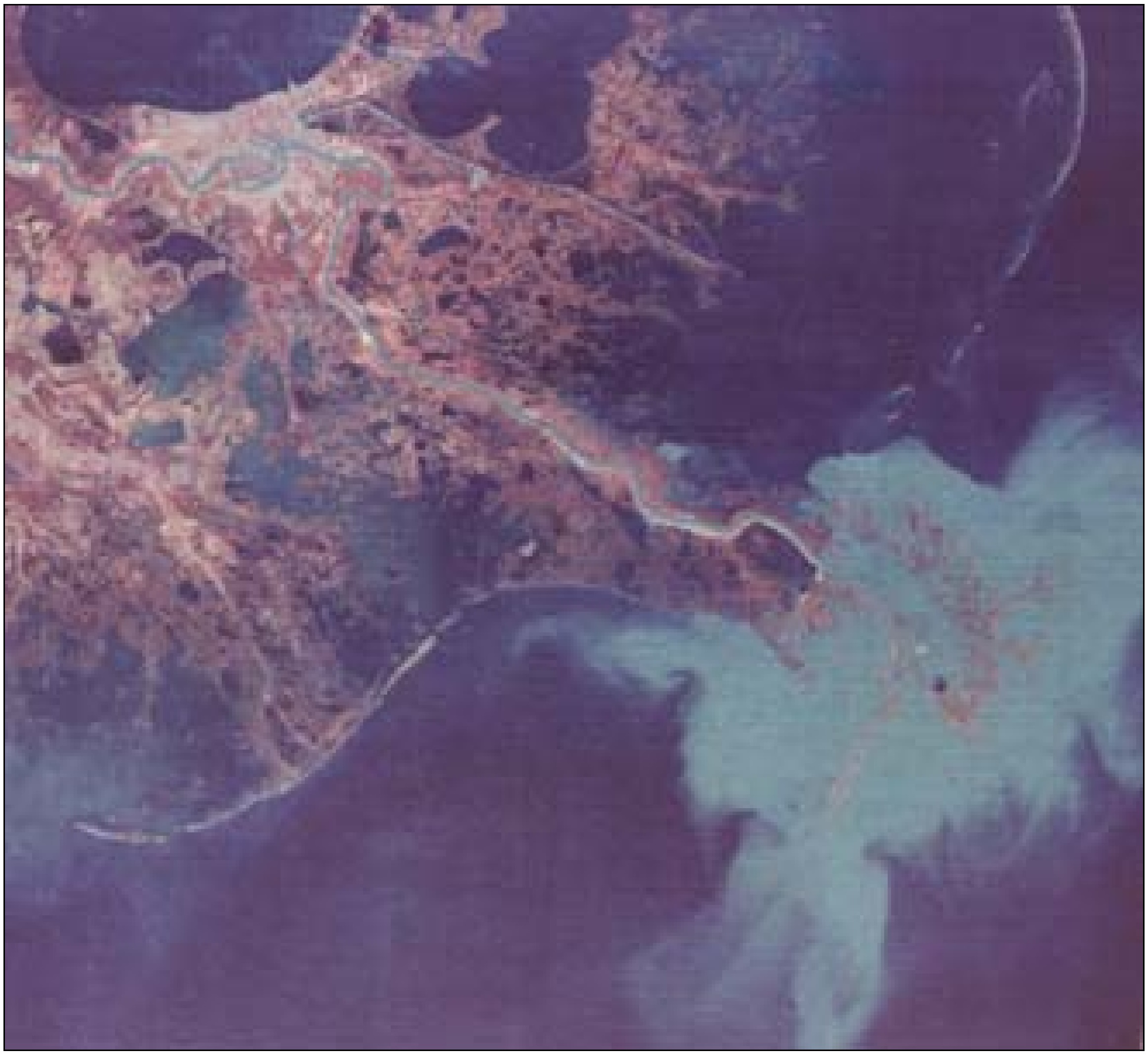

Figure 30: Mississippi River sediment plume.
Source: U.S. Geological Survey

A sequence of tidal inlet morphologies, ranging from wave-dominated to tide-dominated, has been occurring along the shoreline of the Mississippi River Delta Plain. There has been no appreciable variation in the mean tidal range (0.35 m) or mean significant wave height (0.5 m) in this reach of coastal Louisiana. The arrangement of sand bodies in the individual inlets is associated with the tidal prism exchanged between the respective bay and the Gulf of Mexico, and sediment supply. Temporal changes in tidal prism and sediment supply have resulted in a sequential change of inlet morphology. Historically, the increase in tidal discharge at inlets has produced larger channel cross-sections and prograding ebb-tidal deltas. For example, the ebb delta at Barataria Pass has built seaward > 2.2 km since the 1880s. Shoreline erosion and an increasing bay tidal prism also facilitated the formation of new inlets. Inlet evolution has been noted during the abandonment phase of individual delta lobes of the Mississippi River. During the first stage of abandonment, represented by headlands flanked by barrier spits, high rates of subsidence cause bays to expand. As bay area increases, tidal prism increases causing wave-dominated inlets to evolve tide-dominated morphologies. At the beginning of the second stage of delta lobe abandonment (barrier island arc systems) the sediment supply becomes limited. The spits confining tide-dominated inlets fragment causing the inlet throat to widen; tidal current strength decreases and waves begin to fill the main ebb channel with sands derived from the ebb tidal delta (Levin 1993, Fitzgerald et al. 2004).

The Atchafalaya River has had a significant influence on stratigraphic evolution of the inner continental shelf in the northern Gulf of Mexico. Sedimentary, geochemical, and shallow acoustic data have been used to identify the western limit of the distal Atchafalaya subaqueous delta, and to estimate the proportion of the Atchafalaya River's sediment load that accumulates on the inner shelf seaward of Louisiana's chenier-plain coast. The results demonstrate a link between sedimentary facies distribution on the inner shelf and patterns of shoreline accretion and retreat on the chenier plain. Mudflat progradation on the eastern chenier-plain coast corresponds to the location of deltaic mud accumulation on the inner shelf. On the central chenier-plain shelf, west of the subaqueous delta, relict sediment has been exposed. Mass-balance calculations have indicated that the eastern chenier-plain inner shelf and coastal zone form a sink for 7 plus or minus 2% of the sediment load carried by the Atchafalaya River (Allison et al. 2005).

Chronostratigraphic approaches to coastal geomorphology frequently include consideration of salt marsh deposits as indicators of past sea-level positions. Continuous horizons of such deposits can be used to infer that salt marshes have been keeping pace with local rates of relative sea-level rise. Accumulation rates of both organic and inorganic sediments can also be derived at particular time scales and studies from many coastal marshes have demonstrated the episodic nature of inorganic sediment deposition. The frequency and spacing of these events has not necessarily coincided with periods of increased local sea level. In addition, short-term increases in sea level could result in marsh deterioration as soils become excessively waterlogged (Figure 31). Extensive land loss, which has been mostly wetland loss (Figure 32), has taken place during this century in the Mississippi River delta (Reed 2002).

One solution to this problem has been creating artificial crevasses, or cuts in natural levees. Land growth of the crevasses was determined from aerial photographs and was related to crevasse-site characteristics. The newly constructed crevasses create emergent wetlands after 2 years of subaqueous growth at about 4.7 ha/year and an average cost of $21,377 per crevasse. The present total cost per hectare declines with age as new land builds, and it will equal $48 per hectare if all the open water in the receiving ponds fills in. At these rates, the net land loss rates in the Delta National Wildlife Refuge measured from 1958 to 1978 would be compensated for by the building of 63 crevasses, 24 of which have already in been placed. Another solution the problem of wetland area and elevation loss has been that of thin-layer deposition of dredged material by means of high-pressure spray dredging. The impact of spray dredging on vegetated marsh and adjacent shallow-water habitat (formerly vegetated marsh that has deteriorated to open water) has been evaluated in a 0.5-ha Spartina alterniflora-dominated salt marsh in

Figure 31: Marsh deterioration in the Mississippi River delta region
Source: U.S. Geological Survey

coastal Louisiana. The vertical accretion and elevation change measurements were made simultaneously to allow for calculation of shallow subsidence. Measurements made immediately following spraying in July 1996 revealed that stems of Spartina alterniflora were knocked down by the force of the spray and covered with 23 mm of dredged material. Stems of Spartina alterniflora soon recovered, and by July 1997 the percent cover of Spartina alterniflora had increased three-fold over pre-project conditions. Thus, the layer of dredged material was thin enough to allow for survival of the Spartina alterniflora plants, with no subsequent colonization by plant species typical of higher marsh zones. By February 1998, 62 mm of vertical accretion accumulated at this site, and little indication of disturbance was noted. Although not statistically significant, soil elevation change was greater than accretion on average at both the spray and reference marshes, suggesting that subsurface expansion caused by increased root biomass production and/or pore water storage influence elevation in this marsh region (Boyer et al. 1997, Cahoon et al. 1999).

The loss of wetlands has been an important issue particularly due to their abundance of ecological life, but their importance may become paramount for future considerations of wastewater assimilation. The use of wetlands for treatment of wastewaters has a number of important ecological and economic benefits. Adding nutrient rich treated wastewater effluent to selected coastal wetlands results in the following benefits: (1) improved

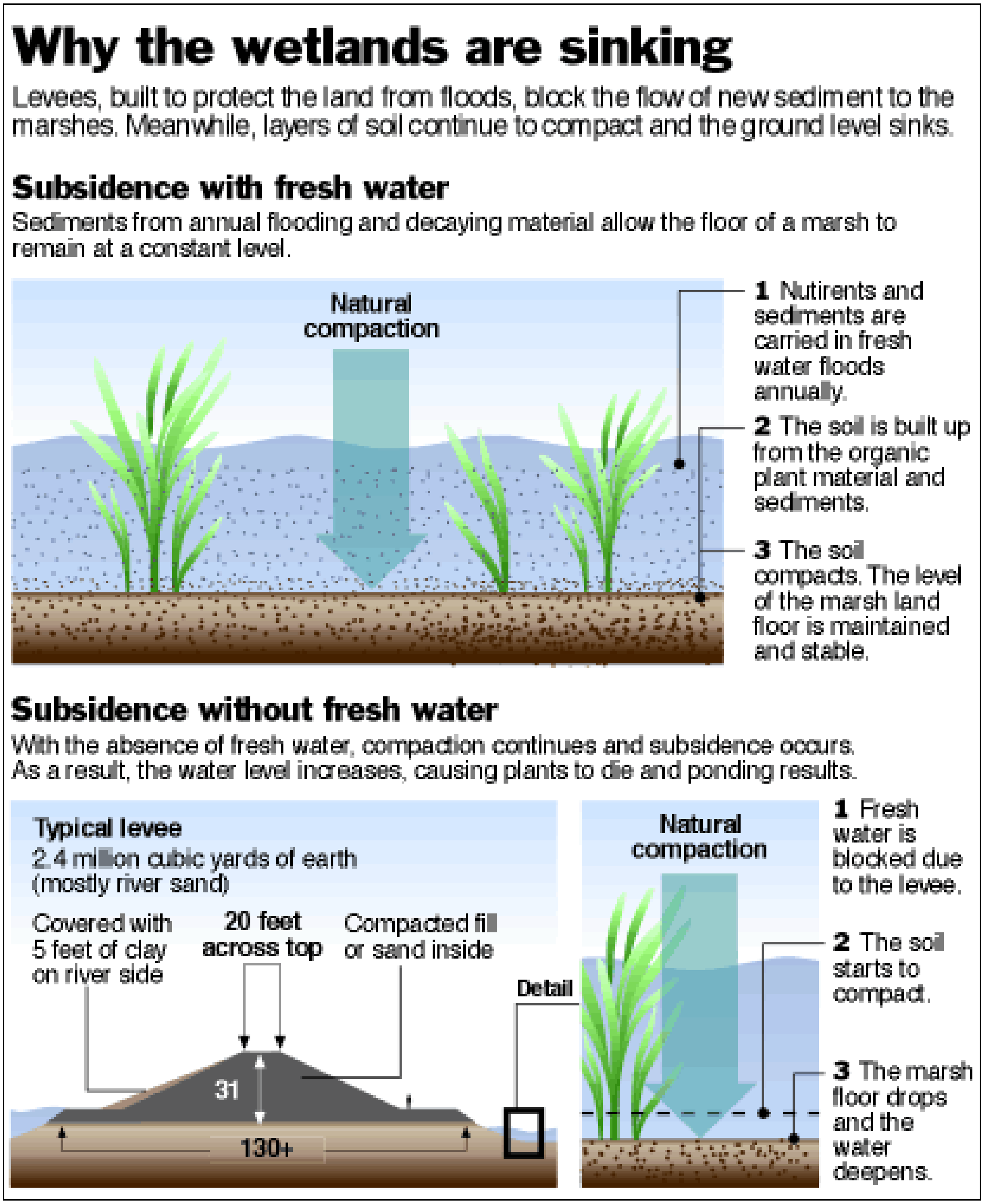

Figure 32: Wetland subsidence cycle and causes
Source: U.S. Fish and Wildlife Service

effluent water quality; (2) increased accretion rates to help offset subsidence; (3) increased productivity of vegetation; and (4) financial and energy savings of capital not invested in conventional tertiary treatment systems. At one site along coastal Louisiana, where sedimentation accumulation was measured, rates of accretion increased significantly after wastewater application began in the treatment site and approached the estimated the rate of regional relative sea level rise. Therefore, the application of nutrient-rich wastewater can help coastal wetlands survive sea level rise. Economic analyses comparing conventional and wetland systems indicate savings range from $500,000 to $2.6 million (Bean et al. 2004).

Water Quality

Under normal flow conditions and prior to cultural development in the Mississippi River Basin, the main stem was a heavy sediment carrier due to the character of the climate and soils in the basin. The relative contributions of various glacial and nonglacial sediments to Wisconsin Episode loess units along the lower Illinois and central Mississippi Valleys have been estimated on the basis of a comparison of magnetic susceptibility and silt and clay mineralogy. A mathematical method of source area calculation, using four compositional parameters, was guided by current knowledge of the regional glacial history. On the basis of this technique, the Roxana Silt, along the Illinois and Mississippi River Valleys, has been found to be composed of significant Superior lobe sediment (35%-40%) as well as Wadena or Des Moines lobe sediment (about 35%), which accounts for its high magnetic susceptibility, feldspar content, kaolinite content, and pink hue. Lower Peoria Silt contains about 25%-35% Lake Michigan lobe sediment with reduced contributions of the other sources. After the Mississippi River's diversion (20.4 ka), the supply of Superior, Des Moines, and Wadena lobe sediment was cut off from the Illinois Valley in favor of Lake Michigan lobe sediment (75%-80% contribution). This major source area shift accounts for higher dolomite and illite contents and a more yellow hue in approximately the upper two-thirds of Peoria Silt in the study area. In loess south of St. Louis, less pronounced, compositional shifts occur because Superior lobe sediment was not cut off and because Des Moines lobe, Wadena lobe, and Missouri River sediments, having more intermediate composition, compose 40%-50% of the loess, thereby diluting other source area changes. Nonglacial sediment, from fluvial and periglacial sources, has been estimated to compose 10%-40% of loess in both regions (Grimley 2000).

The placement of flood control structures and other channel improvement features, and the implementation of improved land management practices throughout the entire basin, have significantly changed the suspended-sediment flow regime and the water quality of the main stem and its tributaries (Causey et al. 1986).

One such change has been that of increased turbidity in several areas of the basin. Studies have indicated that tow traffic on the Illinois and upper Mississippi Rivers, during normal pool conditions, contributed to existing levels of suspended sediment measured as both suspended solids and turbidity, and, furthermore, that sediments resuspended from the main channel move laterally to shoreward areas, including potentially productive side channel areas (Figure 33). Recreational areas, such as lakes, have also been susceptible to degradation of aquatic life due to increased sediment concentrations. For example, the recreational fishing in the Larto-Saline backwater complex of east central Louisiana has been in a state of recent decline due to various land-use changes, which resulted in a loss of forested floodplain habitat, increased watershed erosion and sedimentation as well as alteration of flooding patterns with concomitant reduced inflows of the Black River and

Little River floodwater and increased inflows of the turbid Red River (Johnson 1976, Ewing 1991).

Figure 33: Turbidity and tow traffic on the upper Mississippi River.
Source: U.S. Geological Survey

The chemical quality of the Mississippi River and many of its tributaries has also been influenced dramatically by the industrialization and land use characteristics of each sub-basin. The influence of the pollutants, on each tributary, has been compounded with progression downstream from each of its respective headwaters. Examples of pollutant laden tributaries include the Arkansas, Atchafalaya, Illinois, and Minnesota Rivers. The Illinois River has experienced many water quality problems over the past century. The problems have ranged from aquatic life endangerment from urban wastes to the installation of several dams and levees, which threatened fisheries. The ecosystem has been recently improved with the advent of special programs, which have improved dissolved oxygen levels and reduced non-point pollution (Stout 1985).

Inflows of metal-rich, acidic water, that drain from mine dumps and tailings piles, have entered the non-acidic water in the upper Arkansas River. Hydrous iron oxides precipitated as colloids and moved downstream in suspension. The colloids have influenced the concentrations of metals dissolved in the water and the concentrations in bed sediments. Major element concentrations have been shown to be remarkably stable both spatially and temporally. Trace element concentrations have been shown to be generally stable; however, some spatial and temporal variations have occurred. Substantial load of colloids, dominated by iron and lead, have been transported to the

Pueblo Reservoir, where water quality has greatly declined. The Pueblo Reservoir has also been susceptible to rapid sedimentation. Rapid sedimentation exerts a pronounced influence on early sedimentary diagenesis in that there is insufficient time for a sediment particle to equilibrate in any one sediment layer before that layer may be displaced vertically by another layer (Axtmann et al. 1995, Edwards et al. 1990, Callender 2000).

Lake Pepin is a large, natural riverine lake in the upper Mississippi River downstream of the Twin Cities metropolitan area (Minneapolis and St. Paul) of Minnesota and the confluence with the Minnesota River, which are both sources of high suspended sediments and pollutant loads. The lake has a history of water quality problems and has been an efficient trap for suspended sediment and sediment-associated contaminants. These pollutants, primarily phosphorus, nitrogen, and chlorophyll a, have led to eutrophication of the lake. Eutrophication eventually leads to a general deterioration in the quality of aquatic communities in streams and lakes. Proper soil testing and efficient fertilizer application techniques, such as banding, can reduce potential nutrient discharge significantly. Integrated pest management techniques can substantially reduce the amount of pesticides required. Coliform contamination is a concern for water supplies receiving direct runoff from pastures. Management practices used for sediments, nutrients, and pesticides also help to control nonpoint coliform pollution. The lake has also experienced losses in volume, due to the entrapment of the suspended sediment loads from the Mississippi and Minnesota Rivers (Figure 34). Based on mass balance calculations, the lake trapped about half of the suspended solids entering the lake, but it had a small net export of chlorophyll a. The lake was a sink for phosphorus and nitrogen; however, it had a net export of total phosphorus at times during low flows in the summer of 1987. Internal loading of dissolved reactive phosphorus was prevalent during the summer of 1987. The only substantial export of total nitrogen occurred in June 1987 during a bloom of cyanobacteria. The lake should continue to be an efficient trap for suspended sediment and associated contaminants, but its trapping efficiency and aquatic habitat will continue to decline slowly as lake volume decreases. Reinventing the agricultural systems of the upper Mississippi River basin would be greatly beneficial to areas like Lake Pepin and even the Gulf of Mexico (Cooper and Lipe 1992, Claflin et al. 1995, Keeney 2002).

Chemical quality issues have also been also been prevalent in the lower Mississippi Basin. For instance, several samples have been collected to examine arsenic and mercury concentrations in soil, sediment, water, and fish tissues, from an alluvial floodplain located in northwest Mississippi. Concentrations have been found to increase approximately an order of magnitude from water to fish tissues and an additional two orders of magnitude in soils, lake sediments, and wetlands. Arsenic concentrations represented a low risk. Mercury concentrations were also low but showed a greater tendency to concentrate in fish tissue (Cooper and Gillespie 2001). The Atchafalaya River quality, which is controlled by the discharge and chemical quality in the Red, Black, and Mississippi rivers, has also been under scrutiny for its pollutants. The dominant anions and cations that have been found include bicarbonate and calcium (Demas and Wells 1977).

Figure 34: Confluence of Minnesota (lower) and Mississippi Rivers (upper)
Source: U.S Geological Survey

Changes in plant communities and wetlands have been another area of concern associated with the water quality of the Mississippi River Basin (Figure 35). A recent regional wetland loss prompted the diversion of the lower Mississippi River into Lake Pontachartain, Louisiana via the Bonnet Carre Spillway in order to monitor the fate of nutrients and sediments in the spillway and Lake Pontchartrain. As water passed through the Bonnet Carre Spillway, there were reductions in total suspended sediment concentrations of 82-83%, nitrite + nitrate (NOx) of 28-42%, in total nitrogen (TN) of 26-30%, and in total phosphorus (TP) of 50-59%. 3.9 +/- 1.1 cm of accretion was measured in the spillway. Nutrient concentrations at the freshwater plume edge in Lake Pontchartrain compared to the Mississippi River were lower for NOx (44-81%), TN (37-57%), and TP (40-70%), and generally higher for organic nitrogen (-7-57%). The Si:N ratio generally increased and the N:P ratio decreased from the river to the plume edge. Nutrient stoichiometric ratios indicate water at the plume edge was not silicate limited, suggesting conditions favoring diatomic phytoplankton (Day et al. 2001).

In the upper Mississippi River, water elevation is highly regulated by an extensive system of locks and dams. Completion of this system in the 1930s created productive, biologically diverse backwater habitats. The status of plant communities in these backwater areas has been recently threatened by several factors, including sediment accumulation, recreational use, navigation traffic and water quality. Aerial photography, taken in 1975 and from 1991 to 1995, was used to describe vegetation changes occurring in four backwater areas of Navigation Pool 8. Three general cover classes were

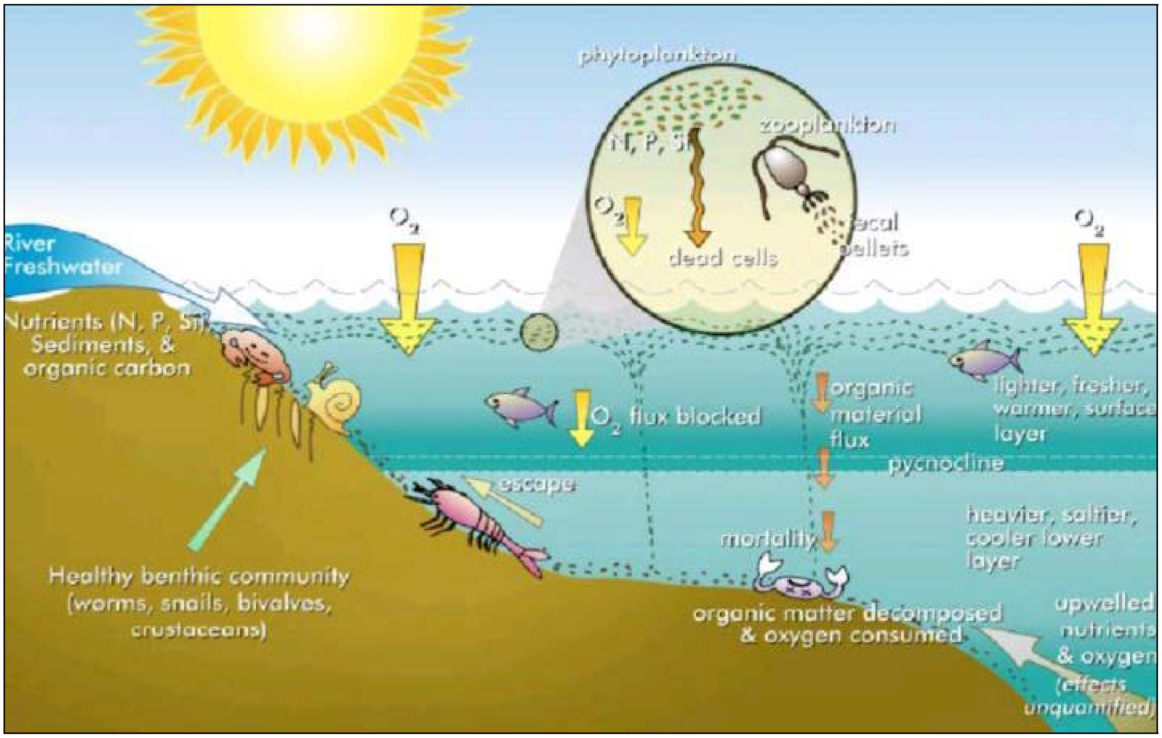

Figure 35: Water quality processes in the delta area of the Mississippi River.
Source: U.S. Environmental Protection Agency

recognized, representing an aquatic to terrestrial gradient. Coverages of specific vegetation types were estimated and evaluated using two indices of community diversity (vegetation richness and the Shannon diversity index). Though some vegetation changes were consistent with expected successional patterns (e.g. increased terrestrialization), other changes were not (e.g. loss of marsh vegetation). Diversity indices and coverages of most aquatic macrophytes declined from 1975 to 1991/1992 but then increased following the 1993 flood (Owens et al. 2001).

The annual flood is not normally considered a disturbance unless its timing or magnitude is atypical. The record flood of 1973 had little effect on the biota at a long-term study site on the Mississippi River, but the absence of a flood during the 1976- 1977 Midwestern drought caused short and long-term changes. Body burdens of contaminants increased temporarily in key species, because of increased concentration resulting from reduced dilution. Reduced runoff and sediment input improved light penetration and increased the depth at which aquatic macrophytes could grow. Developing plant beds exerted a high degree of biotic control and were able to persist, despite the resumption of normal floods and turbidity in subsequent years. In contrast to the discrete event that disturbed the Mississippi River, a major confluent, the Illinois River, has been degraded by a gradual increase in sediment input and sediment resuspension. From 1958-1961 formerly productive backwaters and lakes along a 320 km reach of the Illinois River changed from clear, vegetated areas to turbid, barren basins (Bayley et al. 1990).

In contrast, the upper Mississippi River Basin experienced floods of exceptional magnitude and duration in 1993, especially at its more downstream reaches. Flooding began in late June, peaked in late July and remained at or near flood stage into October 1993. The flood had widespread effects on the vegetation. Submerged species such as Potamogeton pectinatus significantly decreased in abundance, especially at sites with more severe flooding. However, many species were able to regenerate in 1994 from seeds or storage organs. Emergent species such as Scirpus fluviatilis were similarly affected, but in the upstream reaches were able to regrow in the autumn following the flood and at many sites showed exceptionally high productivity in the following year, probably due to nutrient-rich sediment deposition by the flood. Many tree species were very severely impacted, although Acer saccharinum and Populus deltoides have shown some seedling regeneration on newly deposited sediment beneath stands of mature trees (Rogers and Spink 1996).

Effects of the 1993 flood on river water and sediment quality were investigated using historical data and data collected from the Illinois River and upper Mississippi River in a post-flood period. Overall the post-flood results showed systematic reductions and individual changes in the water and sediment constituents. The reductions in sediment metals and nutrients were most obvious at the Keokuk, Lock and Dam 26 stations, and several navigation pools. By analyzing and comparing the physical changes, it was found that the percent clay and total organic carbon in the surficial sediments decreased as a result of an increase in the proportion of coarser sediment. Decreases in pollutant concentration have been attributed to dilution by coarser and relatively less polluted sediment that was mobilized and transported into the upper Mississippi River from its tributaries. While the extreme transports, during the flood, were attributed to unusually high concentrations of some contaminants, low to average concentrations of suspended sediment being transported, and unusually high water discharges (Moody et al. 2000, Ettinger and Soong 2000, Rostad 1997).

The flood of 1993 also prompted an investigation to determine if disturbance by an unpredicted flood event would alter trophic dynamics of river-floodplain systems by creating shifts in the composition of organic matter available to consumers. The Ohio River, which did not flood during the same period, was examined for comparison. Stable isotopic ratios of carbon and nitrogen were used to characterize potential food sources and determine linkages between food sources and invertebrate and fish consumers. The results suggest that consumers continued to rely on sources of organic matter that would be used in the absence of the unpredicted 1993 flood. It is proposed that trophic structure did not change in response to flooding in the Mississippi and Missouri Rivers because both rivers exhibited the same trends observed in the Ohio River (Delong et al. 2001).

Conclusion

The Mississippi River and its tributaries have and will likely always experience problems related to sedimentation due to the basin’s size, dynamic nature, and land use characteristics. However, the majority of the goals and problems, within the entire basin, have been accomplished and mitigated via advances in technology and education. Changes in agricultural techniques have reduced the amount of erosion and subsequent sediment transport throughout the basin, particularly in the upper Mississippi River Basin.

In-stream revetments have improved navigation, flood control and channel stability via locks, dams, levees, dikes, and bank erosion protection techniques and measures. The impacts relative to the presence of revetments, like changes in river discharge, cross section, width, mean bed elevation, water surface elevation, and sediment concentration, have been both beneficial and detrimental to both society and the environment.

Future issues, which could become paramount during this century, include land development and population growth, particularly near waterways. These issues may negate some of the previous century's work towards solving the Mississippi River Basin's sedimentation problems. The benefits of advanced agricultural practices could be jeopardized by augmented flashiness and frequency of flooding due to increased runoff, which could in turn impact revetments, water quality, aquatic and terrestrial life, morphology and migration, and may also contribute further to the process of wetland loss, further exposing coastal cities and towns like New Orleans to potential disaster. The challenge of this century will be in mitigating new sedimentation issues, while continuing to sustain the mitigation of old sedimentation issues, all while minimizing social, environmental and economic impacts.

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