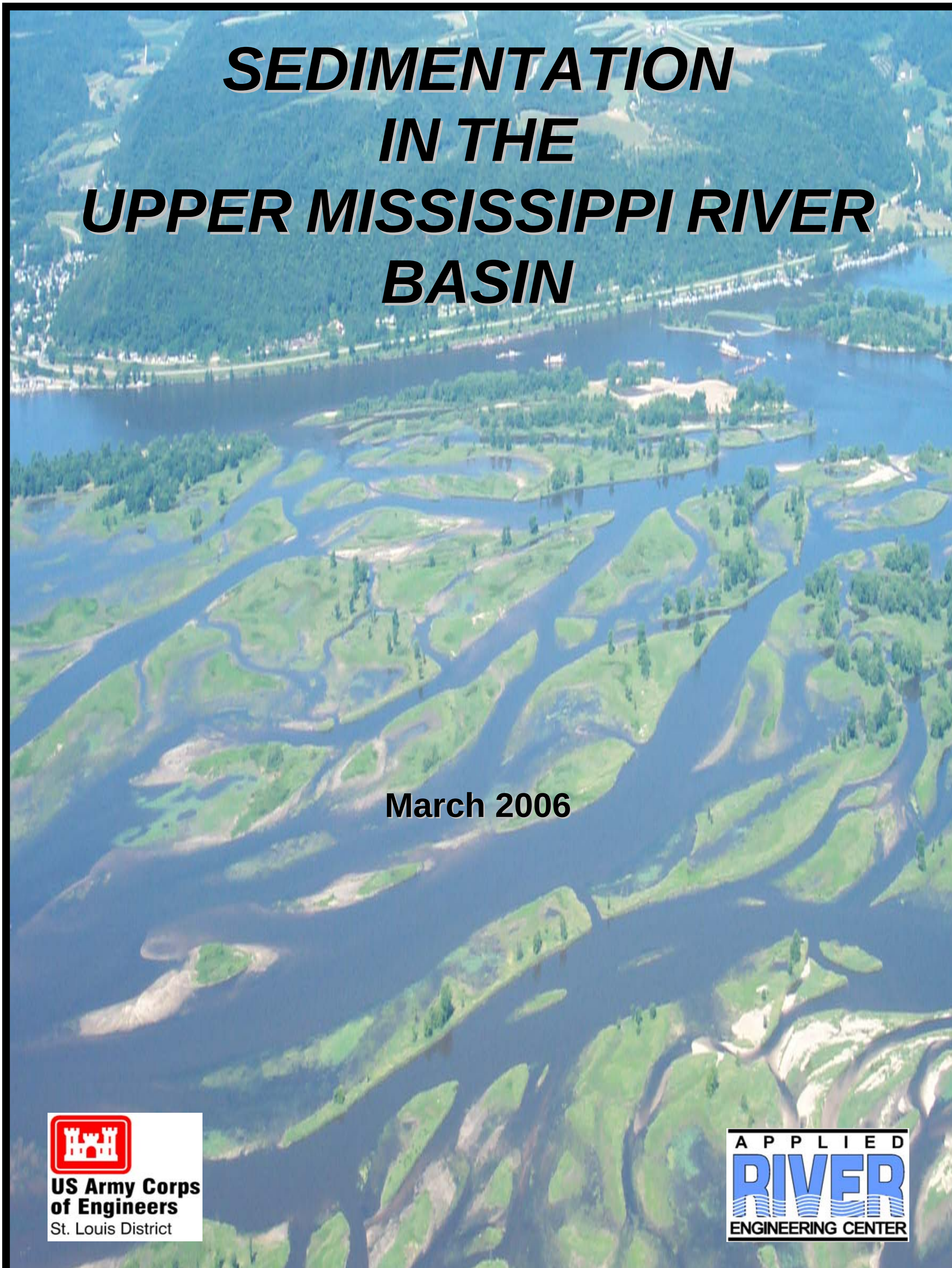
SEDIMENTATION IN THE UPPER MISSISSIPPI RIVER BASIN



March 2006

US Army Corps of Engineers
St. Louis District

APPLIED RIVER ENGINEERING CENTER

SEDIMENTATION IN THE UPPER MISSISSIPPI RIVER BASIN

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FOREWORD

This report was submitted originally as an appendix section for the 2006 Upper Mississippi River Comprehensive Report. It has been re-titled and slightly reformatted for publication, distribution, and reference purposes. The report covers a fair amount of topics and information and contains many graphics and photos, all of which are openly available for use to any interested individual or party. Distribution is unlimited. We welcome and encourage any questions, comments, or discussions to the material presented by contacting:

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INTRODUCTION

Purpose

The text, maps, photos, graphs and tables contained within this appendix are meant to serve as a general summary of the status of sedimentation issues in the Upper Mississippi River Basin. This report is an attempt to modernize the findings of the original "Appendix G, Fluvial Sediment" of the Upper Mississippi River Comprehensive Basin Study", dated 1969.

Additional knowledge has been learned about both basin sedimentation and conservation trends since 1969, mainly due to the perseverant work of the Natural Resource Conservation Service and others. This report highlights some of this work. Test cases for watersheds, rivers, and streams are presented to provide a description of sedimentation trends observed within the basin.

It should be noted that this report addresses sedimentation and erosion problems over an extremely large and varied system. Therefore it would be impossible to capture or describe every particular problem, cause, or cure. In addition, it should be made clear that a fair amount of sedimentation and erosion occurs naturally regardless of the influences of man.

Strategies for decreasing sedimentation problems are discussed, which include:
(1) a call for the development of an interagency sediment reduction/restoration master plan, (2) a priority map by which to rank problem areas of greatest concern, (3) initiation of a public awareness program, (4) an outline of past and modern day sediment reduction measures, (5) an estimate of damages and costs, and lastly, (6) a list of future recommendations.

Preparation of the Report

This report was prepared by Mr. Rob Davinroy, Chief, River Engineering, U.S. Army Corps of Engineers, St. Louis District, with the assistance of Mr. Jon Hendrickson, Hydraulic Engineer, St. Paul District. Mr. Lyle Steffen, Geologist, United States Department of Agriculture (USDA), National Resources Conservation Service (NRCS), provided critical technical knowledge, references, and review.

Special thanks is extended to Mr. Dave Gates, Project Manager, St. Louis District, for providing initial contact with the USDA NRCS and more specifically, starting a dialogue with Mr. Steffen.

Other St. Louis District personnel who provided input and/or review included: Mr. Dave Busse, Chief, Hydrologic and Hydraulics Branch, Mr. Claude N. Strauser, retired H & H Branch Chief and private consultant, Mr. Dennis Stephens, Chief, Hydrologic Engineering Section, Mr. Don Coleman, Chief, Water Control Management & Environmental Quality, Ms. Joan Stemler, Engineering Technician in Water Control, Mr. Jerry Rapp, Hydraulic Engineer, Mr. Leonard Hopkins, Hydraulic Engineer and Project Manager, and the entire staff of River Engineering including Mr. Dave Gordon, Ms. Dawn Lamm, Mr. Mike Rodgers, Mr. Edward Brauer, and Mr. Jasen Brown, Hydraulic Engineers, Mr. Edward Riiff, Engineering Technician, and Mr. Jared Myers, Engineering Intern.

Several technical staff from the United States Geological Service provided input on sediment monitoring including: Mr. Bob Holmes, District Chief, Mr. Gary P Johnson, Hydrologist/Engineer, Mr. Gary Wilson, Hydrologist, and Mr. Greg Mitton, Hydrologist.

Mr. Kevin Landwehr, Rock Island District and lead author for the main report of the Upper Mississippi River Comprehensive Report, also provided review and comments. A list of others who provided input too long to mention here can be found under the "References" section of this report.

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THE UPPER MISSISSIPPI RIVER BASIN

Basin Boundary Map and Major Tributary Locations

Figure 1 is a geological relief map of the Central United States delineating the boundary of the Upper Mississippi River Basin. The Missouri River Basin was not included as part of this study. Runoff and sediment from this basin greatly influences the sediment load of the Mississippi River below St. Louis, which is noted later in this report.

The total drainage area of the basin is approximately 188,000 square miles and incorporates parts of several states of the Midwest including Minnesota, Wisconsin, South Dakota, Indiana, Iowa, Illinois, and Missouri. The highest point is approximately 1,950 feet above sea level at Timms Hill, Wisconsin, while the lowest point is approximately 300 feet above sea level at Cairo, Illinois.

The length of the Mississippi River, from Lake Itasca in Minnesota to Cairo, Illinois is approximately 1,500 river miles. The average slope of the river is approximately 0.5 feet per mile. Most tributaries feeding into the Mississippi River generally flow in either a southeastern or southwestern direction. Major size tributaries include the Illinois and Missouri Rivers. Intermediate size tributaries include the Minnesota, St. Croix, St. Louis, Cannon, Zumbro, Root, Flambeau, Chippewa, Black, Wisconsin, Fox, Wolf, Upper Iowa, Turkey, Maquoketa, Wapsipinicon, Cedar, Raccoon, Wyacanda, Fabius, Big Muddy, Rock, Iowa, Skunk, Des Moines, Sangamon, Salt, Meramec, and Kaskaskia Rivers (Figure 2).

Upper Mississippi River Basin

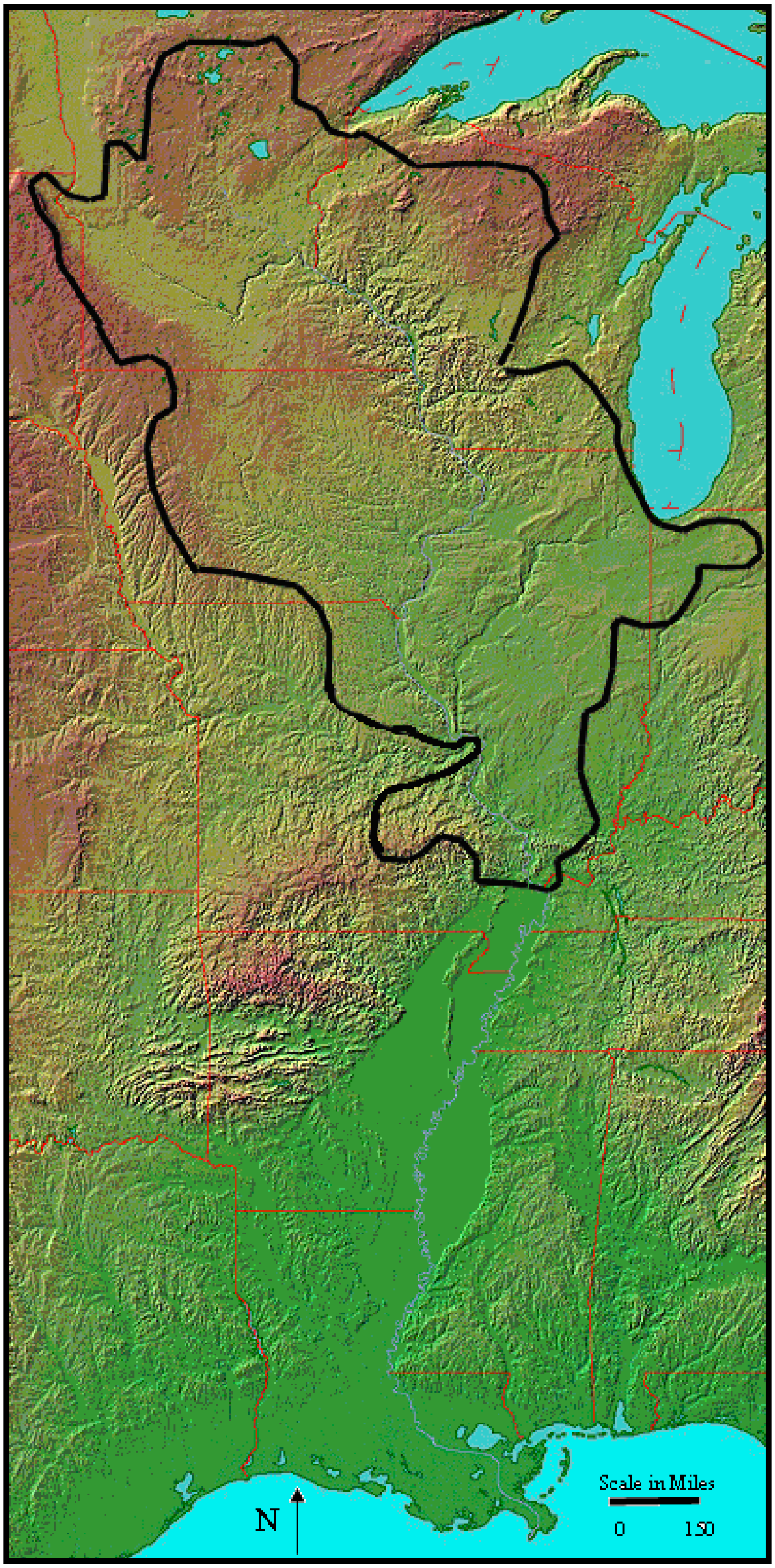

Figure 1: Geological Relief Map of the Upper Mississippi River, Central United States.

Figure 2: Rivers and Streams of the Upper Mississippi River Basin, with Locations of Sediment Gages.

Basin Geology

There are varying explanations describing how the geology of the basin was formed, but all discussions convey that the principle land-shaping process was the advance and retreat of the continental glaciers. Geologists argue about the age of the glaciers, but most agree that the Upper Mississippi River has been in existence for approximately 10,000 years to 12,000 years.

The glaciers, estimated at between 5,000 and 10,000 feet thick and covering hundreds of thousands of square miles, released tremendous amounts of water during melting, forming huge glacial lakes. The largest of the glacial lakes, Lake Agassiz, covered Northwest Minnesota, parts of North Dakota, and the Canadian provinces of Manitoba, Saskatchewan, and Ontario. The southern discharge outlet to this lake was called Glacial River Warren, which eventually excavated the valley now occupied by the Minnesota River (the Mississippi River flows into the valley carved by the River Warren at St. Anthony Falls in Minneapolis).

As the glaciers advanced and receded over the landmass, various drainage patterns were formed. Thousands of lakes were left behind in the northern portion of the basin (karst topography). Glacial melting generated outwash with extremely high sediment loads. Figure 3 typifies the high sediment load associated with glacial outwash (modern day glacier located in Greenland). A predominant layer of glacial till was deposited consisting of silts, clays, sands, and gravels. This material is predominant in all but the extreme southeastern and southwestern portions of the basin. In these portions, (the Ozark Plateau in Missouri and the Shawnee Plateau in Illinois), the landforms are primarily composed of exposed bedrock consisting of limestone, shale, and sandstone (Figure 4, Area 3).   Another exception is the existence of bluff hills, found just adjacent to the Mississippi River and along some of the tributaries.

The predominant landforms in the basin are plains, varying from flat to irregular (Figure 5). The plains are mainly composed of a thick layer of silt deposited over glacial till. Silt deposits range in thickness from approximately 300 feet in the central part of the basin to a few feet in the southern end. These deposits formed the original prairies of Southern Minnesota, Iowa, Illinois, and Northern Missouri. The geological explanation for these silt deposits is that during the retreat of the glaciers, strong wind action followed, thereby causing extensive wind blown sediments (loess) to gradually accumulate over the till.

Plains make up approximately 50 percent of the basin. They are considered some of the most productive agricultural areas of the United States. As a result, the plains have been highly modified for crop production. This has caused widespread effects on sedimentation and erosion in the basin, which will be discussed later in this report.

Figure 3: High Sediment Load Observed in Glacial Outwash in Greenland

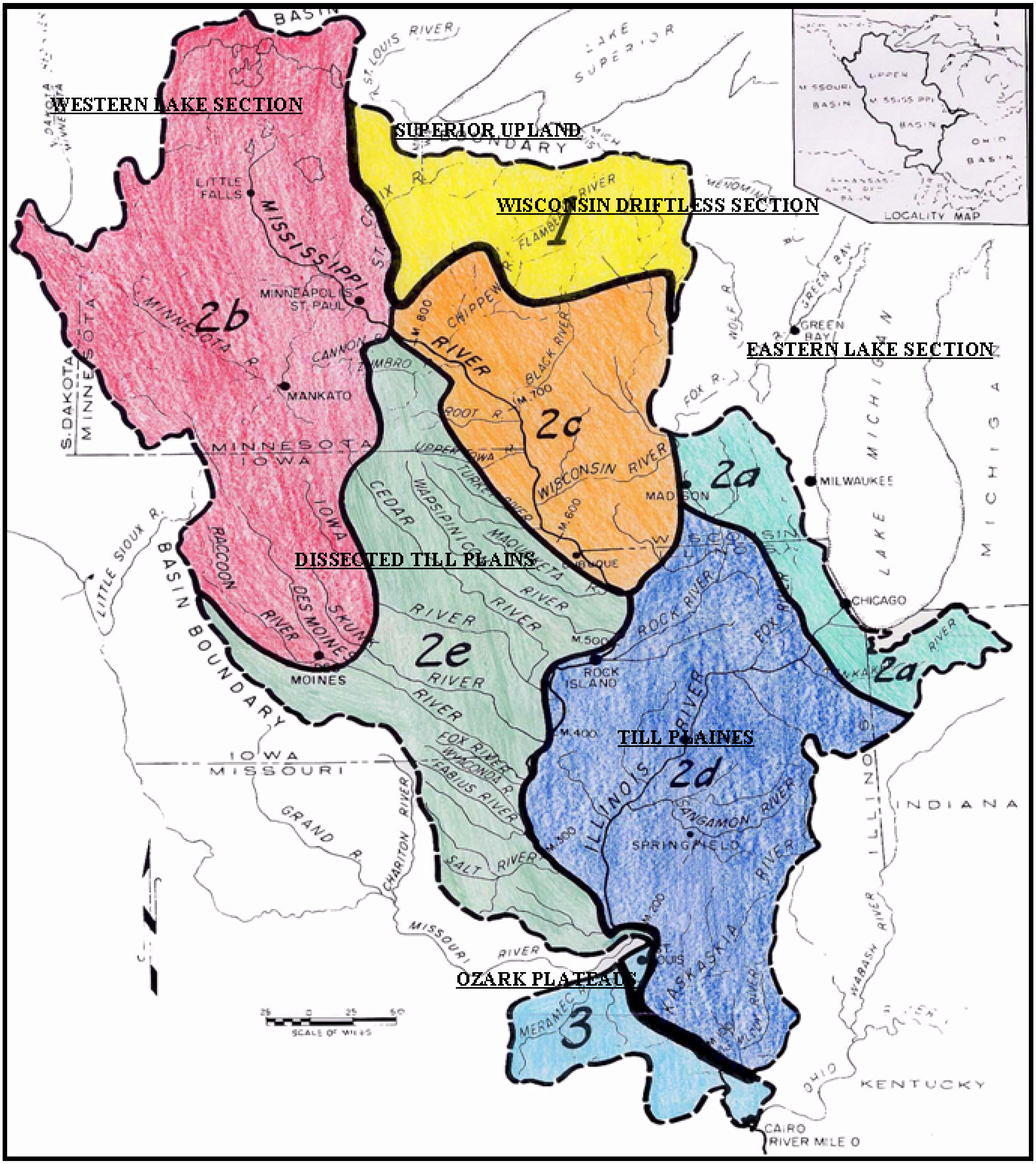

Figure 4: Geologic Land Classes of the Upper Mississippi River Basin

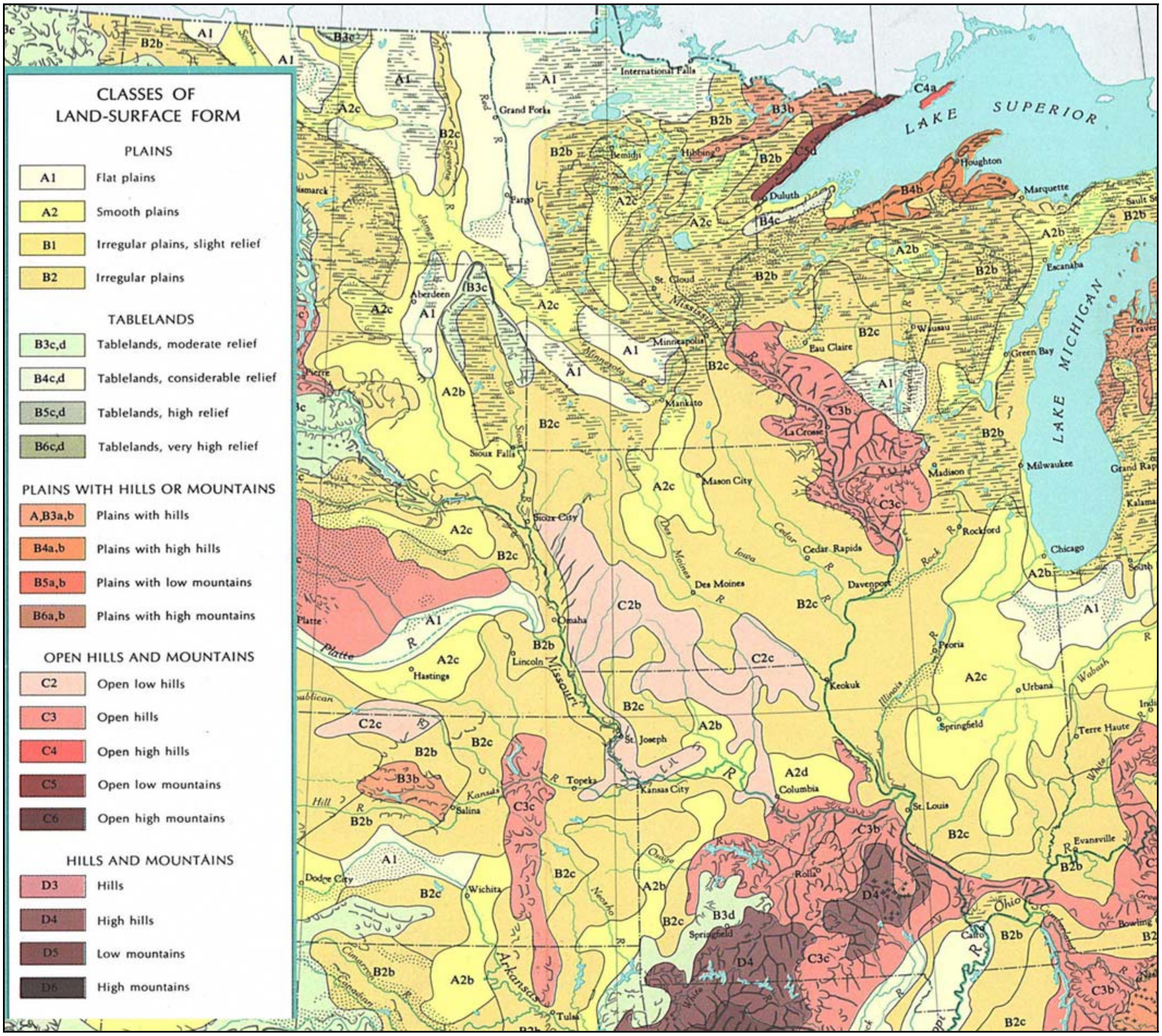

Figure 5: Geological Provinces of the Upper Mississippi River Basin

SEDIMENTATION, THE PROCESS AND THE PROBLEMS

Definition

Sedimentation may be defined as the physical process by which fragments of rock, soil, or organic material are transported from their site of origin and deposited to some other location. The transport may be accomplished by wind, water, ice, earthquakes, volcanic activity, human activity, or other physical actions. The word “sedimentation” refers to the transport of any size of particles. However, the term usually refers to the transport of fragments smaller than 6 mm.

The initial dislodging of the sediment particles for eventual transport or movement is called erosion. Erosion occurs from the same transport processes described above. The rate of natural erosion can be exceeded or reduced by human activities. For example, by converting the natural ground cover from prairie to cropland, or by re-sculpturing a hillside from woodland to cropland, the rate of erosion and the amount of resulting sedimentation may increase dramatically above the natural rate.

Sedimentation and Erosion as Natural Processes

Sedimentation and erosion are natural and necessary processes. Specifically, concerning rivers and streams, these processes are necessary for a healthy and functioning system. In a perfect word, the amount of sedimentation and erosion produces a natural state of dynamic equilibrium, whereby the processes are in perfect balance. “In alluvial river systems, it is a rule rather than the exception that banks will erode, sediments will be deposited, and floodplain islands and side channels will undergo modification with time. Changes may be very slow or dramatically develop” (Simons and Senturk, 1992). However, perfect dynamic equilibrium is a rarity even in natural systems due to the occurrence of extreme natural events. Most systems are subject to continuous but random changes as a normal part of their natural evolution and development. With that being said, man does have the ability to upset or modify the natural equilibrium, sometimes to a small degree and sometimes to a high degree, either inadvertently or on purpose. The goal should be to bring any system into a state that more closely resembles natural equilibrium, if that is possible. This goal is dependent on many sociological factors.

Sedimentation Problems in the Basin

Sedimentation is a major social and economic problem of the world, with the Upper Mississippi River Basin being no exception. As stated previously under the goals of this report, the enormous scale of the basin makes it impossible to specify every problem that may be occurring. Thus, problems specified here are in general terms.

Several unique factors create problems in this particular basin of the United States. First, a large portion of the soil is easily erodible. Second, the basin experiences significant yearly rainfall and runoff. Third, the basin contains a relatively large human population and an extensive infrastructure. These three primary factors have incurred large annual sediment damages, damages far above the less populated and more sediment-laden regions of the West. Even though the sediment concentrations found in the streams and rivers of the basin are generally less than those found in the West, much more water flows throughout the basin on an annual basis, thereby causing far greater sediment damages.

There are two predominant sources of sedimentation observed in the basin, sedimentation resulting from sheet and rill erosion, and sedimentation resulting from channel degradation and/or bank erosion. Figure 6 is a photo describing typical sheet erosion. Sheet and rill erosion have caused some agricultural lands in the basin to become unproductive, and in some cases, hillsides have been transformed to major sources of excessive erosion and sedimentation. Channel degradation and/or bank erosion has caused many of the steams and river channels to degrade (Figure 7) and have increased the efficiency by which water is passed (channel conveyance). In other cases, sedimentation has caused streams, rivers, and in some cases entire floodplains to fill, decreasing the channel conveyance and thereby increasing flooding.

Sedimentation in the basin has caused maintenance problems in reservoirs (Figure 8). Inflow and outflow for water supply facilities and power plants have been restricted by sediment (Figure 9). Harbors and marinas have faced continual sedimentation problems primarily at their entrances (Figure 10). Drainage ditches and canals have filled in with sediment over time (Figure 11). Navigation channels have to be dredged repetitively to maintain adequate depths (Figure 12). Sediment has been the primary cause for the loss of recreational benefits on lakes and waterways. Sedimentation has increased the cost of water treatment for public and industrial water consumption. During flood events, localized, concentrated sediment has been deposited over floodplains thru levee breaches (Figure 13) or from overbank scour, incurring localized agricultural damages. In addition, floodwaters have inundated public or private structures, bringing with it large amounts of sediment and causing considerable aesthetic and structural damage (Figure 14).

Figure 6: Sheet Erosion

Figure 7: Channel Degradation (Downcutting or Headcutting) on a Small Stream in Iowa

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Figure 9: Sediment Restricting Discharge at a Power Plant Facility Near Grand Tower, Illinois on the Mississippi River, Mile 80

Figure 10: Southeast Missouri Port Authority, Mississippi River, Mile 53. Port has Experienced Continual Sedimentation Problems at the Harbor Mouth. Illinois, on the Mississippi River, Mile 80

Figure 11: Sedimentation and New Meander Pattern Established in Channelized Portion of the Upper Iowa River

Figure 12: Sediment Discharge from a Dredge on the Mississippi River

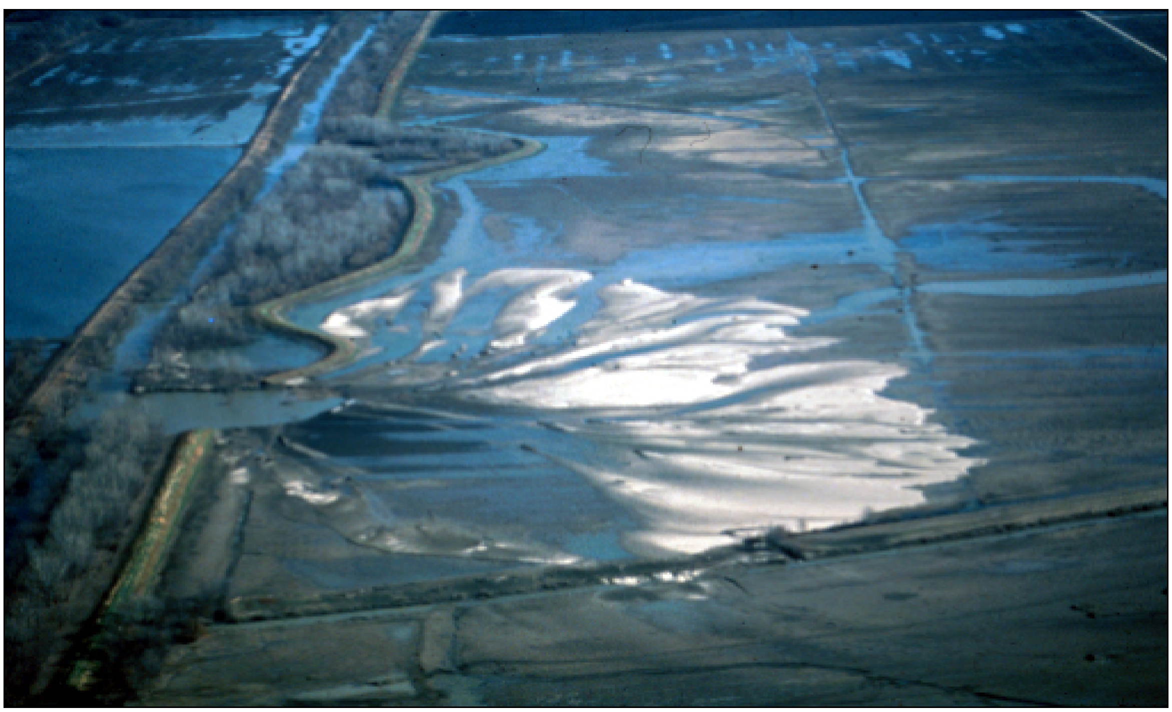

Figure 13: Concentrated Sand Deposit over the Floodplain after a Levee Breach on Bryants Creek, Missouri. near the Mississippi River at Mile 200

Figure 14: Sediment Damage in a Private Home after a Flood Event

Streambank erosion is a major problem throughout the basin (Figure 15). Most of the streams and rivers in the basin are experiencing erosion in some form or another either from natural or human disturbance. Erosion is also found along the banks of reservoirs, drainage ditches, and other man-made features that convey or hold water. As will be discussed later in this report, streambank erosion is now responsible for contributing a large portion of the total sediment load in the rivers and streams of the basin.

Figure 15: Bank Erosion on the Kaskaskia River in Southeastern Illinois

An important infrastructure that is directly associated with erosion problems are highway bridge crossings. There are thousands of bridges crossing most of the rivers and streams in the basin. The majority of these bridge designs do not account for changes in river morphology. Often bridges become the hydraulic controls of the streams. Bridges can serve as hardpoints or permanent fixed points along the floodplains, thereby dictating or controlling the meandering of the streams. In many cases, bridge openings across the channels are designed too small to convey flows during high water events, resulting in elevated water surface elevations, overtopping, and erosion of the roadway approaches to the bridges. This “undersized design” is an economic consideration, because the larger the opening, the larger the cost of the bridge. However, an undersized opening in relation to the natural flow conveyance can cause the stream to meander upstream, which eventually may cause the stream channel to become misaligned with the bridge opening.

Figures 16 and 17 highlight a typical example of a bridge controlling the morphology of the stream and influencing bank erosion. In this particular case, the stream originally passed perpendicular through the bridge. However, because of the restricted opening, the river meandered upstream to the point that the channel became misaligned with the bridge. As a result, the bridge abutment and upstream bankline was eroded severely. With no remedial action, many cases have shown that the stability of the abutment eventually may be compromised, and the stream will scour around the bridge. The bridge may then be severely damaged or fail completely.

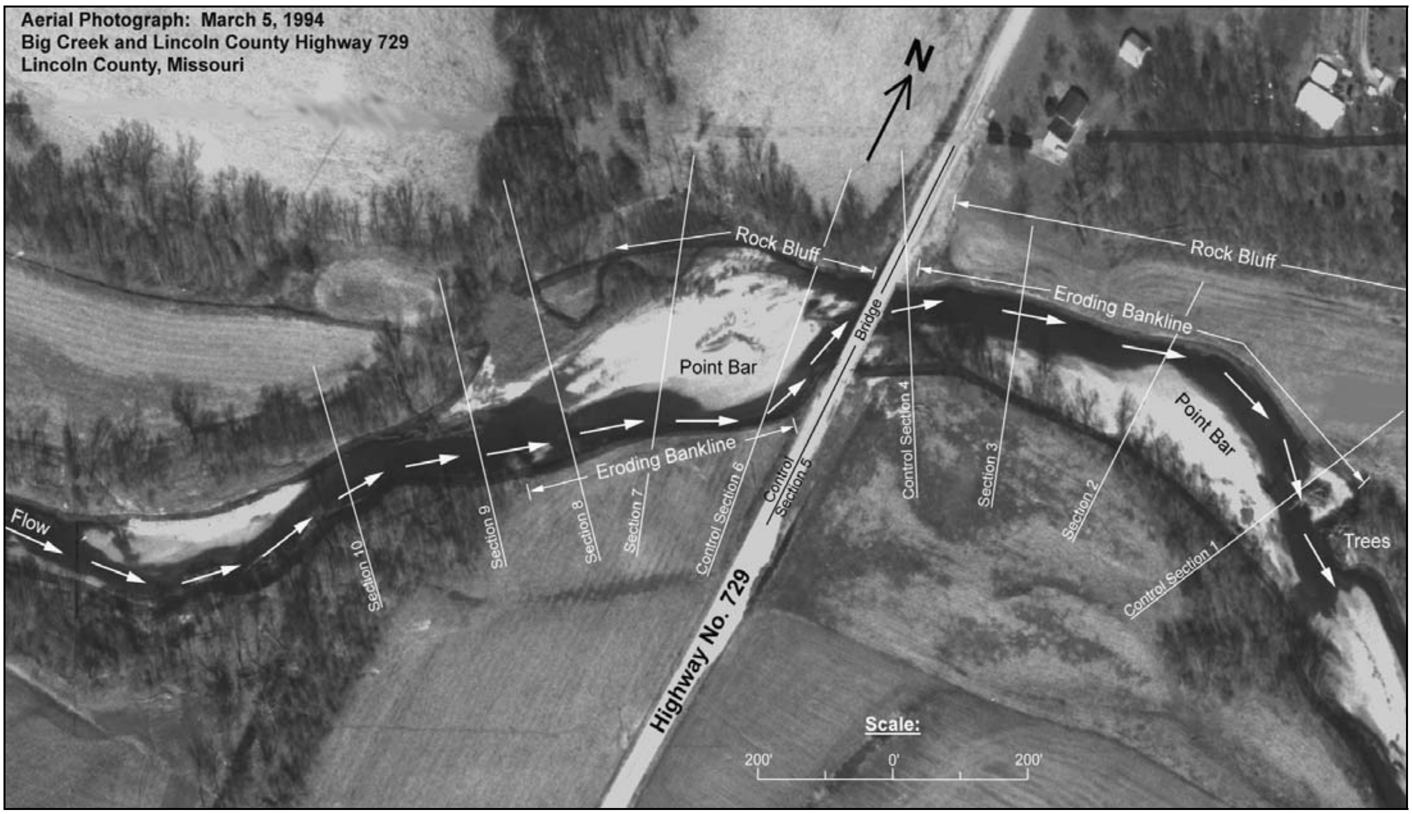

Figure 16: Misaligned Stream at Bridge Crossing, Big Creek, Missouri

After the great flood of 1993, a study was conducted by the National Cooperative Highway Research Program to examine primary and secondary highway infrastructure damages in the Upper Mississippi River Basin. More than $158 million dollars was requested from the Federal Highway Administration (FHWA) by officials in nine states for the repair or replacement of elements of the federal aid highway system at approximately 2,305 sites.

Figure 17: Abutment and Bank Erosion Attack Upstream of Highway Bridge, Big Creek, Missouri

Approximately $100 million additional dollars were requested from the Federal Emergency Management Administration (FEMA) for relief work on secondary highways and associated infrastructure (Parola 1998).

The study concluded that scour around bridge abutments was a much more frequent cause of damage than was local scour around bridge piers. In all cases studied where piers failed or settled as a result of scour, flow around abutments and approach embankments and the associated scour at these locations strongly influenced scour at the piers. The largest amount of damage occurred where abutments had been placed close to the banks of the main stream or river channel. Upstream lateral migration of streams and/or stream widening processes caused or contributed to damage at many abutments. Approximately 77 % of bridge damage to federal aid highways was caused by scour around abutments (Figure 18, Parola 1998). It is clear that unless future measures are taken, erosion at bridges will continue to be a major problem throughout the basin. Highway engineers may be unaware of the impact that bridge constrictions may have on the sediment response of the river or stream. Education on stream response effects, meandering, channel conveyance, and erosion should be mandatory for both past and future bridge designs.

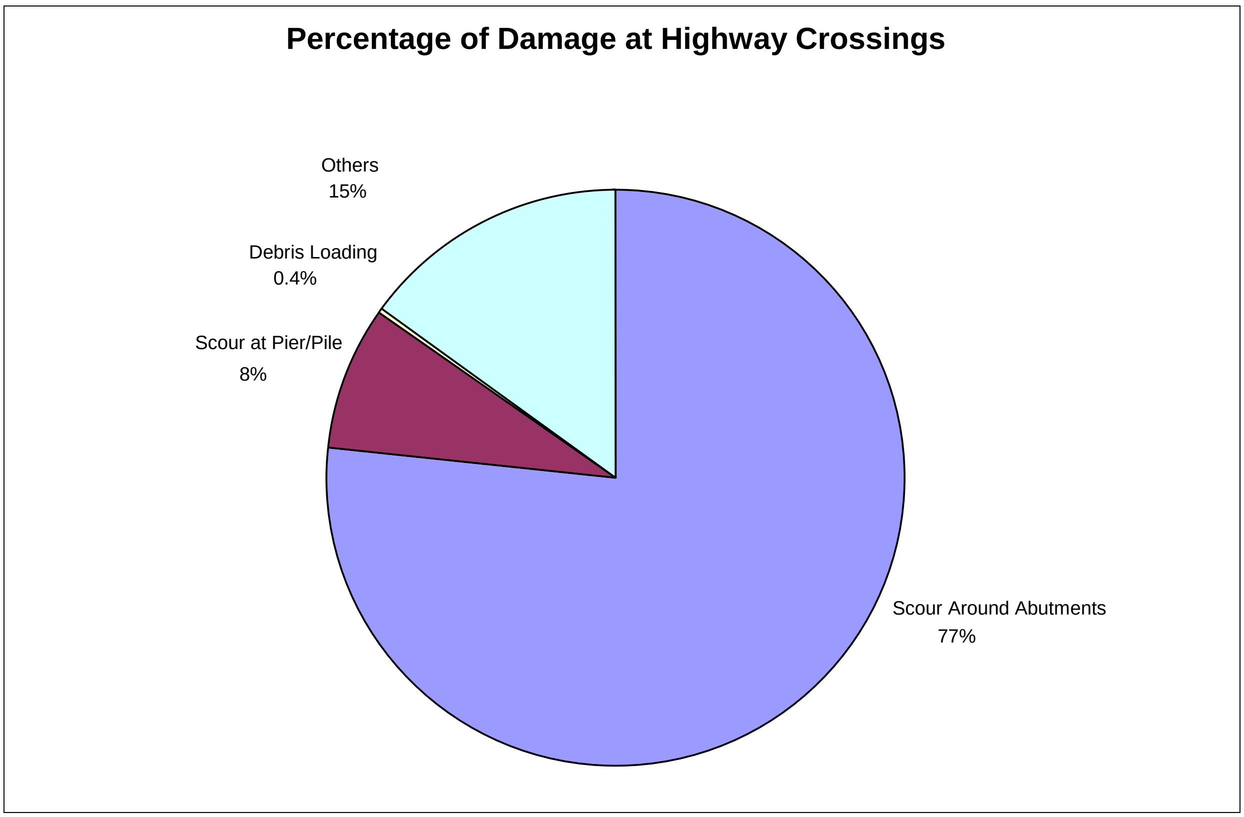

Figure 18: Damage to Federal Aid Highway Bridges in the Upper Mississippi Basin after the 1993 Flood

Sedimentation as a Physical Pollutant

Sediment is the major pollutant in many rivers today, the annual costs of which run into billions of dollars in the United States. Sedimentation as a physical pollutant in the basin can impact receiving waters. High levels of turbidity can limit penetration of sunlight into the water column, thereby limiting or prohibiting growth of algae and rooted aquatic plants. Gravel beds may become blanketed with fine sediment degrading substrate which may inhibit or prevent fish spawning. In either case, the consequence may be disruption to the aquatic ecosystem by alteration or complete destruction of habitat. Notwithstanding these undesirable effects, the hypertrophic (nutrient rich) status of many of the shallow lakes throughout the basin may give rise to an immense growth of algae and rooted plants were it not for the limiting effect of light blockage due to high turbidity levels. In this sense then, sedimentation can be "beneficial" in highly atrophic lakes.

Sedimentation as a Chemical Pollutant

Sedimentation as a chemical pollutant is tied to the particle size of the sediment and to the amount of particulate organic carbon associated with the sediment. The chemically active fraction of sediment is usually cited as that portion which is smaller than 63 microns (a silt + clay fraction). For phosphorus and metals, particle size is of primary importance due to the large surface area provided by very small particles. Phosphorus and metals tend to be highly attracted to ionic exchange sites that are associated with fine clay particles. Iron and manganese coatings commonly found on clay also attract these pollutants.

Many of the persistent, bio-accumulating and toxic organic contaminants, especially chlorinated compounds that include many pesticides, are strongly associated with sediment. Organic carbon is attracted to fine particles and is transported as part of the sediment load in streams and rivers. Measurements of phosphate transport collected in North America indicate that as much as 90% of the total phosphate flux in rivers may be associated with fine suspended sediment.

Phosphate tends to cling to fine sediment particles and organic matter, and is readily transported to streams by surface runoff erosion of eroded soil particles and by bank failure and erosion. The more fine sediment that is found in the river, the higher the phosphate load will be. This has ramifications for increased costs required at water treatment plants (Biedenharn, et. al. 2003).

Phosphate loads are typically the deciding factor of freshwater stream and reservoir productivity. Phosphate tends to move with sediments in the fluvial system (Kronvang et al., 1997).

Organic chemicals associated with sediment enter into the food chain in a variety of ways. Sediment may be directly ingested by fish. More commonly, fine sediment (especially the carbon fraction) is the food supply for benthic (bottom dwelling) organisms, which in turn are the food source for larger organisms. The toxic compounds thus bio-accumulate in fish and other aquatic life. In this way, pesticides that are transported off the land as part of the runoff and the erosion process accumulate in the food chain whereby they may ultimately be consumed by humans.

Figure 19 shows a typical sample of bed sediment collected in the Kaskaskia River Navigation Channel in Southeastern Illinois. The navigation channel is considered a pool or slow-flowing river most of the year because of the backwater effects induced by a lock. As verified by the photo, the bed material is composed of extremely fine silt and clay. Under water quality certification standards established for the State of Illinois, this material is considered a contaminant if dredged, and must be placed in an upland, confined disposal area. Many areas along the Mississippi and Illinois Rivers where repetitive dredging is required also contain fine sediments. Therefore, the dredge disposal must be placed "off-channel" on the floodplain into confined areas for contaminant protection (Figure 20).

Figure 19: Typical Bed Sediment Sample in the Kaskaskia River Navigation Channel

Figure 20: Dredging and Off-Channel Disposal on the Illinois River (Cox 2005)

In the free-flowing reaches of the Mississippi River downstream of St. Louis, Missouri, part of the suspended-sediment load interacts with the channel bed and part of the load is independent of any such interaction. Figure 21 shows examples of data collected from the Mississippi River at Thebes, Illinois, on June 10, 1989, and at Vicksburg, Mississippi, on March 27, 1989. The channel bed at these two sites (and through most of the 1,175 mile length of the Mississippi between St. Louis and the Gulf of Mexico) consists almost entirely of sand and fine gravel, with few particles, if any, finer than 0.063 mm (millimeter) in diameter. Some of the finest sand (mostly 0.125-0.25 mm) is mobilized from the channel bed to become part of the suspended sediment load.

Most of the sediment in suspension, however, is finer than sand. The suspended sediment load can be divided into two fractions called "silt" and "colloid." The division between the two fractions is defined arbitrarily at about 0.001 mm. The relative volumes of silt and colloid shown in Figure 21 represent the sizes of the individual particles after they have been disaggregated in the laboratory with a dispersing agent. In the river itself, most of the colloid-size particles are found in aggregates that are large enough to be transported and deposited as silt particles.

In the Upper Mississippi River pooled reaches above St. Louis, the sizes of the particles in both the bed sediments and suspended sediments are distributed differently from those in the open river reach below St. Louis. The examples shown in Figure 21 are from data collected from the Mississippi River at Hastings, Minnesota, in the upper end of navigation Pool 3 on October 10, 1991. Also, data is shown from off-channel areas of lower Pool 3 on October 11, 1991; and from the Mississippi River near Winfield, Missouri, at the upper end of Pool 26 on July 24, 1991, and from the off channel areas of lower-middle Pool 26 on November 1, 1991.

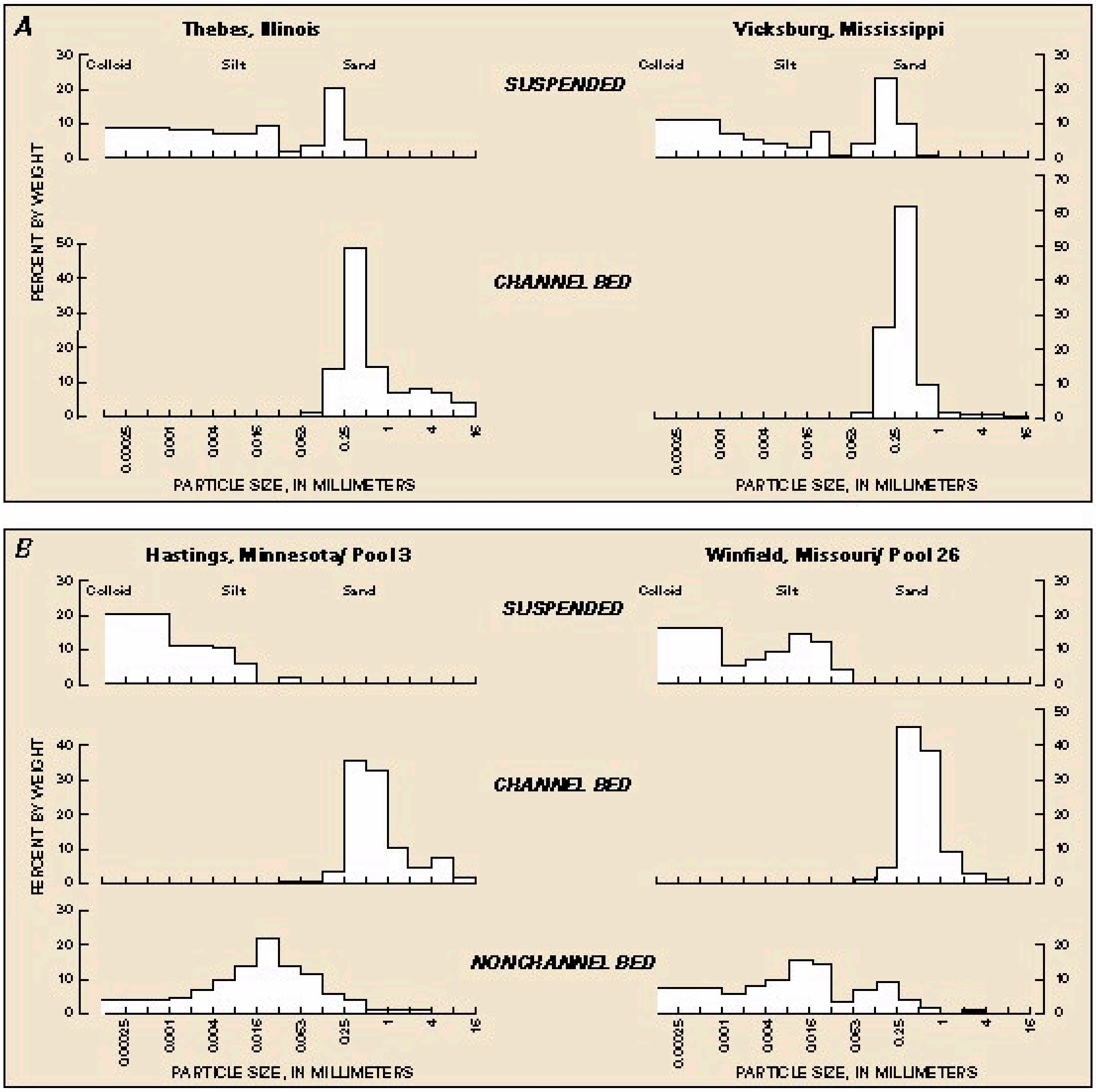

Figure 21: Sediment Samples in the Lower and Upper Mississippi River (USGS 1991)

In the navigation channel, the bed sediments consist largely of sand, as in the channel of the open river. Suspended sediments, however, consist almost entirely of silt and colloidal particles and contain very little sand except during floods. In the shallow off-channel areas of the navigation pools, which cover a portion of the floodplain, the bed sediment is typically intermediate in size and finer than the bed material in the main channels but generally coarser than the bulk of the sediment in suspension.

Additional studies along the impounded reaches of the Upper Mississippi River navigation channel reveal that the bed sediments are almost totally comprised of sand-sized or finer material (<2mm). Between the Des Moines River confluence in Pool 20 and Lock & Dam 26, up to gravel sized material has also been measured. Sediments in the lower third of each pool, along the navigation channel, are typically finer than sediments in upstream portions of the pool. Sediments collected in the main channel, but outside of the navigation channel, in the lower third of each UMR pool are characteristically comprised of fine and very fine sand-sized material (0.0625 to 0.25 mm). Available data indicate that the mean size of sediments in backwater areas of the river is characteristically medium to fine sand-sized material (WEST Consultants, 2000). Table 1 provides data on the fraction of suspended sediment that is sand-size (greater than 0.062 mm) at various locations along the impounded reaches of the Upper Mississippi River.

River and Station	Percent of Suspended Sediment Greater than 0.062 Millimeters	Source of Information
Mississippi River at Royalton	8	Tornes, 1986
Mississippi River at St. Paul	11	Tornes, 1986
Mississippi River at L/D 4	43.5	CSU, 1979
Mississippi River at L/D 5	25.4	CSU, 1979
Mississippi River at L/D 5A	26.6	CSU, 1979
Mississippi River at L/D 6	31.9	CSU, 1979
Mississippi River at L/D 7	27.2	CSU, 1979
Mississippi River at L/D 8	17.2	CSU, 1979
Mississippi River at East Dubuque, IL	13.9	Nakato, 1981
Mississippi River at Burlington, IA	11	Nakato, 1981
Mississippi River at Keokuk, IA	0.6	Nakato, 1981
Mississippi River at Hannibal, MO	2.5	Nakato, 1981

Table 1: Percent Sand Size Particles in Suspended Sediment on the Impounded Reaches of the Mississippi River Tributaries

Sediment particle types found in the other rivers and streams in the basin range in size from fine clays or colloids to coarse sand, gravel, and even large cobbles. Generally, the typical particle sediment type found most in basin streams is fine silty sand.

Nakato (1981), Tornes (1986), and Rose (1992) determined the percentage of sand found in suspended sediment at various tributary gauging stations (Table 6). The amount of sand that is transported in suspension on tributaries is important because this sand contributes to the sand load on the Mississippi River and may end up being deposited in the navigation channel, in channel fringe areas, or in backwater deltas.

River and Station	Percent of Suspended Sediment Greater than 0.062 Millimeters	Source of Information
Minnesota River near Jordan	19	Tornes, 1986
St. Croix River at St. Croix Falls	6	Tornes, 1986
North Fork Whitewater River at Elba	8	Tornes, 1986
Root River near Houston	3	Tornes, 1986
Chippewa River near Caryville, WI	40	Rose, 1992
Chippewa River at Durand	74	Rose, 1992
Chippewa River near Pepin	70	Rose, 1992
Black River near Galesville	66	Rose, 1992
Wisconsin River at Muscoda	60	Rose, 1992
Tukey River at Garber, IA	20.2	Nakato, 1981
Maquoketa at Maquoketa, IA	10.2	Nakato, 1981
Wapsipinicon at DeWitt, IA	34.1	Nakato, 1981
Iowa at Wapello, IA	11.2	Nakato, 1981
Skunk at Augusta, IA	5.4	Nakato, 1981
Des Moines at St. Francisville, MO	40.3	Nakato, 1981

Table 2: Percent Sand Size Particles in Suspended Sediment on Mississippi River Tributaries

Sediment particle types found in the other rivers and streams in the basin range in size from fine clays or colloids to coarse sand, gravel, and even large cobbles. Predominantly, the typical particle sediment type found in most rivers and streams in the basin consist of fine silty sand.

Substrates in Pools 4 and 8 were studied by Rogala (1996) using a device which penetrated bottom sediments with different sized cones. Samples were also collected and analyzed for moisture content, bulk density, and organic content. Most of the samples collected in both pools had low moisture contents suggesting limited amounts of fine sediment accumulation. Sediment samples collected by the Corps of Engineers, St. Paul District in Peterson Lake in Pool 4 showed a gradient of sediment types, with sand dominating the delta areas where secondary channels entered the lake, and fine sediments dominating areas of the lake removed from main channel inflows. Similar results were found in Weaver Bottoms in Pool 5 (Nelson et al., 1998).

Sediment Transport and the Limitations of Measuring Bedload

Different sizes of particles are found in suspension and along the riverbed, and the interrelations between the sediments transported in suspension and those stored or transported along the riverbed are complex and variable. This dynamic movement of sediment in water has transcended into a completely separate science called "Sediment Transport".

The description of the movement of water, referred to as "hydrodynamics", is in itself complex, considering that water flow is three-dimensional. Phenomena such as eddies, turbulence, vortexes, waves, and secondary currents produce an ever-changing and difficult-to-describe process. Combined with the movement of sediment, the process then becomes even more complex. Phenomena such as entrainment (suspended sediment motion), scour, deposition, dune formation, diffusion, historesis, and sediment consolidation, all add to the complexity of sediment transport. Changes in bed forms, vegetation cover, underwater strata, water surface slope and the rate of rise and fall of the hydrograph make matters even more difficult. River processes are so complex that there is not a general accord on which characteristics are causes and which are effects (ASCE 1975).

Many notable historical scholars, including Yang and Einstein, have studied sediment transport. Numerous equations and relationships have been developed to describe this complex phenomenon, all producing different values (Figure 22). As a result, discrepancies and conflicts have been common. Probably no other branch of science contains such great disparity among theory, technique, and practice. Simons, a recognized expert in sedimentation, stated that "a rational explanation for

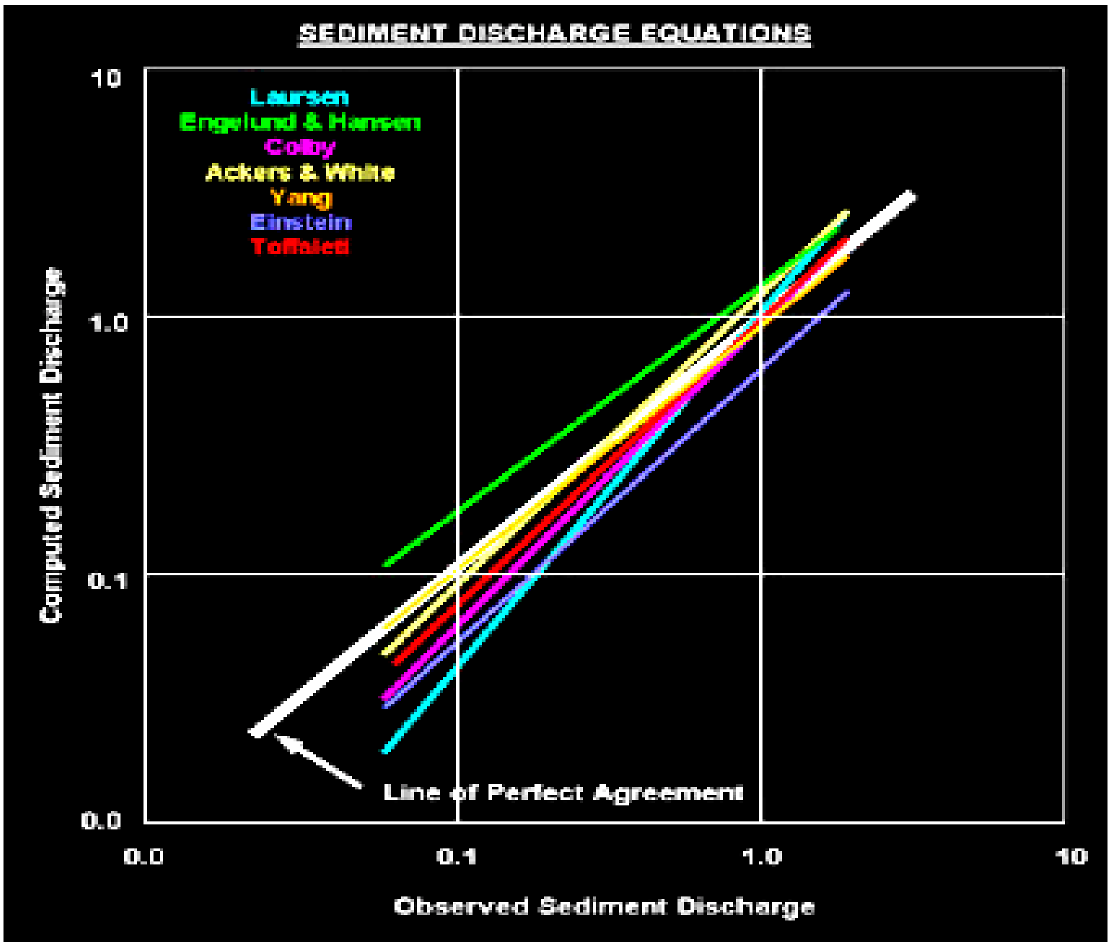

Figure 22: Sediment Discharge Versus Observed Sediment Discharge for 6 Different Empirical Relationships.

sediment transport may never be developed".   One reason so many unknowns still exist is that is extremely difficult if not impossible to measure the bed load on large rivers. At best only unreliable estimates can be made. There has been some recent confidence achieved on smaller tributaries with the use of the Helley-Smith sampler (Figure 23), but extreme caution should be taken on using this device on larger rivers where highly variable and dynamic dune bed forms are encountered.

With the recent advent of the new Doppler hydroacoustics and laser technologies, one day it may be possible to more accurately measure the bed load of the Mississippi River. The research is encouraging. However today one has to still settle for estimates at best.

Figure 23: Helley-Smith Bed Load Sampler

BASIN LAND USE AND CLIMATE

Historical Land Use Changes

The rich, fertile lands of the Upper Mississippi River Basin were utilized early on by Native Americans and later by European settlers. Historical archaeology shows that some of the Indian agricultural tribes would periodically burn large tracks of natural prairie for the planting of crops (Norris, 2002 et. al.) This practice was passed down over generations. To what extent this had on erosion and sediment in the basin is unknown but could have been significant (Norris 2004).

The first European settlers started arriving in the basin by the late 1700s to early 1800s. The basin originally contained vast amounts of forests, wetlands, and natural prairies. Figure 24 is a historical land use map of Fayette County along the Kaskaskia River in Southeastern Illinois. The map was generated using 1820 Government Land Office (GLO) surveys. The map serves as a microcosm of the central part of the basin when the human population was still low. Prairies and forests were abundant, with some wetlands found closer to the river. On this map and others, observations and records indicate that this type of land cover changed dramatically over the next century as more and more land was converted to agricultural use.

Figure 25 is a close-up segment of the 1820 GLO along the Kaskaskia River just south of Vandalia, Illinois. In this map, it can be observed that a swamp on the floodplain was apparently being drained by two man-made canals connected back to the main river channel. This illustrates just how early in time man started to change the natural drainage. In this particular case, later surveys revealed that these drainage canals influenced planform changes on the river. The modern-day river channel of the Kaskaskia River now runs through the original drainage canal locations. Remnant oxbows have been left behind in the original main channel location of 1820.

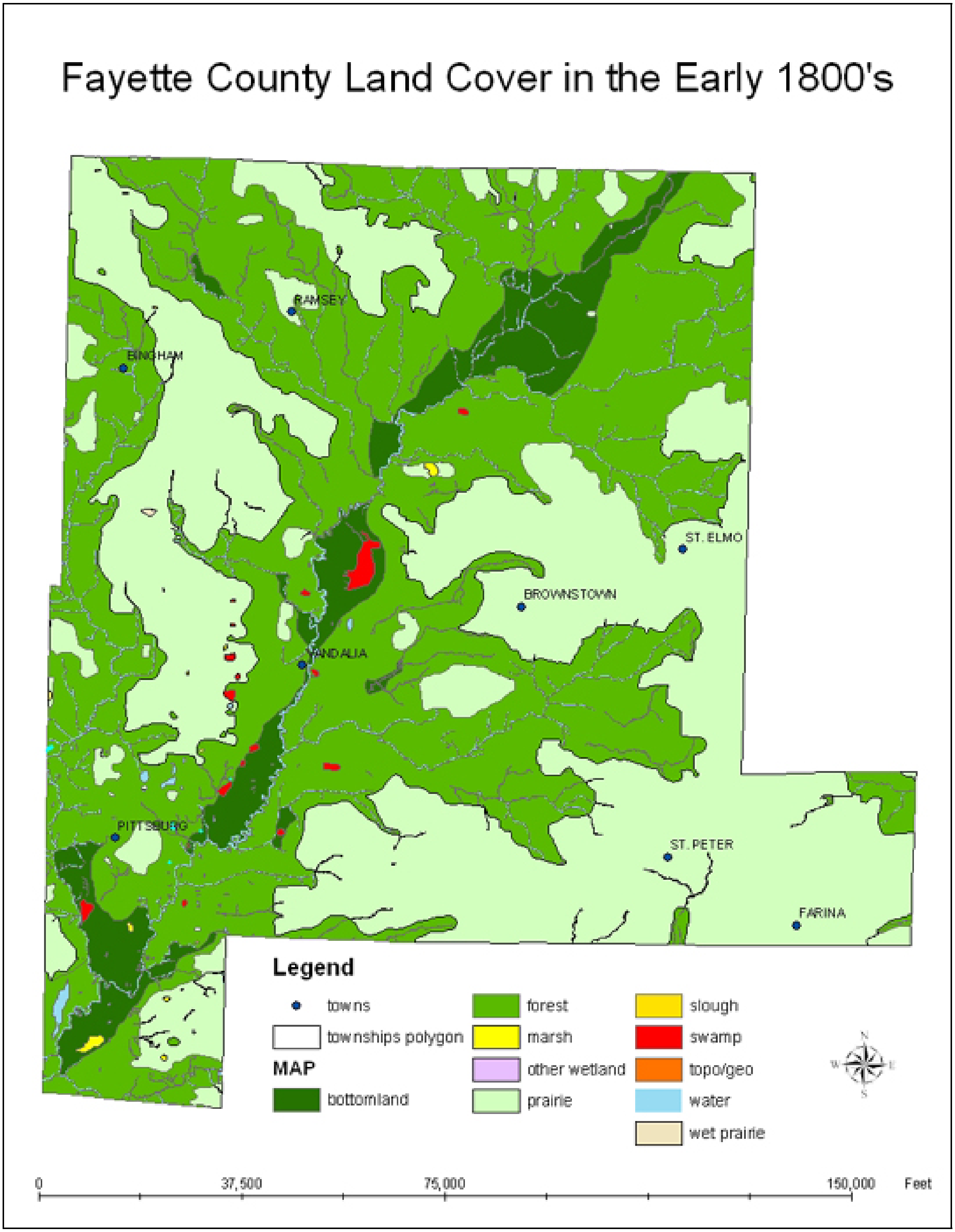

Figure 24: Land Cover in Fayette County, Illinois in Early 1800s

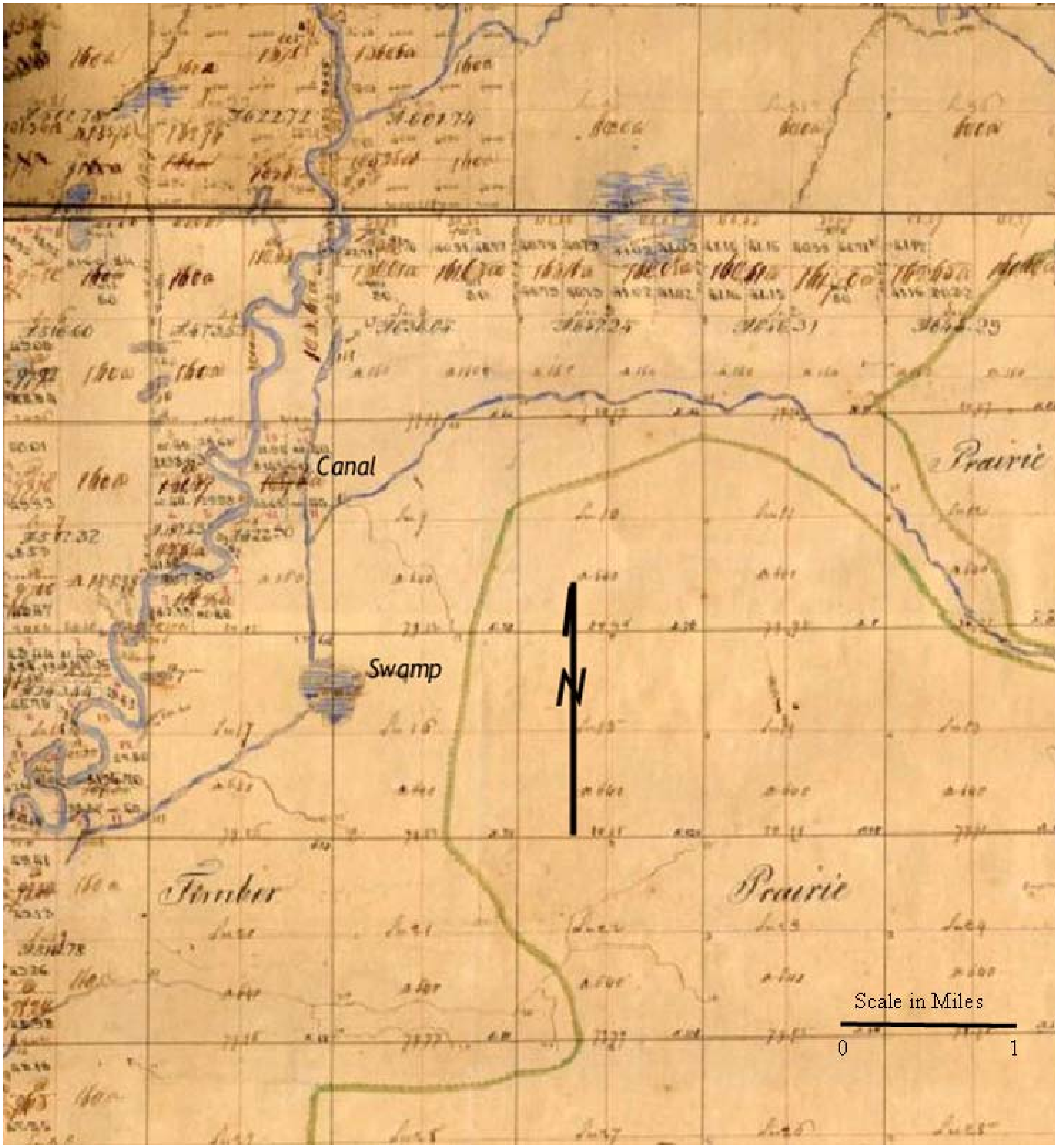

Figure 25: 1820 GLO Survey, Kaskaskia River South of Vandalia, Illinois

Modern Day Land Cover Types

The land cover transformation in the basin occurred over a relatively short period. This is discussed in a proceeding test case section on the Kaskaskia River basin. The modern day land cover regions of the UMR basin are highlighted in the map of Figure 26. The land coverage today can be categorized into four primary types; row crops, cropland/woodland, northern forest, and southern forest. Table 1 shows the percentages of these land cover types as they compare to the total basin area.

LAND COVER REGION TYPE	*APPROXIMATE PERCENT OF TOTAL BASIN AREA*
1. Row Crops	43 %
2. Cropland/Woodland	40 %
3. Northern Forest	12%
4. Southern Forest	5%

Table 3: Percentages of Land Cover Types, Upper Mississippi River Basin

Figure 27 further highlights that croplands are still the predominant land cover type of the basin. The regions where forests prevail are found primarily in Northern Minnesota, Wisconsin and some areas of Southern Missouri and Southern Illinois.

Land use has remained surprisingly the same since the early to mid 1900's. Historical maps have shown that the majority of croplands now farmed are the same parcels of land first cleared by the early settlers. In many cases, this land has remained in the same family, with ownership passing along from generation to generation. In recent times, some major land use changes have occurred around the larger cities such as Minneapolis, St. Louis, and Chicago, primarily due to urban sprawl (Figure 28).

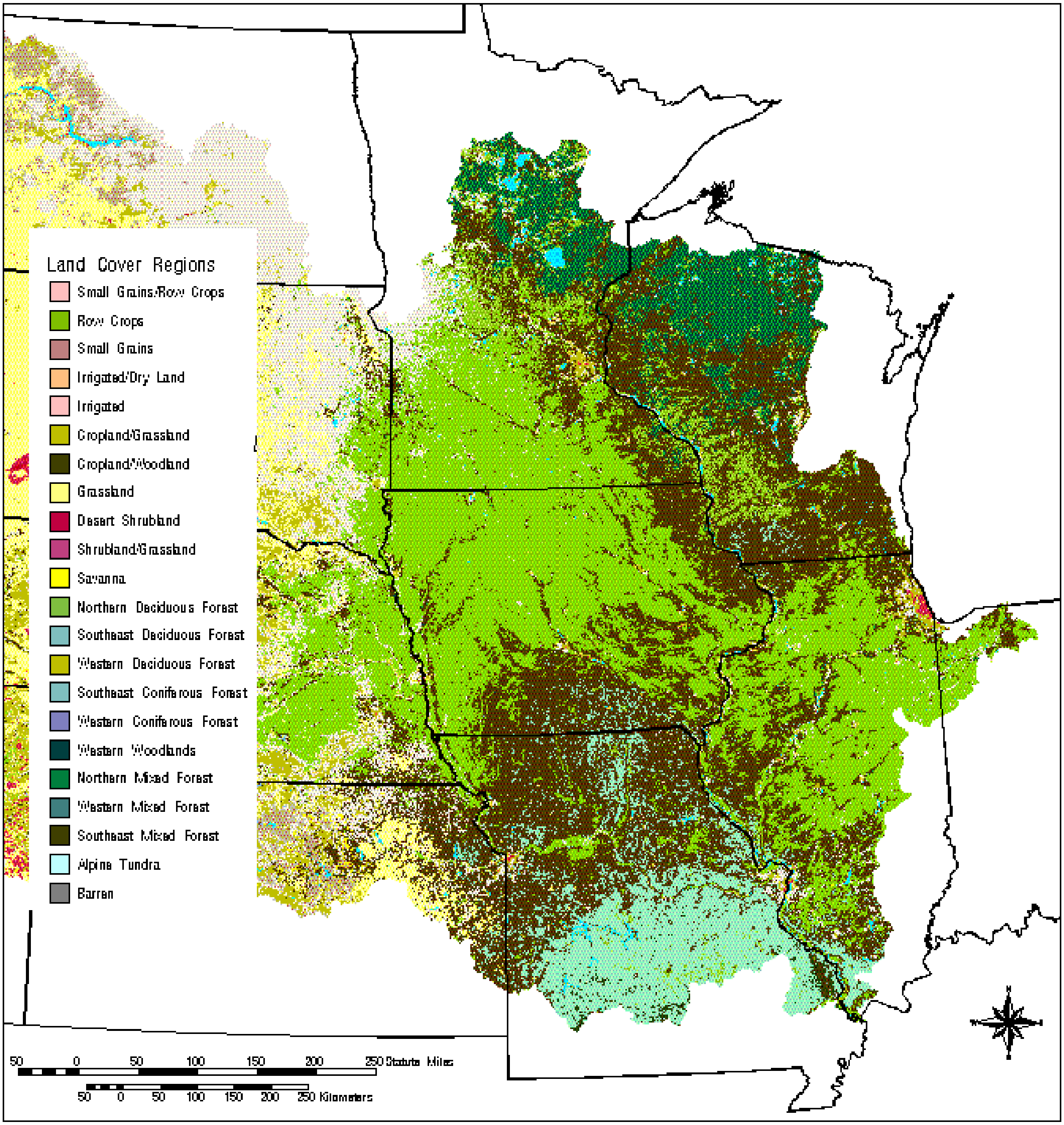

Figure 26: Upper Mississippi River Basin Seasonal Land Cover Regions

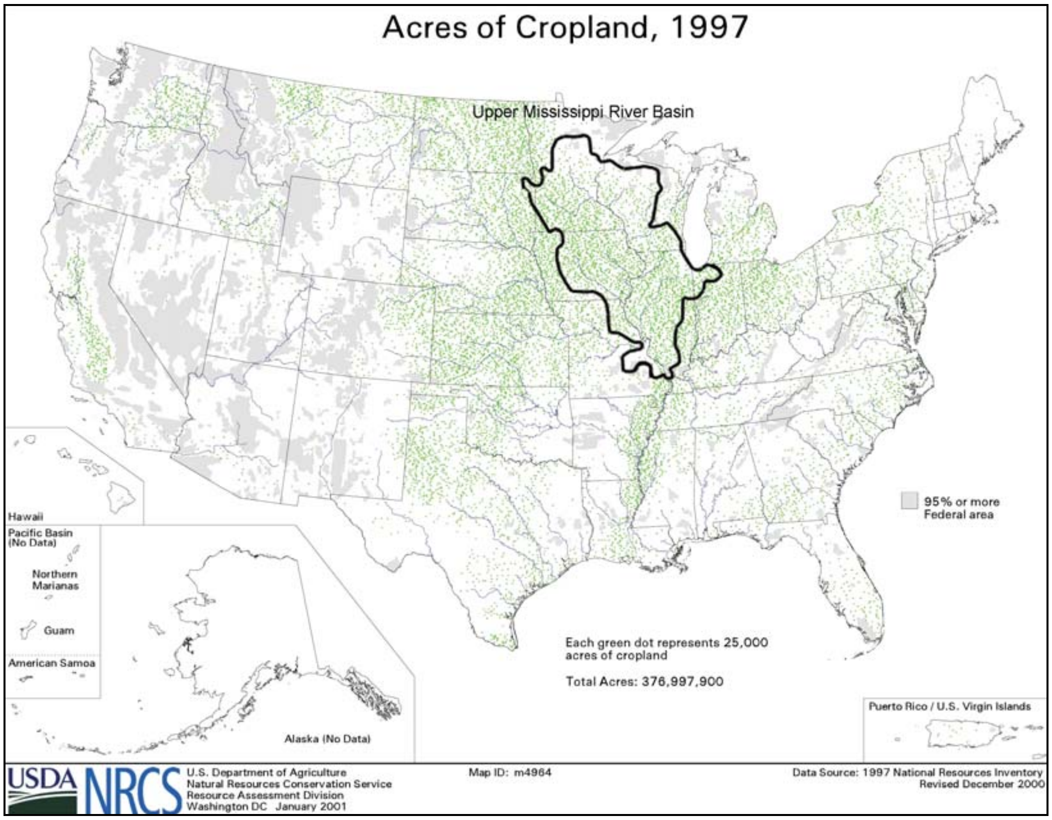

Figure 27: Acres of Cropland in1997

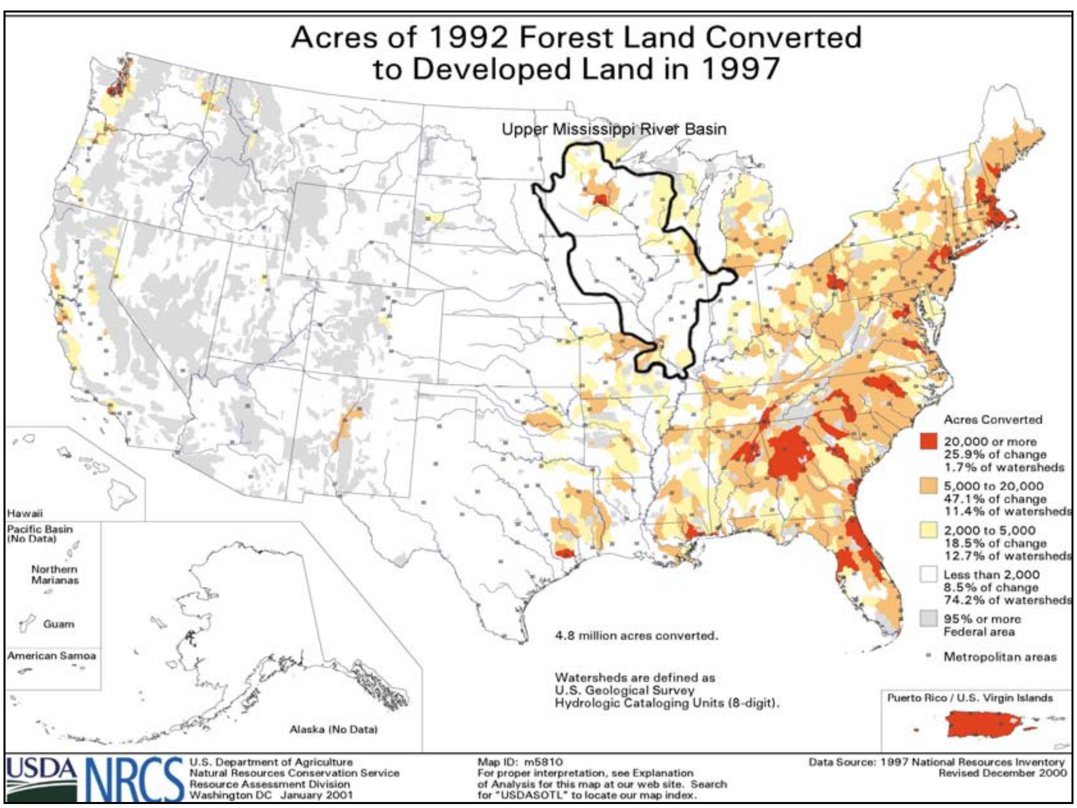

Figure 28: Forest Land Converted to Developed Land, 1992 to 1997

Climate

The basin experiences a fair amount of variability in climate. In the northern part, the average annual temperature is cool at approximately 39 degrees F, with a winter average temperature of about 10 degrees F and a summer average at about 65 degrees. The spring and summer months tend to be more wet than the fall and winter months. About 20 inches of precipitation falls over this region each year.

In the middle portion of the basin, the average annual temperature is about 50 degrees F, with about 32 inches of annual precipitation falling each year. The spring and summer months tend to be more wet than the fall and winter months.

In the southern part of the basin, the average annual temperature is mild at approximately 59 degrees, with a winter average at about 36 degrees F and a summer average of about 75 degrees F. About 45 inches of precipitation falls each year in this region. The precipitation tends to be more evenly distributed throughout the year.

Historical Precipitation Trends

One of the biggest influences on the amount of sedimentation that occurs in a basin is the amount of yearly precipitation. More rain means more runoff. More runoff means more water flowing over the land and down the channels of the streams and rivers. The end result is more erosion and more sediment.

Figures 29 and 30 are historical precipitation trends representing the northern portion of the basin (St. Paul, MN) and the middle and southern portions of the basin (State of Illinois average).

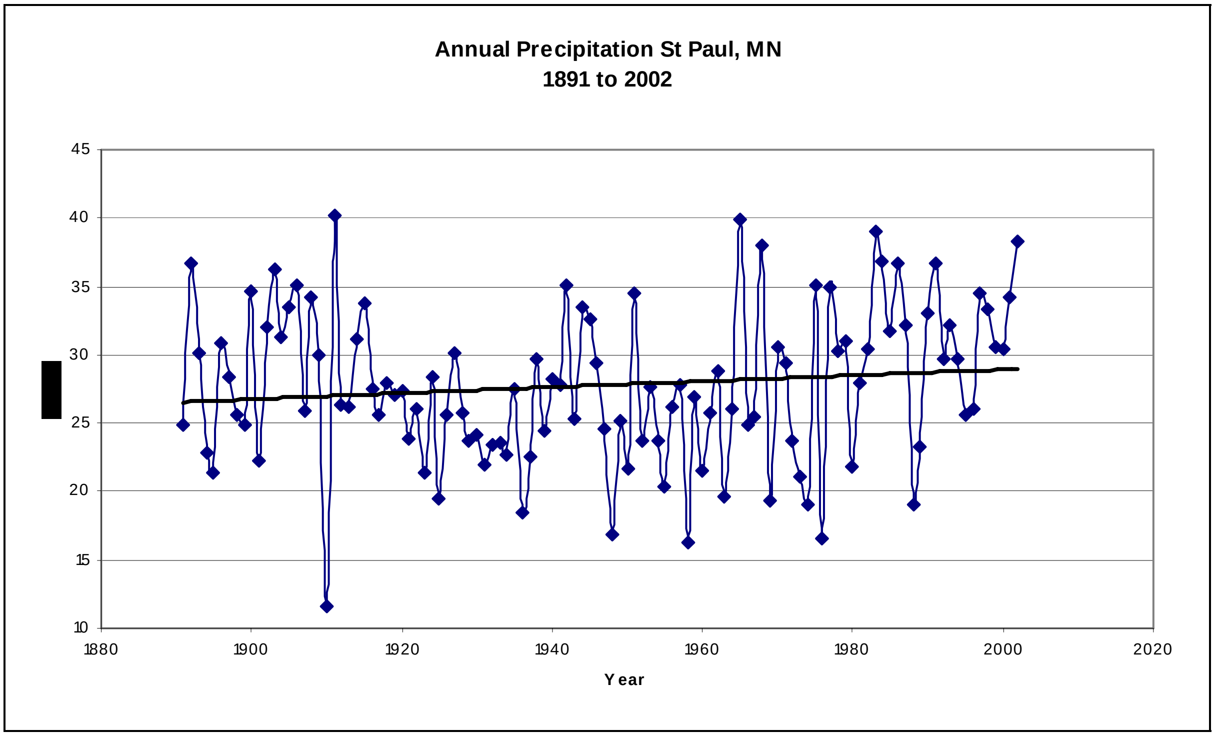

Figure 29: Statistical Trend-Line for Historical Precipitation at St. Paul, Minnesota

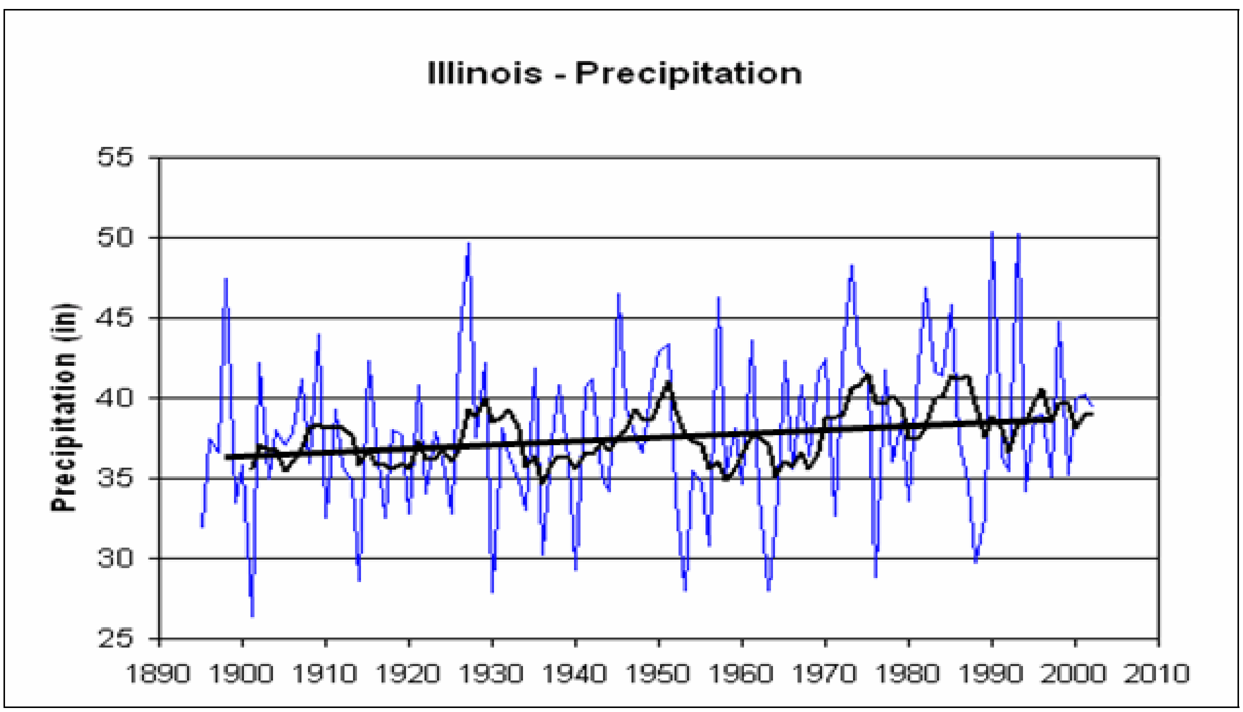

Figure 30: Statistical Trend-Line for Average Historical Precipitation in the State of Illinois

There has been without a doubt an upward trend in historical precipitation over the basin. This is not to say this trend will continue to increase. Data here in the United States covers just over a hundred years. Much longer historical records observed from China and Europe reveal that precipitation patterns and trends are cyclic. In the Central United States, the current wet cycle trend may be followed by a dry cycle. The future tends of precipitation (upward or downward) is unknown and not predictable but will influence the equilibrium of the stream. If the upward trend continues, increased erosion of the rivers and streams is certain.

Drainage Tiles, the Transformation of Runoff in the Basin

Another great human influence on sedimentation throughout the Upper Mississippi River Basin has been the installation of the drain tiles. A drain tile is a cylindrical tube installed beneath the surface of the soil designed to improve drainage. Grids or networks of tiles are usually installed under agricultural fields. These grids may then in turn be tied into additional drainage, including ditches, canals, culverts, and pumps.

Tiles have been used in the world for agricultural drainage for at least two thousand years. In the United States, the first use of tile drainage was attributed to Mr. John Johnson around the mid 1830's. Johnson demonstrated how the drainage of land could be dramatically improved by installing a grid of drain tiles. Johnson's work caught on, and by 1880, there were over 1000 drain tile factories located throughout the Midwest. Over the years, tiles have been made out a variety of materials including clay, concrete, and plastic. Today, plastic tubes are the most widely used subsurface drainage material.

Most of the historic drain tiling was excavated by either hand and shovel (Figure 31) or horse and plow (Figure 32). The steam engine was eventually used where afforded, until the more modern day diesel and gasoline engine trench systems were employed. Recently, cost effective systems utilizing tile plows pulled behind tractors have gained popularity, making it much easier for the smaller farmer or land resource manager to improve drainage.

Figure 31: Hand Digging a Tile Trench in Minnesota, Early 1900s

Figure 32: Construction of a Drainage Ditch by Horse and Plow in Minnesota, 1908

There are literally thousands of miles of drain tiles lying just beneath the surface of most of the developed land in the basin. Figure 33 shows a typical example of a drain tile network in the Upper Little Vermillion River Basin in East Central Illinois. The map serves as a model example of just how extensive these drain tile systems can be.

By installing drain tiles, an agricultural field yielding marginal or zero crop production can be turned into very productive land. However, by enabling the water to drain faster away from a particular land area, studies have shown that the receiving stream or river may experience increased flooding.

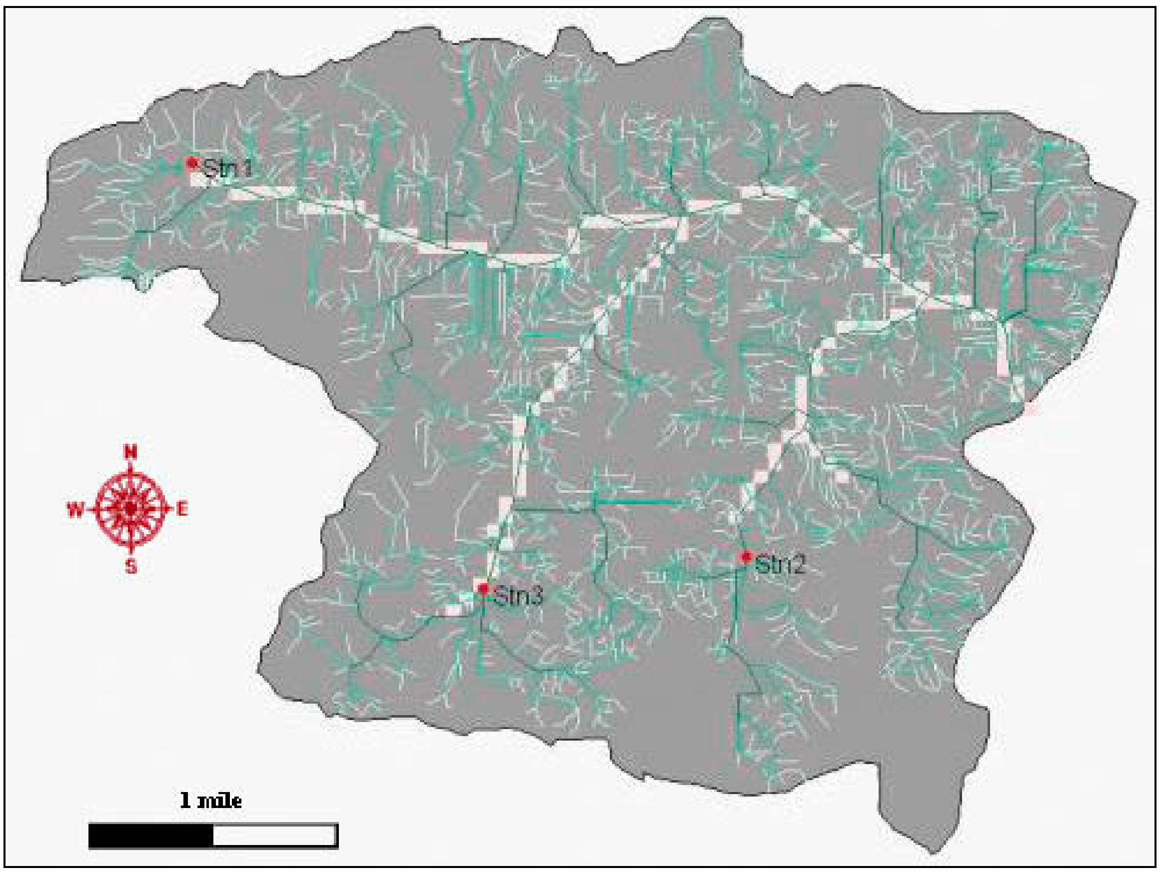

Figure 33:Drain Tile Network on the Upper Little Vermilion River in East Central Illinois

A study was conducted by Moore and Larsen (1979, 1980) for two small watersheds in southwestern Minnesota. They developed a model to examine the hydrologic response of agricultural drainage versus natural drainage. The model was more specifically used to determine the impact of various types of drainage for the Little Sioux River watershed and Jackson County Ditch 11 (Figure 34). The model simulated the following drainage scenarios: (1) natural condition, (2) present condition, (3) improvement in channel only, and (4) maximum drainage possible for the sole benefit of agriculture. Predicted runoff depths of the Little Sioux River watershed for each of these options are shown in Figure 35. Runoff depth was defined as the flow at the watershed outlet and included both surface and subsurface sources.

Results show that subsurface drainage (tile networks) substantially increased the annual runoff depth. Channel improvement had a minor influence on runoff depths. Drainage also increased peak flows in their simulations. These increases were principally caused by channelization. Surface inlets also had significant, though much lesser, influence on peak flows. Subsurface drainage had negligible impact on peak flows.

This example shows just how large an impact improved agricultural drainage can have on the runoff into receiving waters. If the same trend observed here were applied to the enormous combined size of all improved drainage areas of the entire Upper Mississippi River (UMR) Basin, coupled with the observed increased trend in historical precipitation, it is easy to understand why the annual discharge of many of the rivers and streams have been increasing over time. The basin runoff has been transformed. As emphasized previously, this means increased erosion and sedimentation.

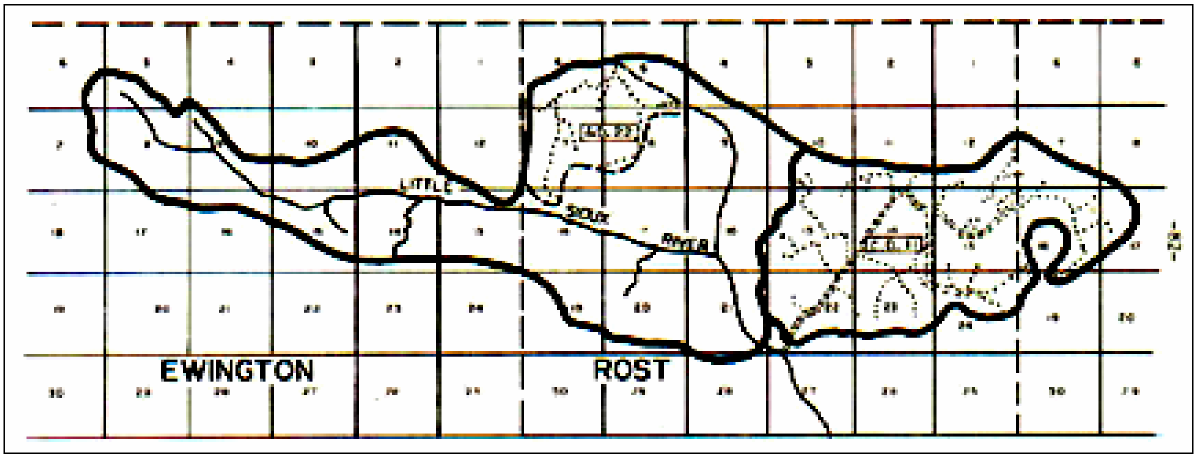

Figure 34: Watersheds Used to Study the Impact of Drainage on Runoff (Moore and Larson, 1980)

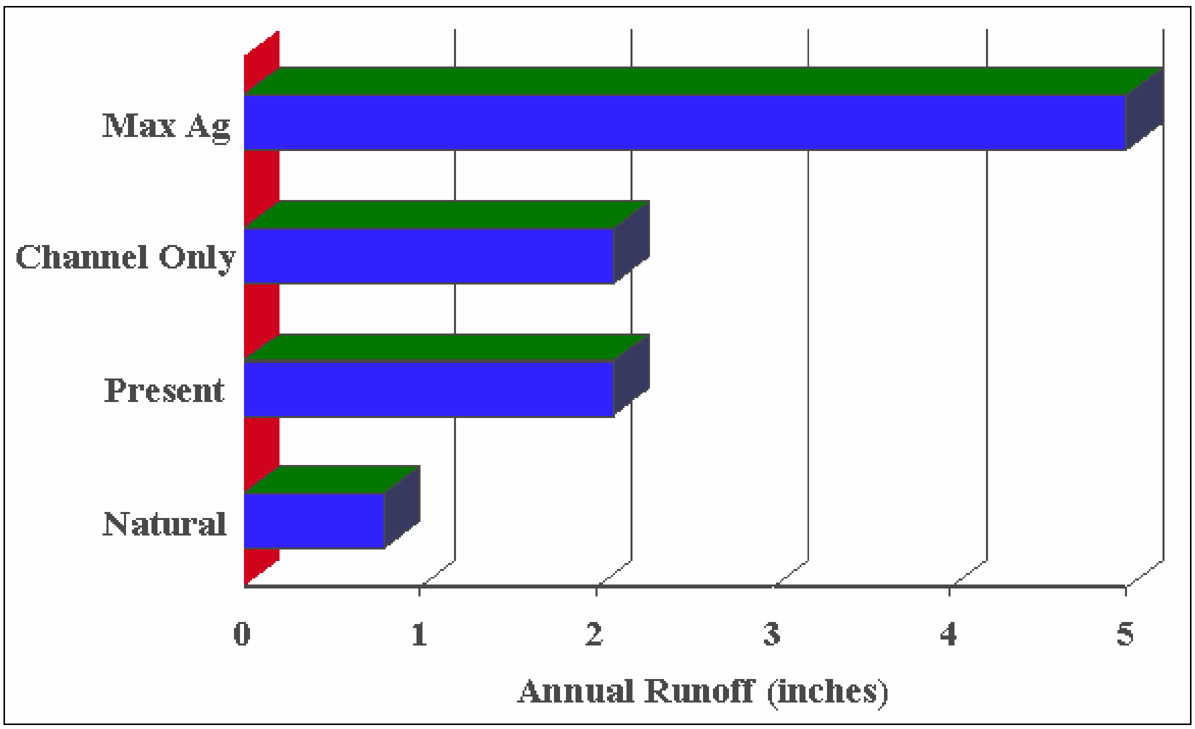

Figure 35: Hydrologic Model Output Showing Projected Annual Runoff from Four Different Drainage Conditions, Upper Little Sioux River Basin, South Western Minnesota (Moore and Larsen (1979, 1980)

A little known but interesting result of the installation of drain tiles has been the creation of a new, unique environmental habitat within the basin. Larimore (2002) studied invertebrates flushed out of adjacent drain tiles along Jordan Creek in East-Central Illinois. He discovered that drain tiles form a unique habitat for a variety of subterranean and cavern inhabiting aquatic animals. Drain tiles have largely replaced springs and marsh-seepage outlets in the flat, agricultural areas in Midwestern prairies. He also found a variety of subterranean fauna. Species included various macro and micro invertebrates, including crawfish. The tile environment is characterized by stable water temperatures, gradation in light intensities, and periodic, often significant fluctuations in discharge. These species during high discharge events ultimately are flushed out into the rivers and streams of the basin, serving as a protected food source for the higher order riverine animals.

Figure 36: Invertebrates Found in Drain Tiles

Sedimentation and the Call for Action, the National Resource Conservation Service (NRCS)

The farmlands in the basin are some of the most productive in the nation. The hard labor provided by the people clearing these lands for farming over the past century has enabled our nation to prosper and become a world agricultural trade power. To increase crop production, the landscape of these fertile lands was changed to improve the drainage. Furrowing, ditching, canal construction, drain tile placement, and re-contouring were conducted over most of the lands, which dramatically increased crop production. Unfortunately, while the farmers were achieving their abundant harvest, soil erosion was becoming a major problem. Whether it was a farm on the side of a hill or a farm on a flat plain, farmers observed early in history that the soil was either being washed away after each runoff event or being slowly blown away by the wind.

The dust bowl of the thirties caused even more public concern over soil erosion. Therefore, at the request of the people, Congress stepped in and established the Soil Conservation Service (SCS), which was eventually renamed the National Resource Conservation Service (NRCS). The main purpose of this government agency was to conserve the lands of the United States.

Between 1930 and the end of the World War II, the soil conservation practices in the basin were limited to just a few site specific initiatives. Funding was very limited. It was not until after the war, in the early 1950's, that appropriations were finally made available. The NRCS was then able to become much more active in establishing "on the ground" conservation measures such as terracing, diversion ponds, and other types of aggressive, erosion reducing measures in the basin.

By the early 1980s, the concept of reduced tilling or "no tilling" of croplands was first introduced. At first, the practice was met with skepticism by many farmers. However, with agricultural science improvements in pesticides, herbicides, higher yield crop strains, and with the rising costs of fossil fuels, more and more farmers were willing to incorporate the “no till” concept into their normal farming practices. By 1985, with the passing of the Farm Bill, all participating farmers requesting federal aid were required to develop a conservation plan that incorporated many of the erosion reducing measures developed by the NRCS.

The Success of Soil Conservation and the National Resource Inventory

Have the soil conservation practices made a difference in the basin in the last two decades? Have sheet and rill erosion been reduced? NRCS scientists wanted these same questions answered. Thus, in 1992, the National Resources Inventory (NRI) was established. The NRI is a statistical survey of natural resource conditions and trends on non-federal lands in the United States. Non-federal lands include privately owned lands, tribal and trust lands, and lands controlled by State and local governments. The NRI provided nationally consistent statistical data on erosion resulting from water (sheet and rill) and wind processes on cropland for the period 1982 - 2001. Erosion on cropland is of particular interest because of the potential off-site impacts on water and air resources as well as the relationship to land productivity and long-term cropland sustainability.

The statistics presented from the NRI in Figure 37 represent trends occurring over the entire United States, but scientists from NRCS have noted that these same general trends have been observed within the Upper Mississippi River Basin. The significant gains in erosion control that were made between 1982 and 1997 were sustained in the period between 1997 and 2001.

Soil erosion on cropland declined from 3.1 billion tons per year in 1982 to 1.8 billion tons per year in 2001. Sheet and rill erosion dropped by almost 41 percent during this time period, while wind erosion dropped by 43 percent.

Erosion rates per acre also declined between 1982 and 2001. Sheet and rill erosion dropped from 4.0 tons per acre per year to 2.7 tons per acre per year, and wind erosion dropped from 3.3 tons per acre per year to 2.1 tons per acre per year.

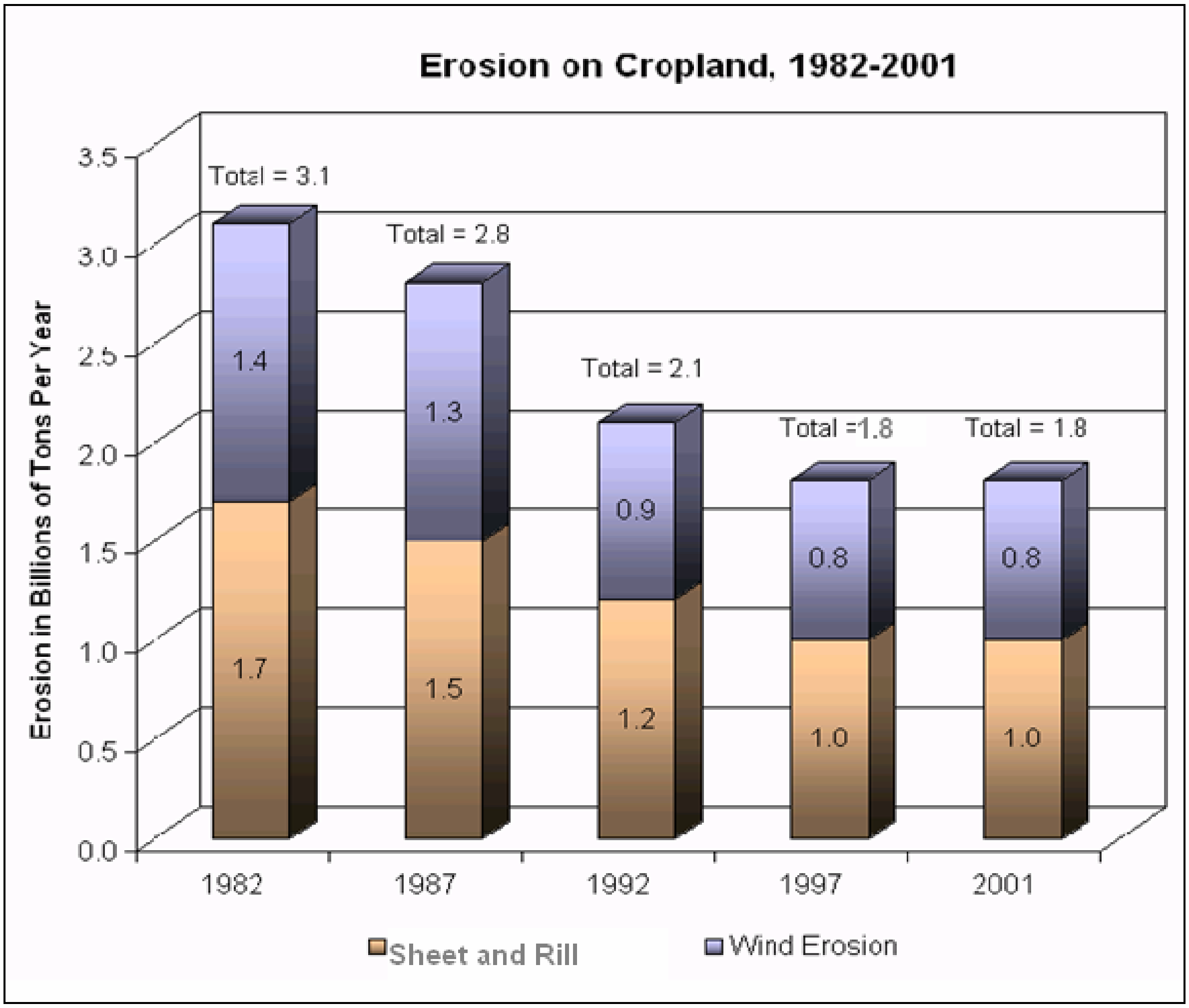

Figure 37: Erosion on Croplands in the United States

Figure 38 shows that Highly Erodible Land (HEL) cropland acreage declined from 123.9 million acres in 1982 to 101.1 million acres in 2001. The decline occurred in HEL acreage eroding at excessive rates, while HEL acreage eroding at acceptable soil loss tolerance rates increased slightly. Gains in erosion control occurred even though cropland acreage has continued to change over time as some cropland was retired or converted to other uses and other land uses were converted to cropland.

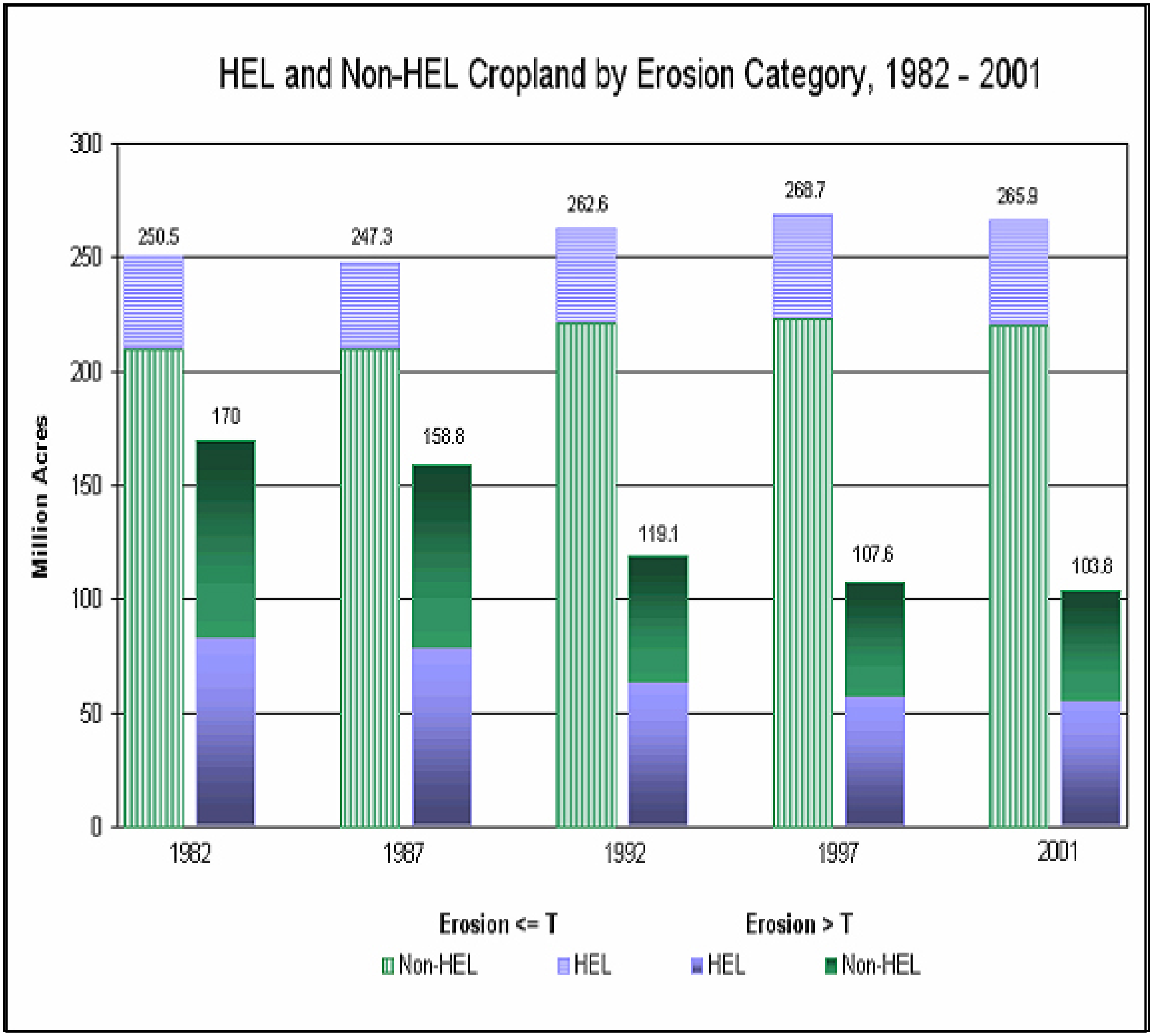

Figure 38: Highly Erodible Land (HEL) in the United States

These statistical trends show that soil conservation practices established by the NRCS and carried out by landowners since the early 1980s have made very positive impacts. Reducing sheet and rill erosion has implications for ensuring future long-term cropland sustainability within the basin while also ensuring future benefits to the environment. More soil conservation practices should continue to be encouraged in the basin. In addition, data must continue to be collected and incorporated into the NRI database for future monitoring.

As encouraging as these trends may be, there is still much erosion reduction on cropland work remaining to be done in the basin. Figure 39 shows that there are expansive areas in the basin where excessive erosion on cropland is still a problem, further signifying the need for more widespread conservation initiatives.

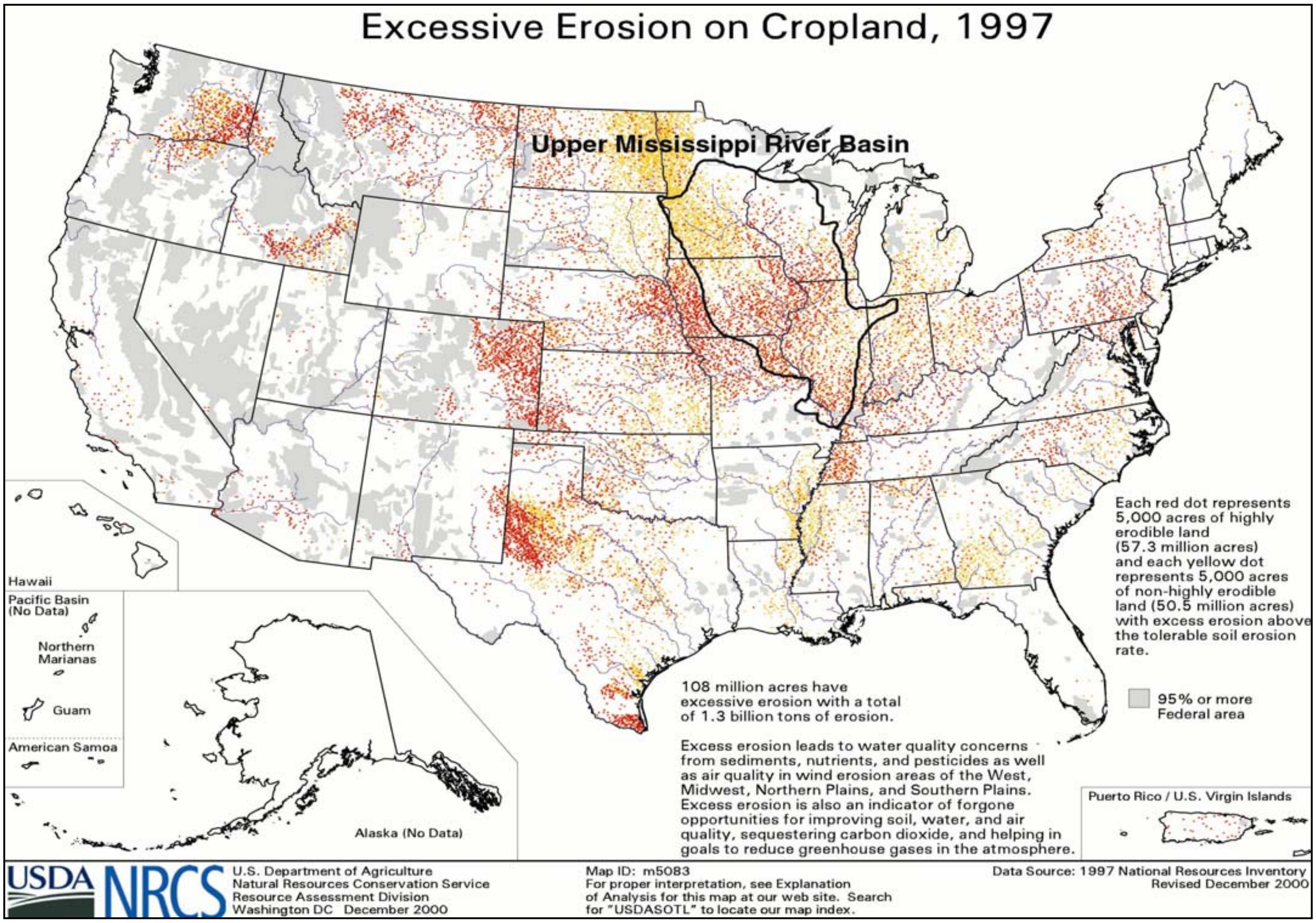

Figure 39: Excessive Erosion on Croplands in the United States in 1997

SEDIMENT YIELD

Definition

Sediment yield is defined as the quantity of sediment delivered from a drainage area, generally expressed in tons per square mile per year. It is usually calculated by either collecting suspended sediment data from a river or stream or by collecting comparative bottom surveys of a reservoir. Sediment load is the quantity (tons) of sediment passing a gage or section of river within a specified period. Sediment yield at the gage is equal to the measured sediment load divided by the drainage area. The yield is a summation at the collection point of all sediment contributed from the drainage area, regardless of the source. It does not distinguish between sediment contributions from sheet and rill erosion or contributions from river and stream erosion. In most rivers, and particularly larger rivers with very large watersheds, sediment will be deposited in the channel, floodplains, lakes, and impoundments along the river upstream from the sampling site.

Sediment Yield Trends in the Basin

In 1969, a large interagency effort was focused on estimating sediment yields throughout the basin. Sediment yields between 1945 and 1969 were computed by using suspended sediment records collected on various streams and adding the bed load as an estimated percentage. Sediment yields were also computed from reservoir deposition surveys conducted throughout the basin. The previous map of Figure 2 outlines the location of the suspended sediment stations and the reservoir survey sights. A total of 83 sediment load stations and 57 reservoir sights were used for the analysis. The resultant combined sediment yields, in tons per square mile per year, were plotted against drainage areas. A sediment isogram map (Figure 40) of annual sediment yield for 100 sq. mile drainage

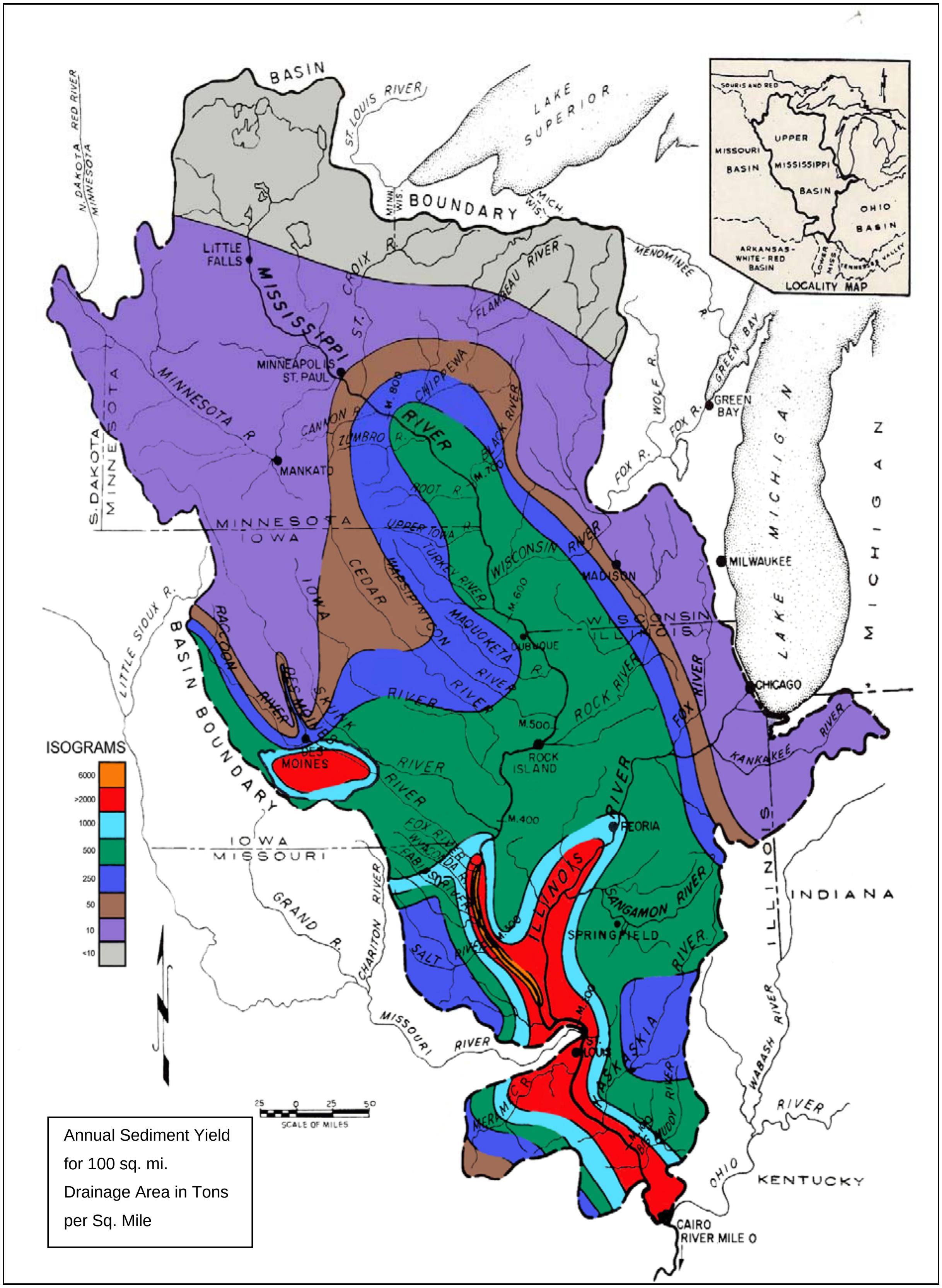

Figure 40: Annual Sediment Yield for 100 sq. mi. Drainage Area in Tons per Sq. Mile

area was then produced. This map showed general sediment yield trends within the basin. Data gaps and the discontinuation of most field collection sites due to budget constraints did not allow for updated yield computations to be conducted in this report. Soballe and DeHaan (1999) examined suspended sediment concentrations in the basin between the 1970's and 1990's. The analysis was limited to far less data because of the discontinuation of many of the gauging stations. Typically, the analysis focused on sediment loads at the mouth of major tributaries, and generally reflected the relative rates of sediment yields observed in the earlier detailed study. Although sedimentation conditions have no doubt changed, the original map completed for the historical 20-year period of record still serves as an indicator of at least the "relative" sediment yields that can be expected to occur in different regions of the basin.

The sediment yield map shows that yields in the upper part of the basin are relatively low and increase in magnitude toward the southeastern region. A large area of high sediment yield between 500 and 1000 tons per sq. mile flanks the Mississippi River in the central region of the basin. This area, covering a large portion of Central Illinois, Southeastern Iowa, and Southern Wisconsin, contains primarily heavily farmed cropland. The land use found today in the basin is for the most part the same as it was in 1969.

A very high sediment yield area greater than 2000 tons per sq. mile exists along much of the Illinois River and along the Mississippi River from just below the Iowa border all the way to Cairo, Illinois, and in the Des Moines, Iowa area. This yield is about 40 or 50 times the yield found in the northern part of the basin. An excessively high yield (> 6000 tons per sq. mile) occurs along the Mississippi River from just south of the Iowa border to just north of the confluence of the Illinois River.

As discussed in the previous section, the conservation efforts conducted in the basin have substantially reduced sheet and rill erosion. However, the overall sediment yield may not have necessarily decreased because of increases in streambank erosion (Steffen, Hendrickson, Davinroy, et. al, 2004). Evidence suggests that downcutting (headcutting) along the streams and feeder creeks throughout the basin occurred early on after the land use changes. The degradation probably occurred between the mid 1800s to early 1900s when much of the soil was first disturbed. Streambank erosion resulting from the headcutting is still occurring. Considering the increased precipitation trend, the yield rates could be the same or even greater than past history. Contributions from streambank erosion are further discussed in this report under the test cases.

Reservoir Sediment Surveys, Important Gauges

In 1995, NRCS geologist provided information for a report for the Resource Conservation Act of 1995. The geologist queried the Reservoir Sediment Information System (RESIS) to report several important trends. RESIS is a nationwide database containing historical reservoir sediment surveys. The data has been compiled over the years by NRCS scientists and adopted by several agencies, including the Department of Agriculture, the Department of the Interior, the Army Corps of Engineers, the Department of Transportation, the Department of Commerce, the Environmental Protection Agency, the Tennessee Valley Authority, and the United States Geological Survey (USGS). The USGS has recently compiled a CD of RESIS.

Reservoir surveys are important because they serve as the most accurate way to determine sedimentation rates, far superior to suspended sediment measurements (Reckendorf 2004). The surveys capture the total sediment load whereas in the case of river sediment measurements, the bed load must be estimated by using empirical sediment transport relationships.   However, it should still be noted that even reservoir surveys have shortcomings because they are dependent upon the amount and resolution of cross sections taken and the method by which the elevation of the bed is determined (Rapp, Davinroy, et. al. 2005).

One important issue must be emphasized concerning the collection of reservoir surveys in this country. Very little reservoir data has been collected since 1980 due to budgetary cuts. Figure 41 highlights the status of reservoir surveys collected across the United States. The average date of the last survey on reservoirs is around 1960. Since the most recent surveys were collected in 1985, many reservoirs have not been surveyed in the last 25 years, some even longer. About 65 percent of the reservoirs were surveyed in the period between 1950 and 1970. Only 380 reservoirs were surveyed between 1970 and 1985 as compared to 1,051 reservoirs surveyed between 1950 and 1970. Funding must be made available in the future for these important surveys in order for scientist to continue to gauge both present and future sedimentation trends in this country. This also applies specifically for the continued collection of reservoir surveys in the Upper Mississippi River Basin.

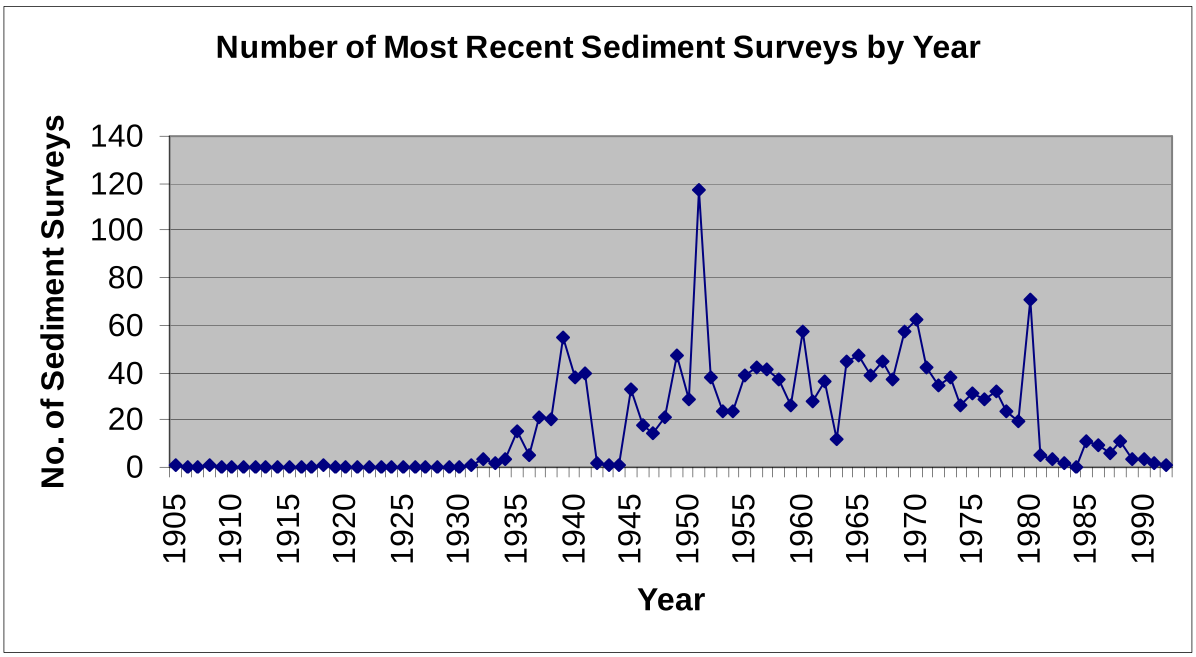

Figure 41: Historical Reservoir Surveys Collected in the United States

Reservoir Sedimentation Trends

According to approximately 4000 reservoir sediment surveys, sediment deposition rates have been increasing across the United States (Figure 42). The rate of accumulation in reservoirs in the country averaged approximately 0.11 acre-feet per square mile per year (ac-ft/sq mi/yr) prior to 1930. Between 1930 and 1950, the rate almost doubled to 0.2 ac ft/sq/ mi/yr. The rate between 1970 and 1985 was computed as 0.66 ac-ft/sq mi/yr, which is 6 times the pre-1930's rate (NRCS RCA Narrative 1995).

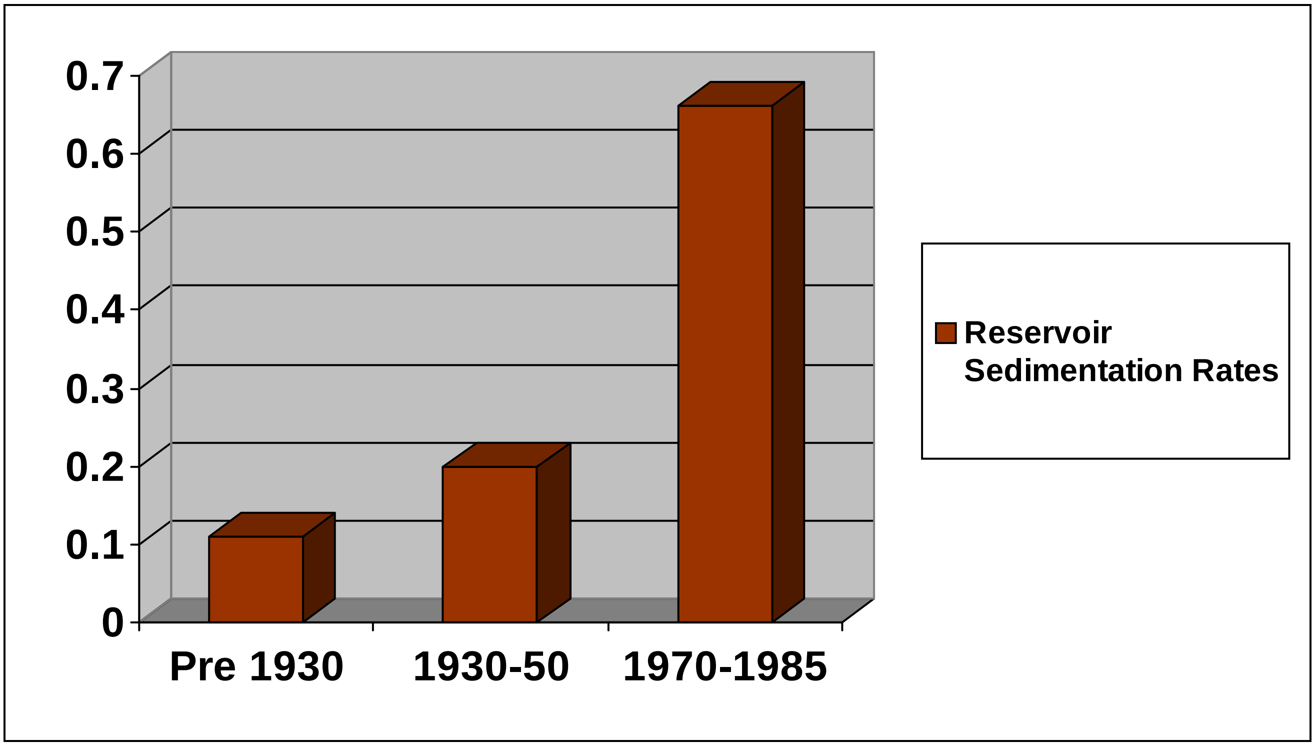

Figure 42: United States Reservoir Sedimentation Rates, in acre-feet per square mile per year (NRCS 1995)

Approximately 42 percent of the combined total storage capacity in the 1,600 reservoirs analyzed was lost to sediment accumulations as of 1985. This figure was small because there were some very large reservoirs in the database that skewed the total storage capacity. The majority of reservoirs were of much smaller capacity but also contained much higher sedimentation rates.

Approximately 40 percent of all these reservoirs were projected to be half full of sediment by 1993. These reservoirs were not surveyed in 1993. The deposition rate determined from the most recent survey on each reservoir was used to estimate future storage losses in 1993, 1998, 2003, and 2018.

By the year 2018, it is estimated that over half the reservoirs in the database will be approximately half full of sediment (NRCS 2005). Assuming the reservoirs in the database are a representative sample of all reservoirs in the United States, storage capacity in most reservoirs will become a problem by the turn of the century. This will be more of a concern for smaller reservoirs. Over 60 percent of the reservoirs that were surveyed control less than five square miles of drainage area. Larger reservoirs were not included in this analysis. For example, Corps of Engineers reservoirs such as Mark Twain, Carlyle, Rend, and Shelbyville within the St. Louis District Corps of Engineers have not experienced the filling trend observed on the smaller reservoirs above, and will not be half full of sediment by the year 2018 (Rapp 2005). The tremendous storage capacity provided by these large reservoirs, coupled with the fact that the sediment from many of the tributaries that flow into these reservoirs is being intercepted by smaller reservoirs, is probably the main reason the observed filling trend is much lower (Rapp, Davinroy, et al 2005).

Historical sediment increases in the smaller reservoirs suggest that sedimentation yields are increasing, further indicating that material from increased streambank erosion may be the main source of sedimentation today.

SEDIMENTATION TRENDS ON RIVERS AND STREAMS IN THE BASIN

Perspective Case Studies

In order to gain an understanding of sedimentation trends that have occurred on the rivers and streams within the Upper Mississippi River Basin, perspective case studies are presented. The case studies supply insight to the morphological changes. They serve as a benchmark for engineers, planners, and resource managers for understanding not only what has taken place in the past, but for understanding what can be expected to occur in the future.

A total of six studies are presented as follows:

1. Erosion and Sedimentation in the Whitewater Valley in Minnesota. Severe bluff erosion from aggressive farming and catastrophic alluvial valley deposition is outlined.
2. Sedimentation on the Lower Chippewa River in Northwestern Wisconsin. A studying describing the sediment budget of the river is summarized.
3. Bank Erosion and Historical Morphology of the Kaskaskia River. This study describes channel widening and bank erosion along a 100-mile stretch of the Kaskaskia River in Southwestern Illinois.
4. Coon Creek Watershed. Major NRCS conservation efforts applied to Coon Creek in Southwestern Wisconsin is outlined.
5. Buffalo River. A short description of observed trends on the Buffalo River in Eastern Wisconsin is discussed.
6. Upper Mississippi River. Observed sediment trends of the Upper Mississippi River are briefly outlined.

Case Study 1. Erosion and Sedimentation in the Whitewater Valley in Minnesota

Saari (date unknown) documented that two towns, Beaver and Whitewater Falls, both within the Whitewater Valley in Minnesota, had disappeared over time because they became buried by sediment. Whitewater Valley is located about 20 miles from the Mississippi River town of Winona (Figure 43).

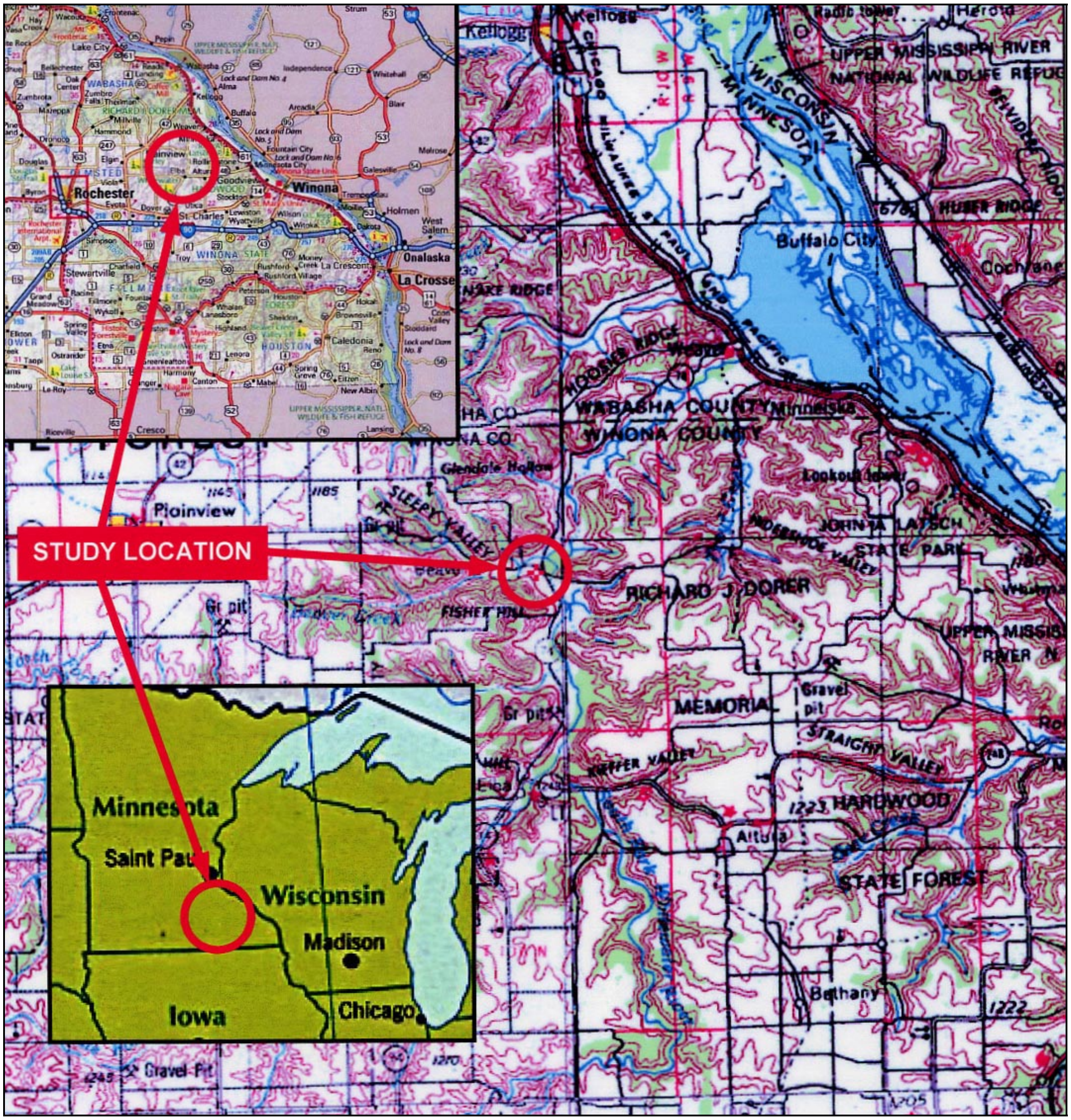

Figure 43: Vicinity Map of Whitewater Valley in Minnesota

Both of these towns were inundated with huge amounts of sediments that came from the adjacent hillsides. Places in Beaver (Figure 44) were buried by as much as 15 feet of sediment, while buildings, fences, telephone poles, roads, and bridges were covered with mud in the village of Whitewater Falls. Over 100 farms within the valley were completely buried with sediment and lost.

In the late 1800s to early 1900s, settlers began farming the region. Not only was the valley farmed, by the surrounding hills as well. In these early years, people cleared, planted, and harvested in the hills without worrying about soil erosion. No contour methods or other conservation practices were used during these times. As a result, years of hill cropping had reduced the humus content of the soil, causing the land to lose much of its water-holding properties and it's resistance to erosion. After every major rain, the soil slowly eroded off the hills and into the valley. By the 1920s, the problems were becoming intolerable. The farms and towns along the Whitewater River and tributaries were being flooded up to 20 times per year. Low-lying fields and homes were buried under 15 feet of eroded sand and gravel (Figure 45).

The result was total land devastation in both the hills and the valley. Rather than suffer the high maintenance costs, the towns and farms were abandoned. Much of the land was eventually acquired as wildlife refuge and managed by the Minnesota Department of Natural Resources. Whitewater State Park, Crystal Springs Trout Hatchery, the Whitewater Wildlife Management Area, and the Memorial Hardwood Forest were designated natural areas in the lower Whitewater River Watershed.

Since this action has occurred, the remaining farmers that have survived have adapted farming practices to conserve their lands. The valley is now slowing starting to recover. The area serves as an example for what happens when soil conservation practices are not followed, and shows how erosion and sedimentation can change the entire landscape of an area over a relatively short amount of time.

Figure 44: The town of Beaver (top) and the same scene 50 years later. (Saari, MN Dept. Conservation).

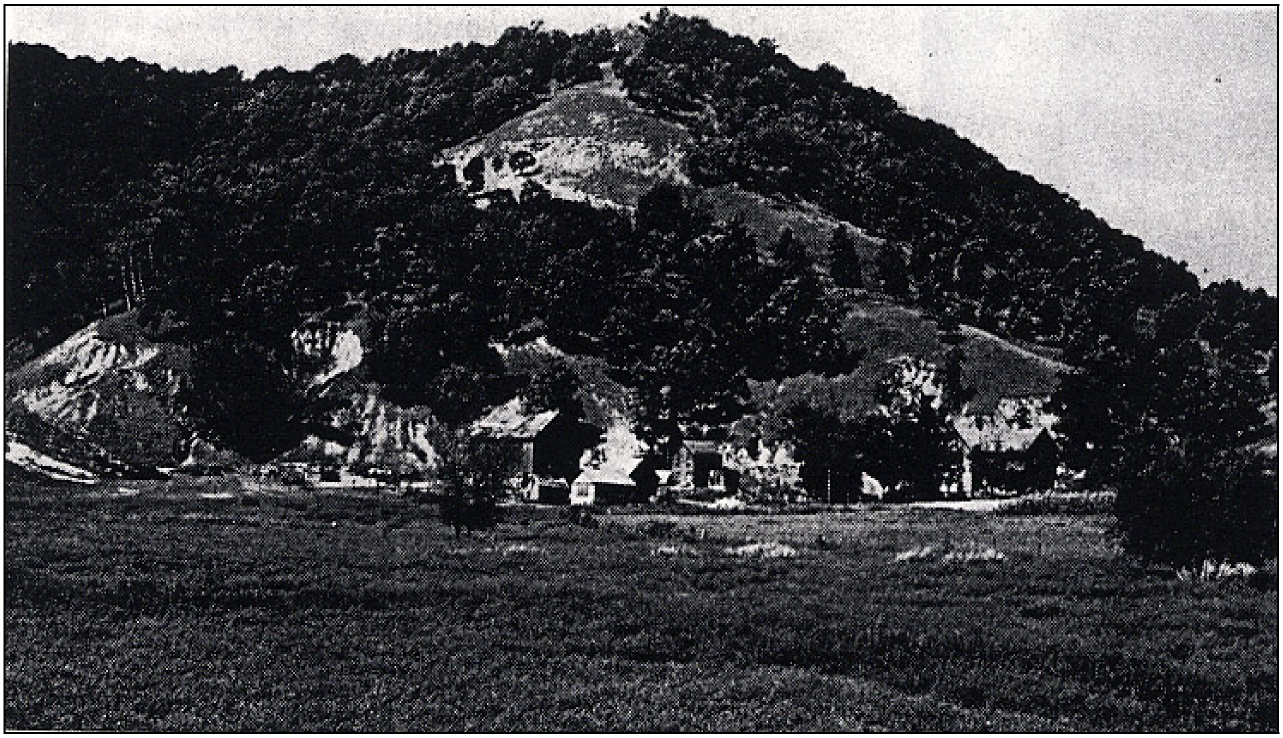

Figure 45: Surrounding Hill of Whitewater Valley Showing Abandoned Farm and Hillside Erosion and Sedimentation Effects

In 1994, scientists from the NRCS performed a sediment budget for the Whitewater River watershed. A computer program was used to model sediment sources from sheet and rill, ephemeral and classic gully erosion. Floodplain sediment storage and channel bed changes were quantified by re-surveying 44 valley-wide cross sections that had been previously surveyed in 1939 and 1965 by Happ, a sedimentation geologist. Streambank erosion was further delineated by field surveying 64-percent (148 miles) of the channels within the watershed. Figure 46 shows a schematic of the resulting sediment budget.

The watershed's total yield from sheet and rill, ephemeral, and classic gully and streambank sources was computed as approximately 713,100 tons/yr. About 78-percent of the total watershed yield was deposited as colluvium on the surrounding hills and the floodplain of the river valley and never reached the waterways. Of the 22-percent of the total yield that entered the waterways, the majority was re-deposited in the river valley or streambanks. Only 6-percent of the total sediment yield made it to the mouth of the

Whitewater River, where half was deposited in the Whitewater River delta, and half entered Weaver Bottoms, a backwater area of the Mississippi River.

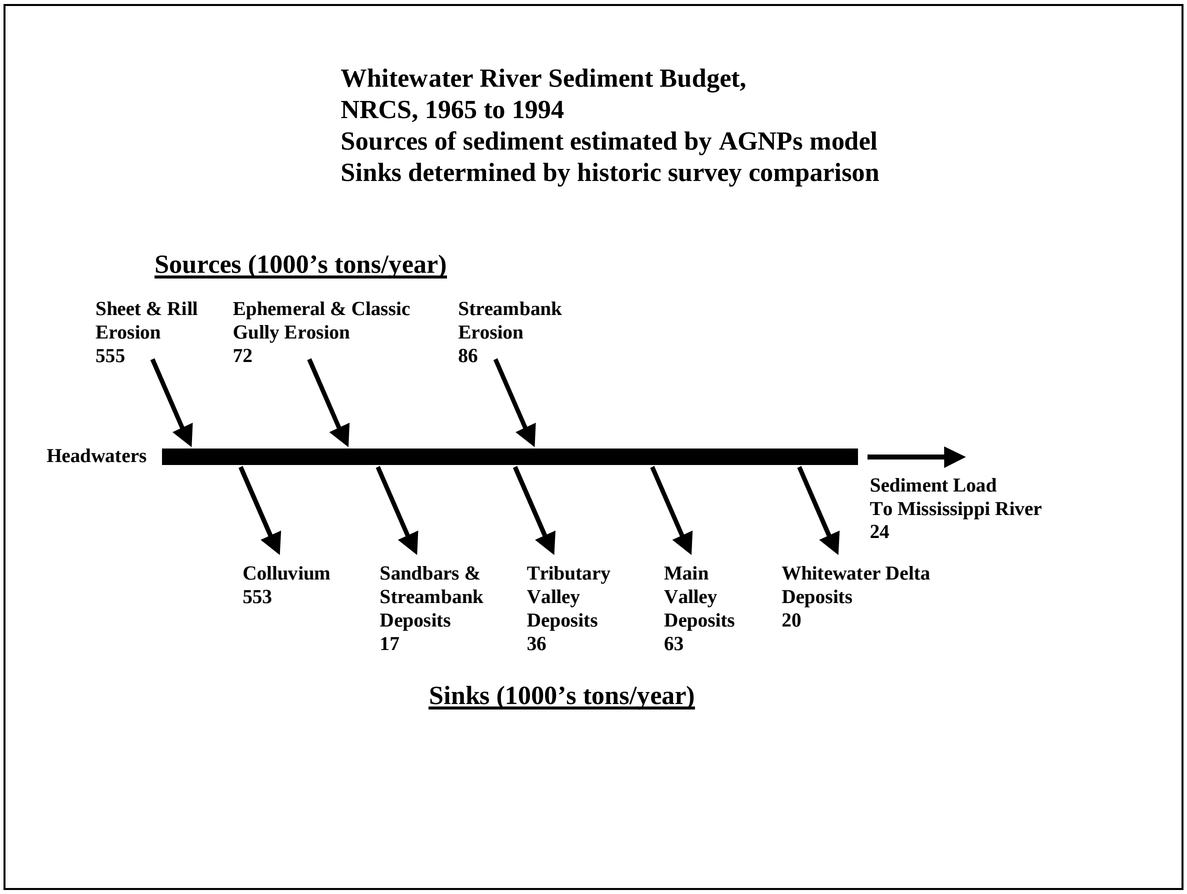

Figure 46: Whitewater River Sediment Budget Schematic (NRCS)

The sediment budget analysis showed that for this particular case there was a high percentage of sedimentation storage in the floodplain. Cooper of the NRCS further supported this by the following record:

"In a 13-month period (1932-3), the U.S. Engineers determined the silt load of the Whitewater at Station 0 to be 154,200 tons per annum. The amount of sedimentation occurring near every tributary of the main Whitewater indicates clearly that but a fraction of the silt brought into the valley reaches the mouth, or Station 0. They found that only 77,000 tons of sediment passed the mouth during 3 storm events in March, June, and

July, but the contribution from the many branches of the Whitewater River could have amounted to 291,000 tons, nearly four times the amount that passed the mouth.”

Comparing the U.S. Engineers' numbers reveals that only 26-percent of the sediment that is contributed by the many branches of the Whitewater River actually passes the mouth. This compares well with the more recent 1965 to 1994 NRCS sediment budget analysis. A total of 44,000 tons per year is transported to the mouth (i.e. 20,000 tons per year is deposited in the delta and 24,000 tons per year enters the Mississippi). This equals 27-percent of the total watershed yield that enters the stream network, 160,000 tons per year (i.e. sheet and rill, classic gully and ephemeral, and streambank erosion minus colluvial deposits).

USCOE surveys of the lower 6 miles of the Whitewater River in 1990 were compared to surveys that were obtained in 1935 and 1945. This comparison revealed that sediment deposition had decreased from 274,000 tons per year during the time period 1935 to 1945, to 81,000 tons per year from 1945 to 1990.

Case Study 2, Sedimentation of the Lower Chippewa River

On the Lower Chippewa River in Northwestern Wisconsin (Figure 47), a sedimentation study determined that bed and bank erosion accounted for the majority of the sediment transported, and nearly 90-percent of this material was delivered to the Mississippi River. Using USGS measurements of bed load and suspended sediment at various gage stations along the Chippewa River during water years 1976-83 (Rose, 1992), D. B Simons and Associates Inc. (1998) developed a sediment budget schematic (Figure 48).

The sediment transport relationship for the Chippewa River at Durand, Ws. was used to estimate the sediment contribution from the Red Cedar River. Between Carryville, Ws. and Durand, the total sediment load increased almost an order of magnitude from 123,000 tons per year to 1,073,000 tons year. Bed and bank erosion in the 26 river miles between Carryville and Durand accounted for 82-percent of the total sediment load at

Durand with the Red Cedar River adding only about 7-percent of the total. At Pepin, Ws. near the mouth of the Chippewa River, the total sediment load had dropped to 940,000 tons per year, due to 133,000 tons per year of floodplain deposition. At the confluence of the Chippewa and Mississippi Rivers, a sediment trap is maintained by the St. Paul District Corps of Engineers. Dredging this trap averages 120,000 tons per year. The remaining 820,000 tons per year coming out of the Chippewa enters the Mississippi River.

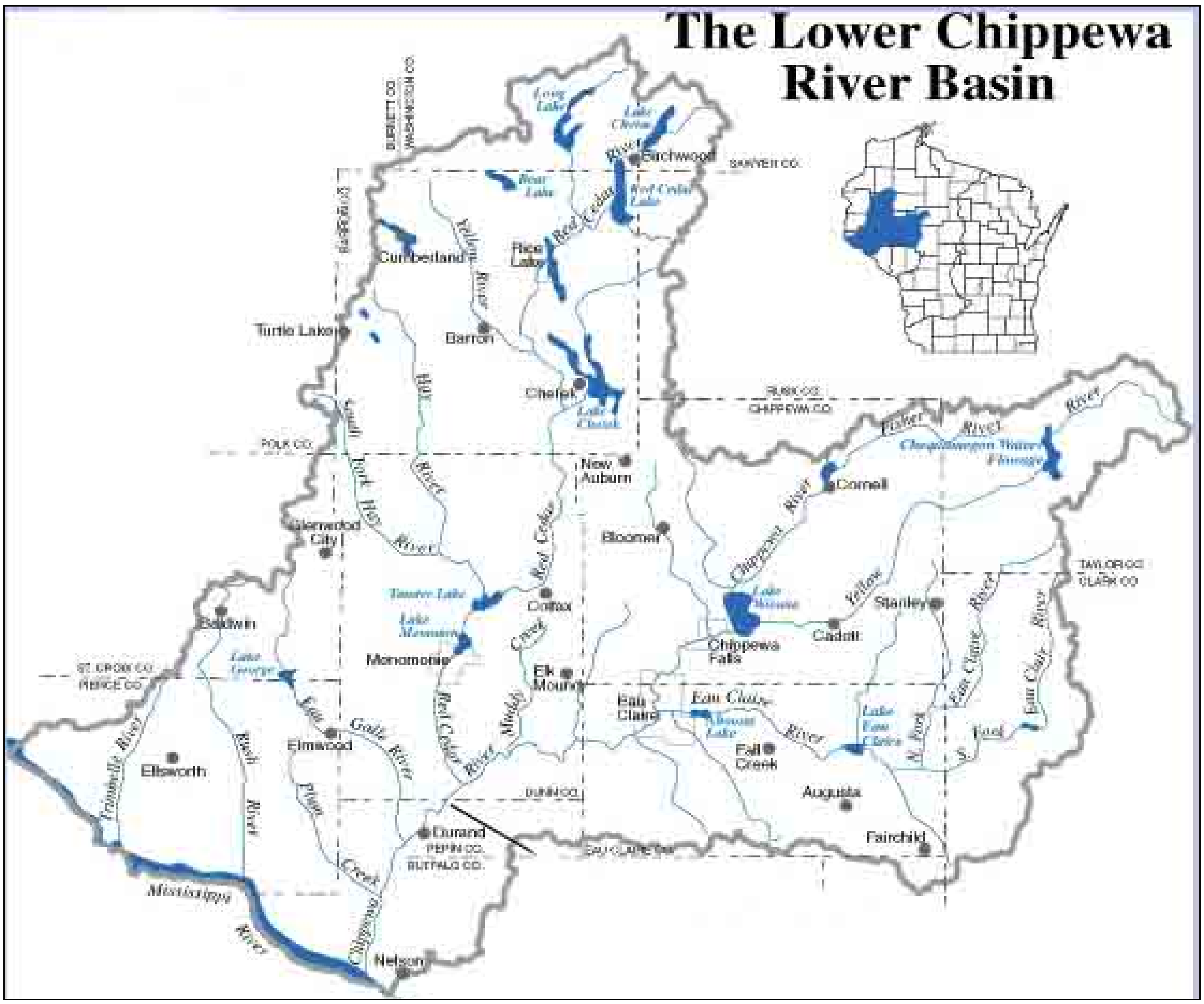

Figure 47: Map of Chippewa River Basin

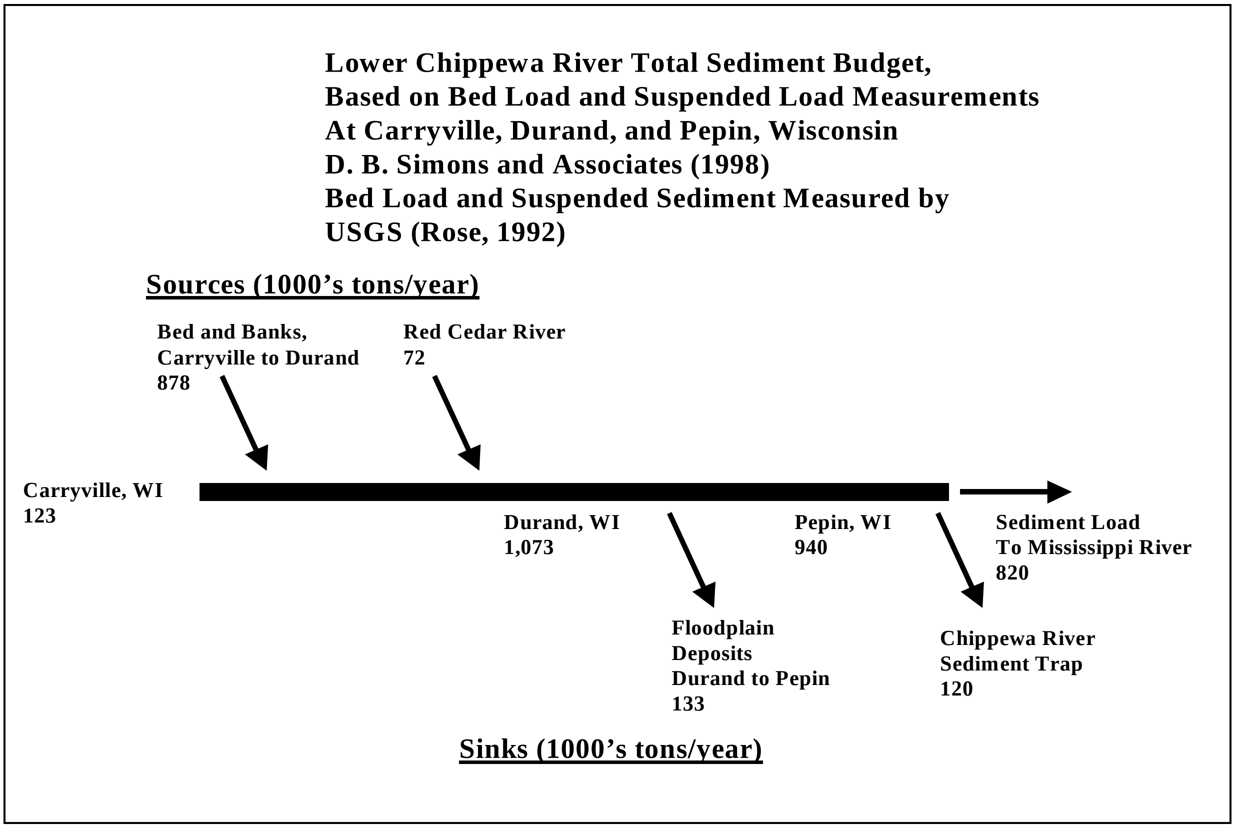

Figure 48: Lower Chippewa River Sediment Budget, Wisconsin

Case Study 3. Bank Erosion and Historical River Morphology Study of the Kaskaskia River

A study was conducted by the U.S. Army Corps of Engineers St. Louis District examining 100 miles of the Kaskaskia River, including associated tributary and basin conditions (Davinroy, Rodgers, Brauer, Lamm 2003). Figure 49 is a vicinity map of the study reach. The study concluded that most of the tributaries had been channelized or ditched in the upper plains of the basin. The effects of downcutting (headcutting) were observed along most of these channels. Widespread deposition of fine material and the formation of new meandering channels and floodplains were also observed in the upper reaches of the tributaries. Figure 50 describing the typical effects of headcutting that has taken place in the upper plains.

The Kaskaskia River Basin has undergone some dramatic land uses changes, most occurring in the late 1800's to early 1900's. Visual observation of modern day maps (USGS quad) versus historical maps (1820 GLO) indicated that approximately 70 to 80 percent of the basin within the study reach had been cleared of forests and prairies. The majority of this clearing probably occurred between 1820 and 1938. Figure 50 shows the amount of forest cleared along the floodplain over time along a 50-mile stretch of river.

The changes in land use in the basin, including the ditching and draining of the adjacent upper plains, have had profound effects on bank erosion and historical widening in the main channel of the Kaskaskia River. For the 100-mile study reach, data showed that overall meandering or lateral movement of the river was greater between the early 1800s to the late 1930s. The sinuosity of the river had decreased historically over the years, while the channel width had substantially increased, from an average width of about 90 feet in 1938 to about 140 feet in 1998 (Figures 52 and 53).

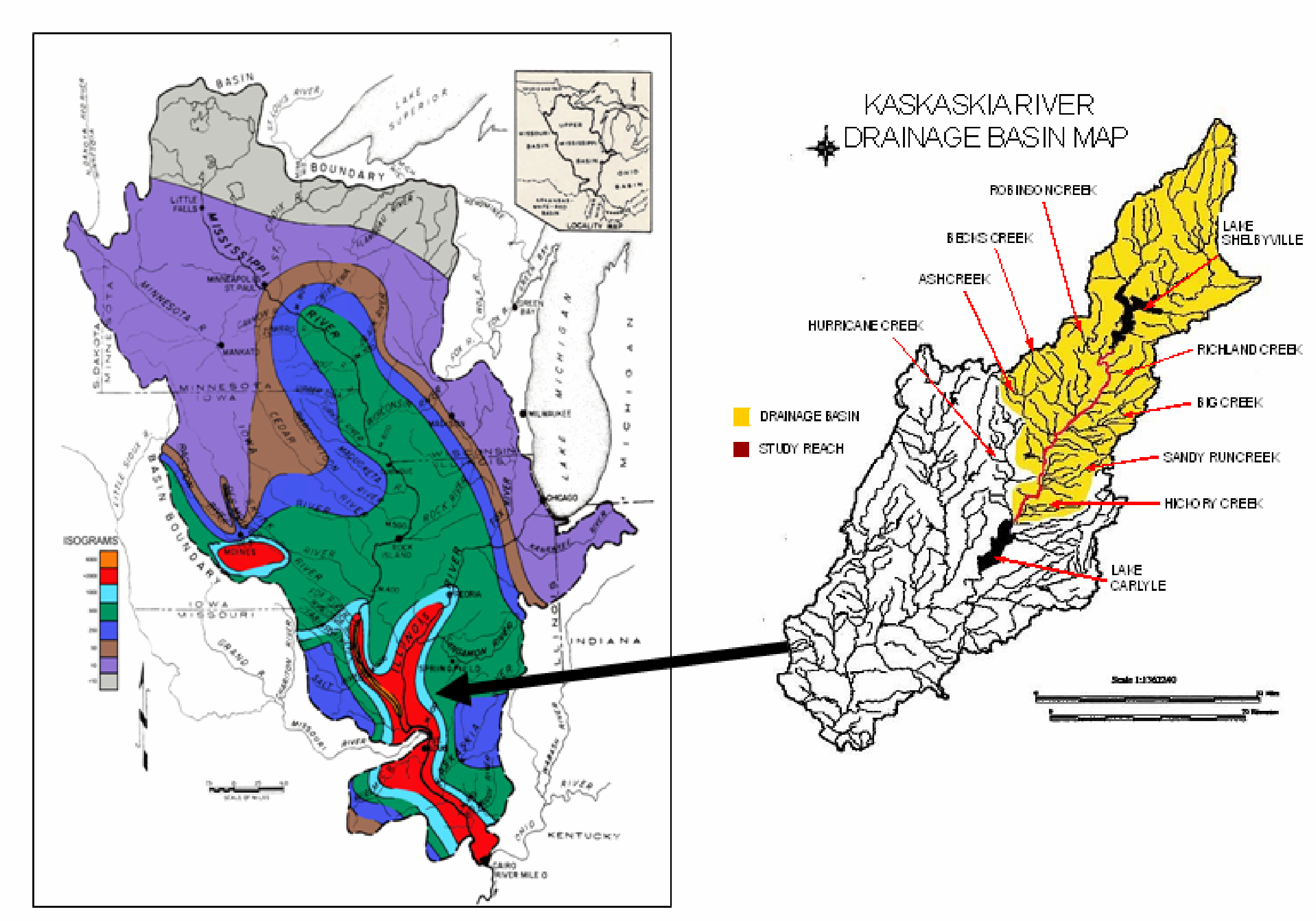

Figure 49: Kaskaskia River Basin Vicinity Map

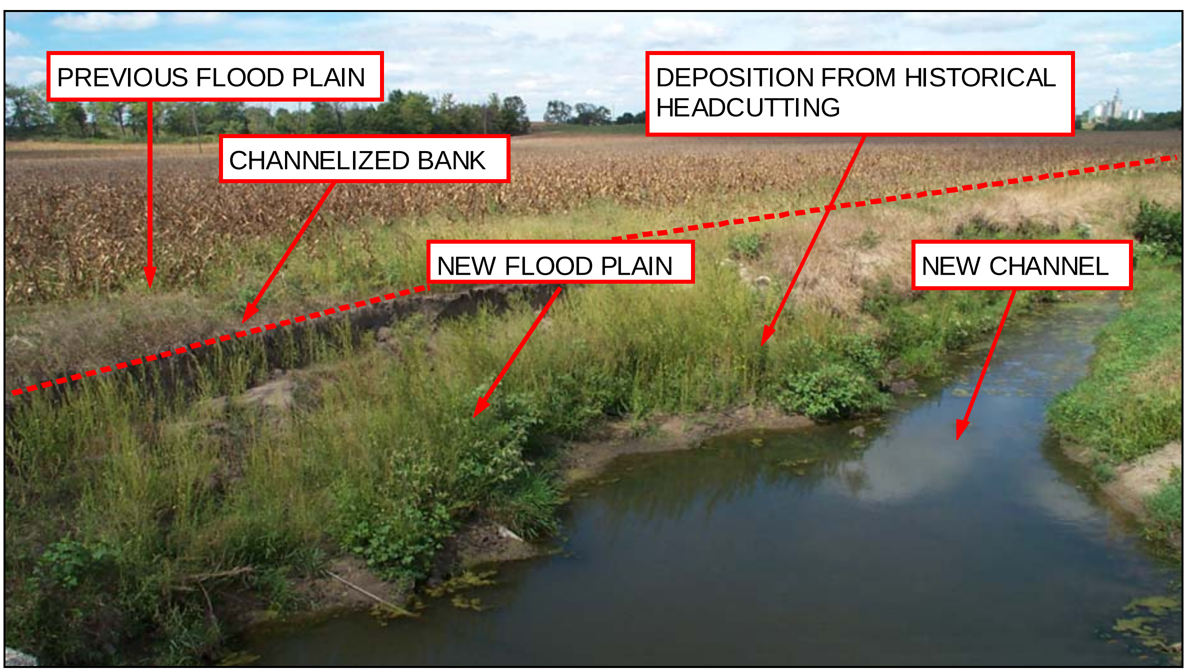

Figure 50: Headcutting and Deposition in Drainage Ditch in Upper Kaskaskia Basin

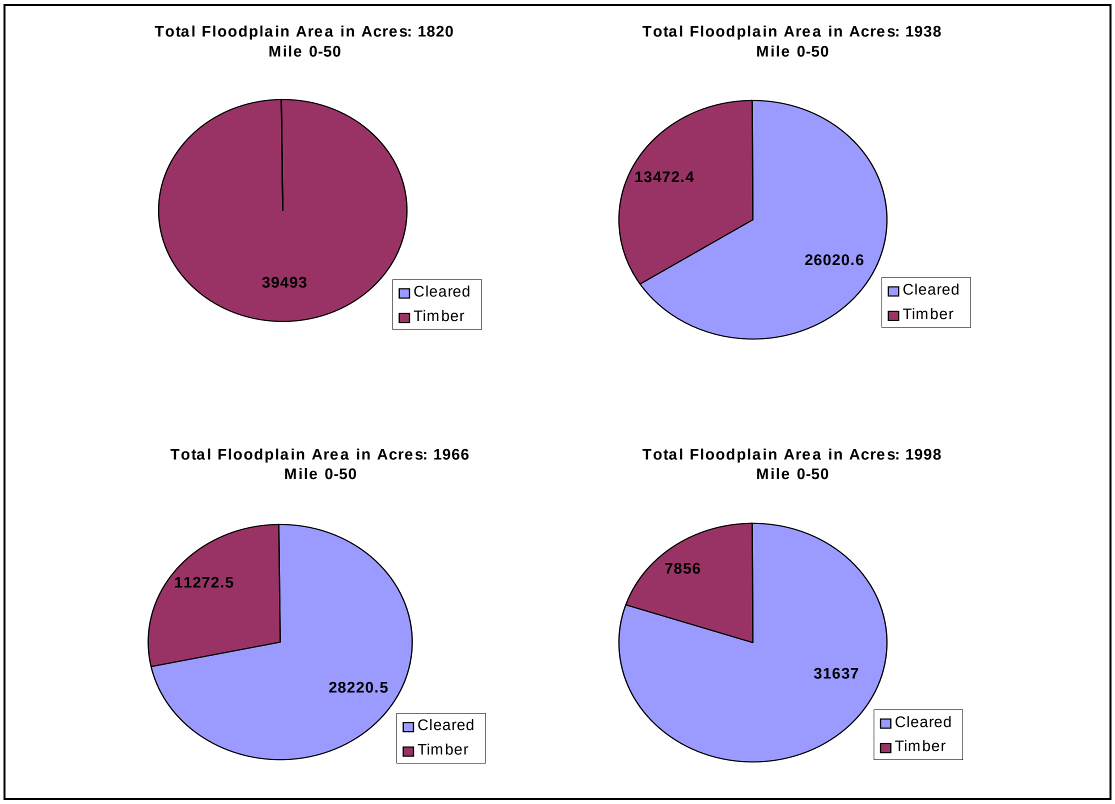

Figure 51: Land Use Changes Over Time in the Floodplain of the Kaskaskia River

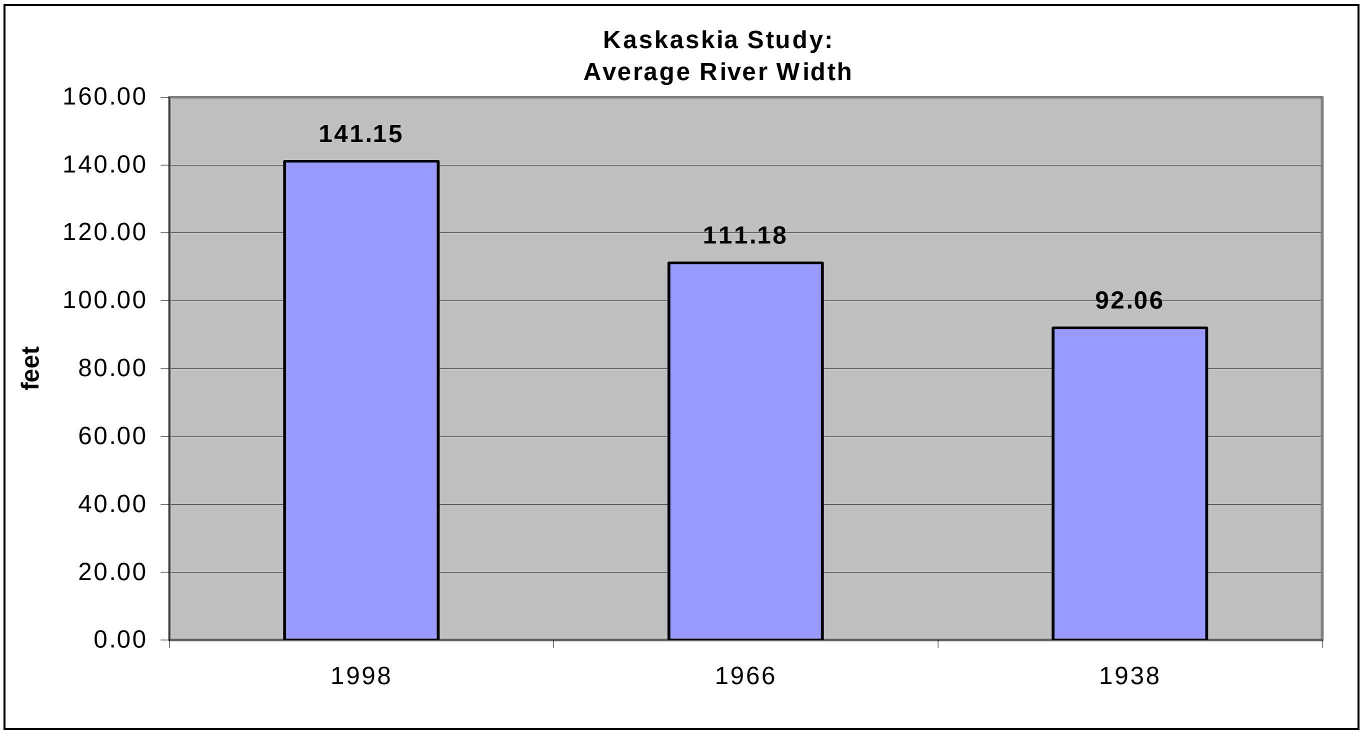

Figure 52: Historical Average River Widths on the Kaskaskia River

Figure 53 shows that in many places the river had more than doubled in width within 50 years. This extreme widening and associated bank erosion has impacted land owners, water intake facilities, bridges, levees, and other infrastructure.

For this particular stretch of the Kaskaskia, it appeared that the channel had not experienced any obvious downcutting. This may have been because of a layer of consolidated clay and rock that was observed in several locations. Data and interviews with landowners indicated that the channel capacity had been lost over the years, which would verify the wider, shallower channel development. The initial downcutting of the channel problem probably occurred in the early 1900s.

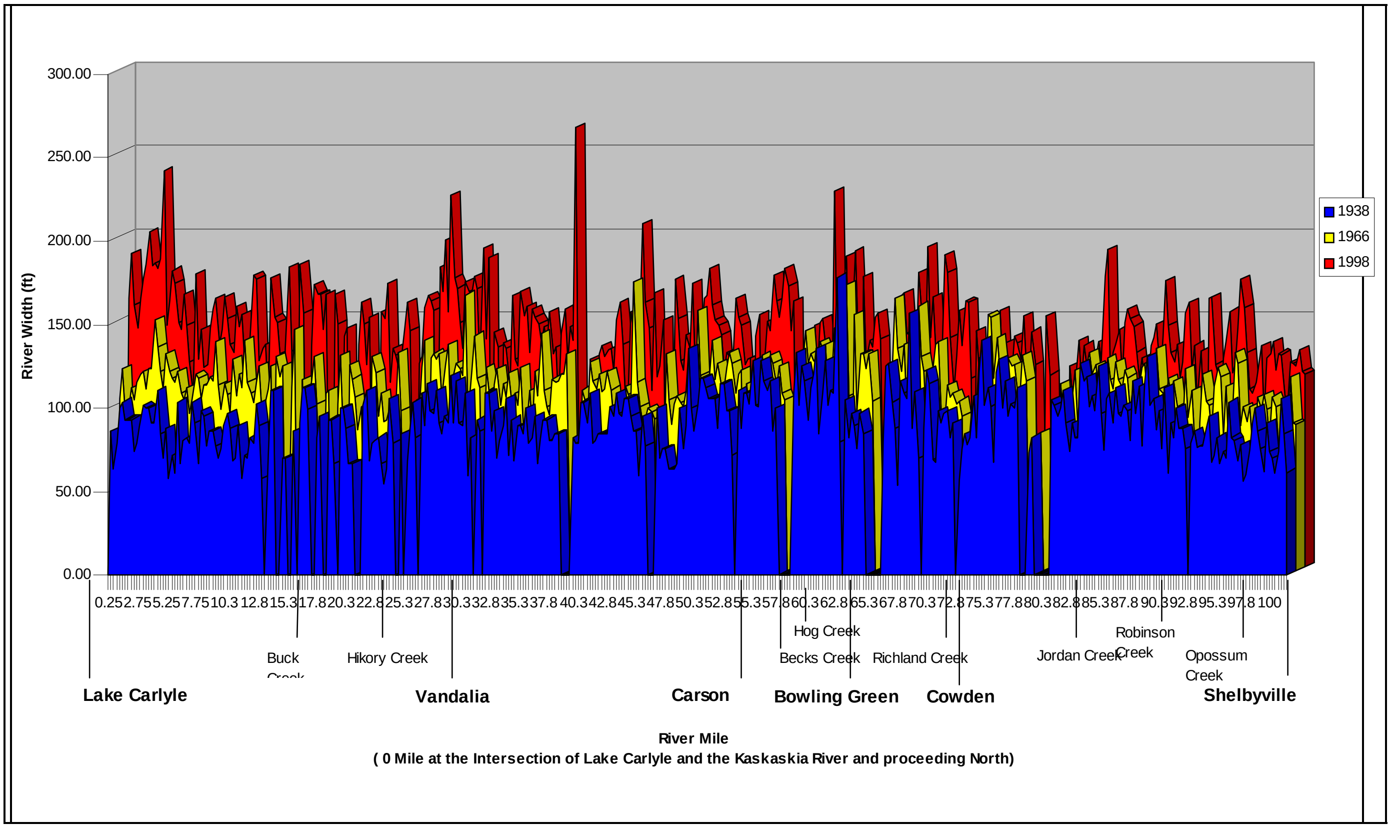

Figure 53: Historical Comparison of Channel Widths over 100-mile Stretch of the Middle Kaskaskia River

The problems on the Kaskaskia cannot be solved using the techniques that have been developed on smaller streams because of the relative size of the channel. Natural vegetative measures (willow plantings, posts, etc.) were found not to be feasible because of sustained higher flows from reservoir releases. In addition, historical aerial photograph comparisons showed that riparian zones along the floodplain have had no effect on slowing down bank erosion or channel widening. This is because the average channel depth is between 20 and 25 feet deep. Combined with the fact that the bank soil composition is mainly silty sand, even large standing trees in the floodplain have not slowed the erosion. Measures for stabilization and/or restoration on intermediate size rivers as the Kaskaskia require bank revetment and stone dike construction measures similar to what is used on larger rivers such as the Mississippi.

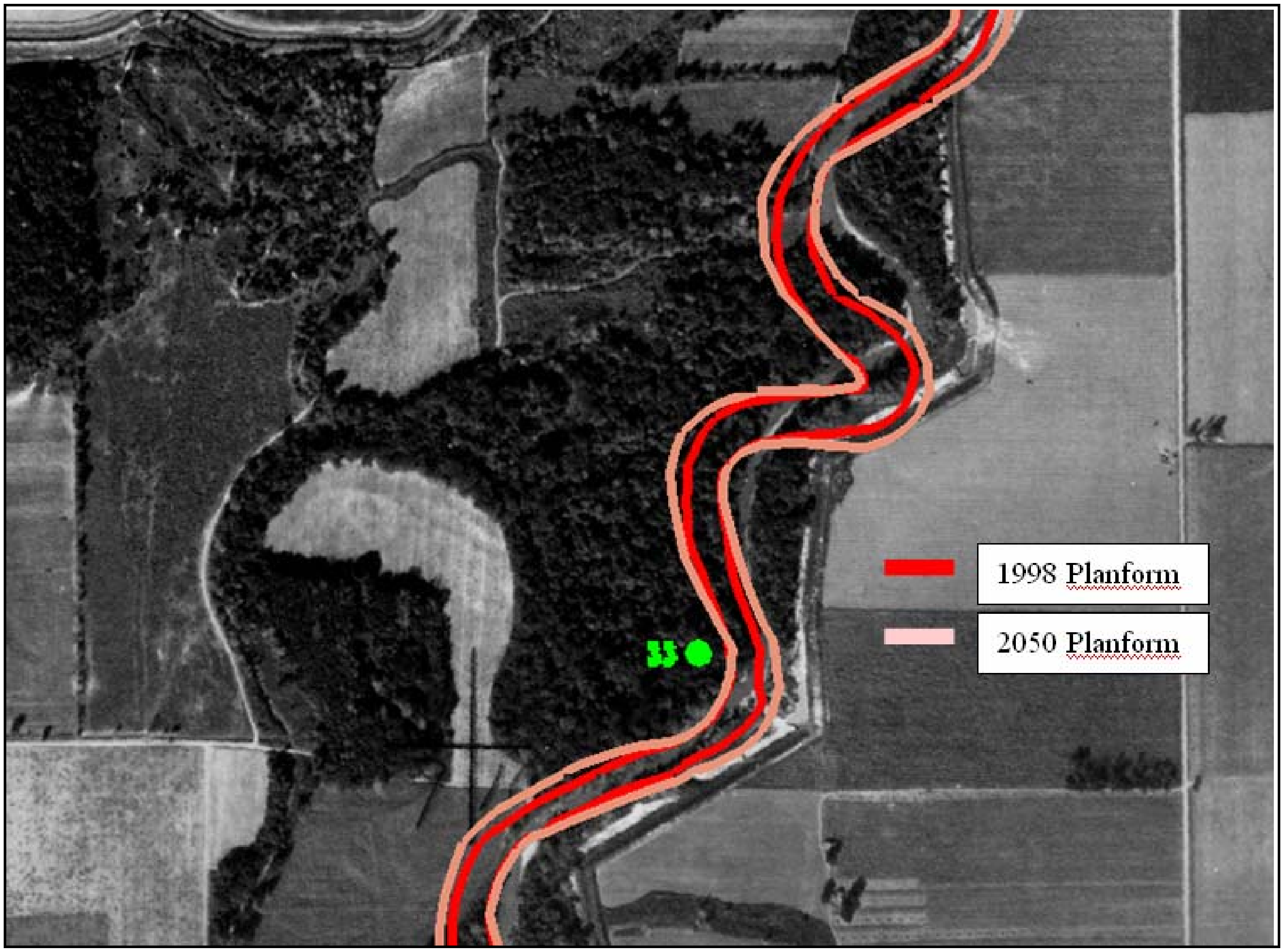

Figure 54: 1938 Aerial Photograph, 1998 and Projected 2050 Planform, Kaskaskia

Figure 54 above shows a comparison of the 1938 planform (the background photo) with the 1998 planform (red) and the predicted future planform (peach). By 2050, the river will have widened an additional average width of 50 feet if no corrective measures are taken and river equilibrium is not achieved. This will impact bridges, levees, private property, and will continue to degrade the environmental health of the river (Sauer 2004). Channel conveyance, or the ability to carry water by the channel, will be significantly reduced, which will increase flooding and incur additional flood damages.

Case Study 4, Coon Creek Watershed Study

Coon Creek is located just southeast of the City of Lacrosse in Southwestern Wisconsin. The associated watershed became the first Soil Conservation Service's Pilot Watershed project in the nation because of tremendous sedimentation problems. Most of the sediment reaching the mouth of Coon Creek from 1853 to 1938 was from severe sheet and rill erosion occurring on sloping cropland-covered hills that were formally covered by forest and prairie. Intensive conservation measures were used for this project. Trimble and Lund (1982) found that the average net rate of sedimentation on the floodplain of Coon Creek for recent years was only on the order of 1 or 2-percent of that in the 1930s. They concluded that this reduction has been due to the intensive conservation practices including contour plowing, contour strip cropping, long rotation, crop residue management, cover crops, improved fertilization, and controlled livestock grazing.

Trimble (1983) prepared a sediment budget (Figure 55) illustrating that the sediment yield at the mouth of Coon Creek changed very little over a long period even though the individual sources and volumes of sediment changed dramatically over time. From 1938 to 1975, similar sediment loads were reaching the mouth of the watershed as compared to the period 1853 to 1938. However, the sources of these modern day loads were different, mainly coming from channel erosion. The streams in the basin have been widening and excavating all the deposits that had accumulated on the floodplains following the land use conversion near the turn of the century (Steffen 2004). Some of the stored sediment in Coon Creek is now becoming mobile, and the present sediment yield per unit area may actually be increasing downstream with the augmentation coming from storage loss.

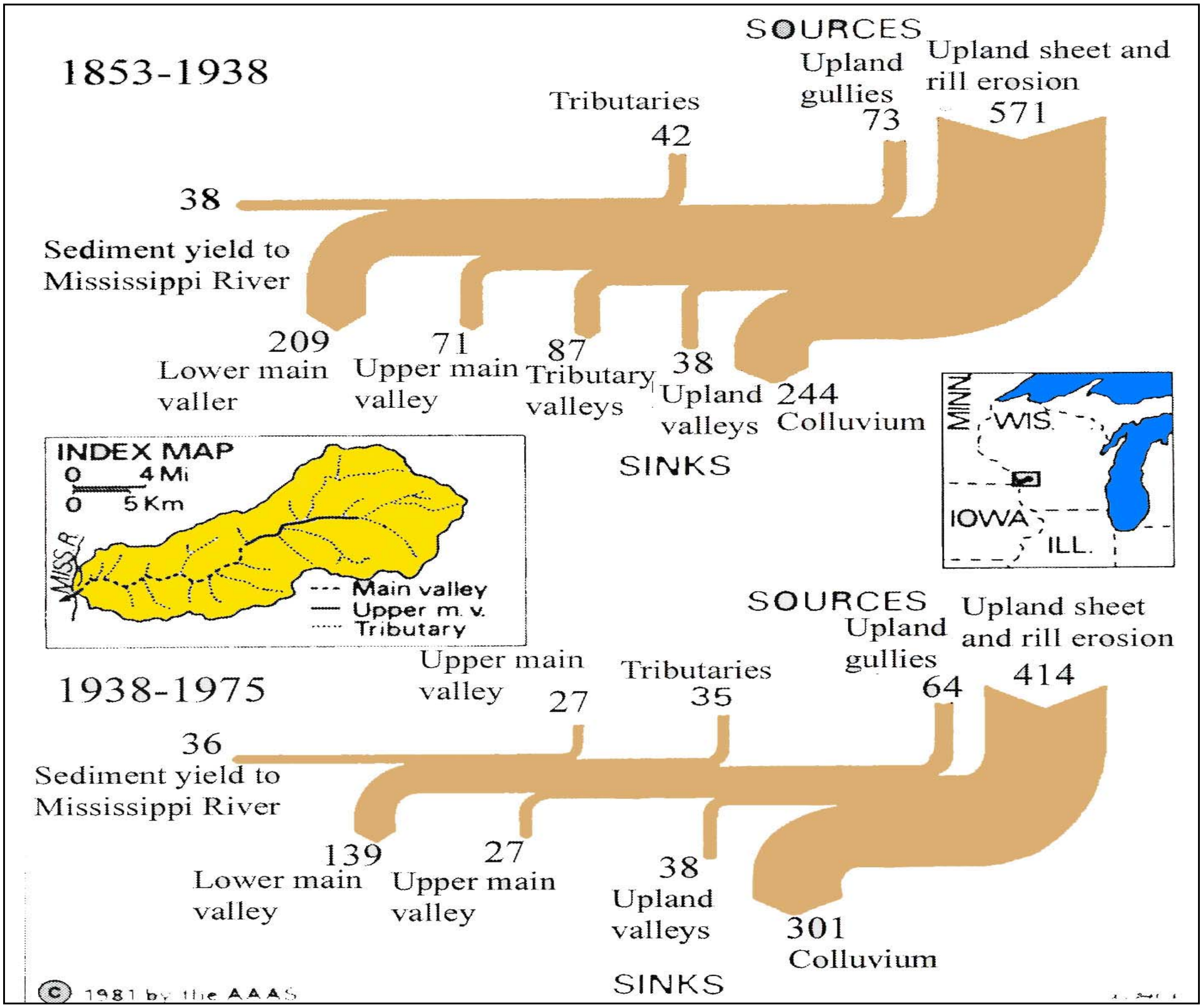

Figure 55: Sediment Budget for Coon Creek, Wis. Numbers are in Mg /Km2. 100 Mg/Km^2 = 290 tons/mi ^{2} (Trimble 1983)

Case Study 5, Buffalo River Study

Knox and Faulkner (1994), studying the Buffalo River located in eastern Wisconsin, found that by the 1960s, active valley-bottom gullying had been brought largely under control, although by then most tributary streams (i.e. the smaller creeks feeding the Buffalo River) had been incised to some degree. In addition to remobilizing stored sediment, gully development had created an efficient network for the downstream delivery of sediment due to the greatly increased conveyance capacity of the enlarged stream channels. In general, the steep sub-watersheds in the lower part of the Buffalo River watershed have been more significant sources of sediment than the sub-watersheds found in the watershed's upper reaches. Knox and Faulkner found that sedimentation rates in the lower main valley since the 1950s were generally lower than they were immediately following the completion of Lock and Dam 4 in the mid 1930s; however, they have remained at moderately high levels.

Case Study 6. Sedimentation Trends on the Upper Mississippi River

Several perspectives are presented under this case study to outline sedimentation trends on the Upper Mississippi River. This reach of the Mississippi is unique because it represents two different hydraulic conditions, the pooled or impounded reach of river between St. Paul, Minnesota and St. Louis, Missouri, and the open river reach of river between St. Louis and Cairo, Illinois.

Bed Material Budget, Pools 1 through 10

Hendrickson (2003), as part of the UMRS Navigation Study, Expert Panel, developed a bed material sediment budget developed for Pools 1 through 10 of the Upper Mississippi River using available information on sediment transport at USGS gauging stations, long-term channel dredging data, studies of sediment deposition, and hydraulic data. The quantity of bed material on tributaries was based on measured data where it existed, and was estimated in the many cases where data didn't exist. Adjustments to the bed material loads were made as needed so that the sediment budget produced reasonable results. In several cases, the bed material load had to be increased to prevent the Mississippi River load from going negative. Hydraulic parameters such as the hydraulic slope or flow distribution were also used to adjust the bed material loads. This effort resulted in the sediment transport statistics given in Table 2 for tributaries to the Mississippi River in Pools 1 through 10. Sediment transport rates at tributary gages were increased to represent rates at the mouth using the ratio of drainage areas at the mouth versus the gage to determine the increase. This method is accepted if the drainage area at the mouth is less than 2 times the drainage area at the gage (USACE Engineering Manual 1110-2-4000, 1989).

	At Gage							At Mouth (4)		
Gage	Q_{ss} (tons/year)	Q_b (tons/year)	Q_t (tons/year)	Q_b/Q_t	% sand in Qss	Q_{sand} (tons/year) (4)	Area (sq. miles)	A_{mouth}/A_{gage}	Q_t	Q_{sand}
Minnesota at Mankato	1,328,300 (2)	148,000 (2)	1,476,000 (2)	.10 (2)	10 (4)	281,000	14900	1.111	1,640,000	312,200
St. Croix at St. Croix Falls	78,800 (2)	32,000 (4)	110,800 (2,4)	.4 (4)	40 (4)	64,000 (4)	6240	1.226	135,800	0
Cannon River						66,000 (4)	1440			66,000
Chippewa at Pepin	526,400 (1)	413,600 (1)	940,000(1)	.44(1)	70 (1)	782,000 (1)	9410	1.0	940,000	782,000
Buffalo River	All bed material deposits before mouth. No contribution to Mississippi.						465			0
Zumbro River at Kellogg	233,800 (2	133,000 (3)	366,800 (2,3)	.36 (2,3)	5 (4)	144,700	1400	1	366,800	144,700
Whitewater at Beaver	All bed material deposits before mouth. No contribution to Mississippi.						302			0
Trempealeau at Dodge	All bed material deposits before mouth. No contribution to Mississippi.						250			0
Black at Galesville	157,900 (1)	119,100 (1)	277,000 (1)	.43 (1)	66 (1)	223,300 (1)	2080	1.082	299,700 (4)	0 (4)
Root River at Houston	725,700 (2)	136,000 (4)	907,100 (2,4)	.15 (4)	3 (5)	157,800	1270	1.307	1,186,000 (4)	206,200 (4)
Upper Iowa at Dorchester	351,300 (2)	65,900 (4)	439,100 (2,4)	.15 (4)	5 (4)	83,500 (4)	770	1.377	604,600 (4)	115,000 (4)
Wisconsin at Muscoda	284,600 (1)	273,400 (1)	558,000 (1)	.49 (1)	60 (1)	444,160 (1)	10400	1.125	627,800 (4)	499,700 (4)

Table 4: Sediment Transport Statistics on the Tributaries to the Mississippi River in the St. Paul District

1 Rose, USGS, 2 Nakato, 3 Simons, 4 St. Paul District, 5 Tornes

Q_{ss}= Suspended Sediment Load, Q_b= Bed Load, $_{Qt}$=Total Load, Q_{sand}=Sand Load, A_{mouth}=Drainage Area above Mouth, A_{gage} = Drainage Area above Gage

Each tributary for the above transport statistics in Table 2 was researched and summarized by Hendrickson as follows:

Minnesota River

In the Cumulative Effects Report (2000), Nakato determined the suspended sediment load for the Minnesota River at Mankato given in Table 2. He assumed that bed load was 10-percent of the total load which resulted in bed load and total loads of 148,000 tons per year and 1,476,000 tons per year. Tornes (1986) measured the fraction of sand in suspended sediment samples at Jordan and found that 19-percent of the suspended sediment samples consisted of sand size material. When this value was applied to the suspended sediment load at Mankato, however, the resulting total bed material load in the sediment budget was too high, so a value of 10-percent was used instead. The bed material at the mouth of the Minnesota River was increased from the value at Mankato using the ratio of drainage areas, however dredging quantities on the Minnesota River were taken out. The hydraulic slope of the Minnesota River gradually flattens out from a value of 0.000166 between River Miles 51 and 60, to 0.000086 between River Miles 25 and 51, to .00007 from the mouth to River Mile 25.

Chippewa, Black, and Wisconsin Rivers

The Chippewa River was characterized as supply limited, and the Wisconsin River as partially transport limited in a study by Espinoza, et al (2003). During water years 1976-1983, the USGS collected hydraulic and sediment data on the Chippewa, Black, and Wisconsin Rivers (Rose, 1992). Instantaneous total-sediment discharges were obtained by two methods. The first method consisted of summing measured Helley-Smith bedload discharge and suspended sediment discharge, as determined from concurrently collected bedload and suspended sediment samples. The second method was the modified-Einstein procedure. The results are given in table 4 above. The ratio of bed load to total sediment load was 0.44, 0.43 and 0.49 for the Chippewa, Black, and Wisconsin Rivers respectively, while the percent sand found in the measured suspended sediment was 70, 66, and 60-percent for the 3 rivers. These values are much higher than was typically reported for other tributaries.

The Corps of Engineers, St. Paul District and the Wisconsin Department of Natural Resources studied hydrodynamic conditions in the delta of the Black River in 1992 and

1993 (Hendrickson and Haase, 1994). They found that over 80-percent of the total river flow entered directly into Lake Onalaska and the remaining 20-percent flowed through floodplain areas where most of the sand size particles were trapped. This means that all of the 223,000 tons/year of bed material shown in Table 2 was trapped in the delta of the Black River. This material did not contribute to the Mississippi River sediment load.

Zumbro River

The bed load for the Zumbro River was based on the work done by Colorado State University (1979). The percent sand in the suspended sediment load was set at 5 percent. This was estimated based on measured values on the adjacent watersheds of the Root and the Whitewater Rivers, 3- and 8-percent respectively (Tornes, 1986).

Cannon River

For the sediment budget, the Cannon River bed load was initially set equal to the Zumbro River since each have about the same drainage area and the watersheds lie adjacent to each other in the same lithographic area. However this resulted in too much sand load in Upper Pool 4. Upper Pool 4 has a slope about the same as Lower Pool 8, Pool 9, and Upper Pool 10, but its 2-yr flood discharge is only 59,000 cfs compared with 97,000 cfs in LP8, P9, and UP10, so the Cannon River load was reduced to half of the Zumbro's (66,000 t/yr of sand). The Cannon River has a very significant delta upon entering the Mississippi River and perhaps this is the reason the sand load is reduced so much before entering the Mississippi. It could be that the Cannon River sand load at Welch is as high as the Zumbro, but deposition in the delta reduces delivery to the Mississippi River.

Buffalo River (465 sq. miles), Whitewater River (302 sq. miles), Trempealeau River (250 sq. miles)

Riecks Lake, Weaver Bottoms, and Trempealeau Bay, which are large backwaters located at the mouths of the Buffalo, Whitewater, and Trempealeau Rivers trap the majority of the sand transported by these rivers. Nielson (in Fremling, 1973) found that the Trempealeau River was not an important bed load source for the Mississippi River because the sediment is trapped in Trempealeau Bay. Jefferson, et al., 1994 speculated that continued deposition of sediment in Trempealeau Bay eventually will fill the bay and at that time, the Trempealeau sediment will be deposited in the Mississippi River. Knox & Falkner (1994) did a comprehensive study of the Buffalo River and concluded that the natural levee along Riecks Lake would grow in size and increase downstream transport of sediment to backwater areas along the Mississippi River. However, now, most of the coarse sediment is trapped in Rieck's Lake. An interagency task force did a 10-year study of conditions in the Weaver Bottoms area in Pool 5 (Nelson et al, 1998). Based on this work it was found that while the Whitewater River had an impact on water quality in Weaver Bottoms, due to suspended sediment transport of fine sediments, the coarse sediments were trapped in the delta located at the mouth of the Whitewater River and were not transported downstream in the Mississippi River.

<u>Other Tributaries</u> – Many smaller tributaries with drainage areas less than 300 square miles enter the Mississippi River along this reach. These include rivers such as the Vermillion (215 sq. miles), Rush (240 sq. miles), Bad Axe (170 sq. miles), and Yellow (245 sq. miles). Although it is desirable to eventually include these tributaries in the sediment budget, little information exists on their sediment loads. These small tributaries can significantly contribute to the sediment load of a pool, however. Gaugush (1997) found that while gauged tributaries that entered directly into Pool 13 only accounted for 3% of the drainage area and discharge, they provided for a disproportionate 14 % of the suspended sediment load.

Hendrickson (2003) developed a bed material sediment budget for the St. Paul District reach of the Upper Mississippi River between Anoka, Minnesota and Guttenburg, Iowa (Figure 56). The Minnesota, Chippewa, and Wisconsin Rivers are by far the largest sources of sand to the Mississippi River in the St. Paul District. The graph shows several distinct reaches. Reach 1 is upstream of Lake Pepin, and the bed material load in this reach is influenced by inputs from the Mississippi River upstream of Anoka and by the Minnesota River. Reach 2 extends the length of Lake Pepin, and because of the reduced flow velocities in this reach, all of the bed material entering from Reach 1 deposits in the upstream end of Lake Pepin. Sediment grain size analysis by Engstrom and

Almendinger, 1998 support this conclusion since the mean grain size on the lake bed is less than 10 microns, even at the upstream end of the lake.

In Reach 3 downstream of Lake Pepin, the bed material load is influenced by the large quantity of sand entering from the Chippewa River. In Reaches 1 and 3, the bed material load gradually decreases in a downstream direction due to dredging and backwater sediment deposition. Superimposed on this gradual decrease are occasional spikes in the bed material load due to inputs from smaller tributaries like the Cannon, Zumbro, Root, and Upper Iowa Rivers. These tributary inputs have a strong influence on the sediment load in the Mississippi River that is disproportionately larger than their contributing drainage area. Significant amounts of main channel dredging are required downstream of both large and small tributaries. It is interesting to note that the Black River, which has a drainage area of over 2000 square miles, contributes no sand to the Mississippi main channel because the majority of its flow is conveyed through floodplain areas, which trap the sediment.

Other sediment studies support the sand budget trends found for Reach 3. Colorado State University research (1979) indicated a significant decrease in sediment load between Lock and Dam 4 and Lock and Dam 8. Their work was based on a combination of traditional sediment transport equations and measured field data.

A sediment budget of Pools 11 to 26 was done by Nakato for the Cumulative Effects Study (WEST Consultants, 2000). This sediment budget indicated that some tributary sediment loads have decreased by about 40 to 50 percent since construction of the 9-ft Channel Project. This is most likely due to construction of numerous large reservoirs on tributaries; improved land use management practices over time, backwater effects up the tributaries from pools created by the lock and dams, or a combination thereof (Hendrickson, Davinroy, et al 2005).

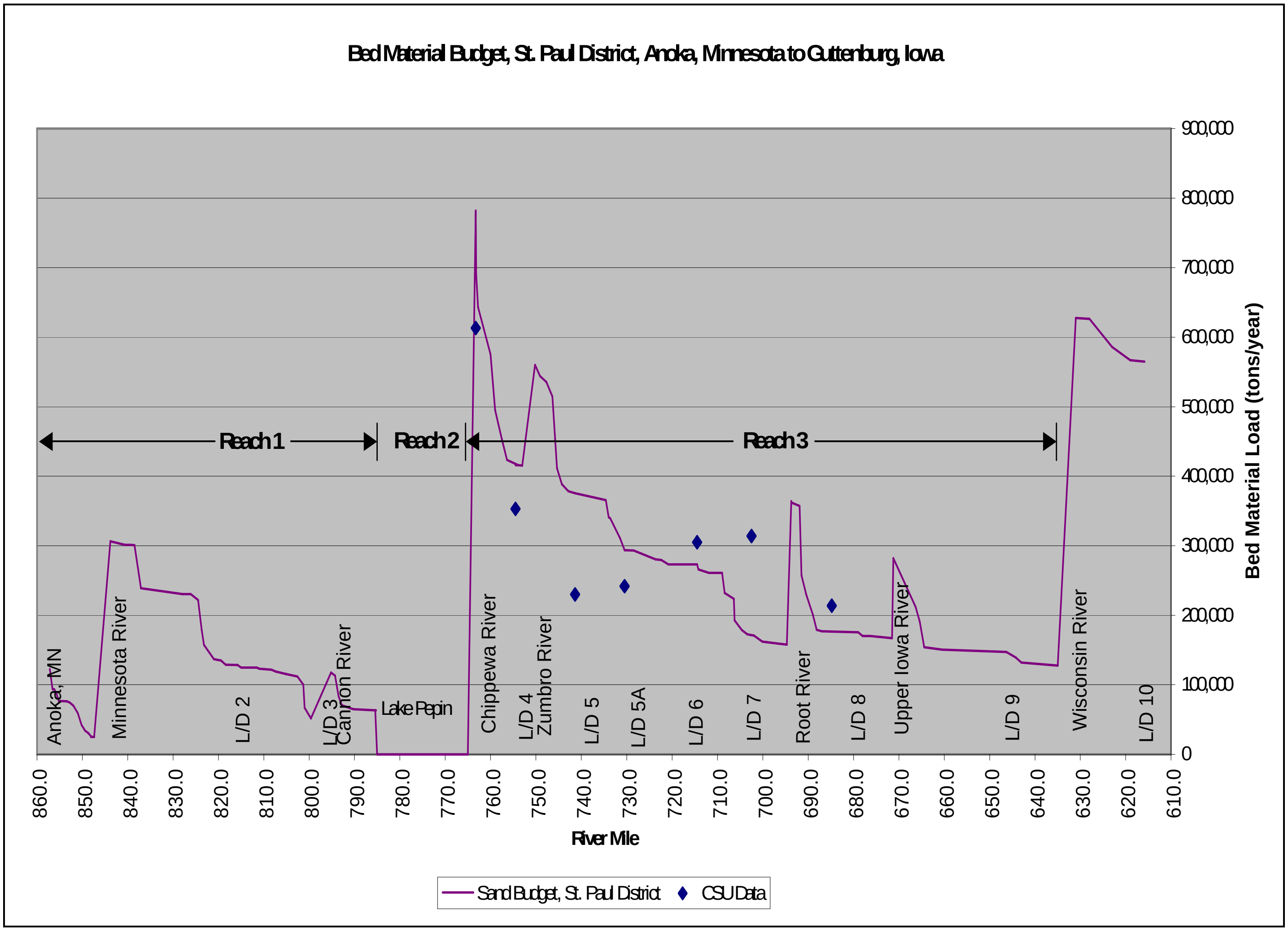

Figure 56: Bed Material Load Budget of the Upper Mississippi River in the St. Paul District

Suspended Sediment and Dredging Trends on the Pooled Reaches of the Mississippi River

Figure 57 is a histogram record (1976-2002) of the suspended sediment load at MacGregor, Iowa, located in Pool 10 of the Mississippi River. Figure 58 shows historical dredging quantities for the Minnesota, St. Croix, and Mississippi Rivers. There appears to be a decreasing trend in dredging during the period. The load trend appears downward as well, but the period of record is short and thus there are not enough points to be considered statistically significant for any reliable trend analysis. There could be a variety of reasons for this recent reduction in dredging if it eventually does become a future trend, including sediment input to the main stem either halted or temporarily reduced from the effects of some of the pools at the tributary entrances (raised deltas), less dredging from changed and more efficient dredging practices (Nanda 1988), and channel training structure construction, repair, and/or modifications.

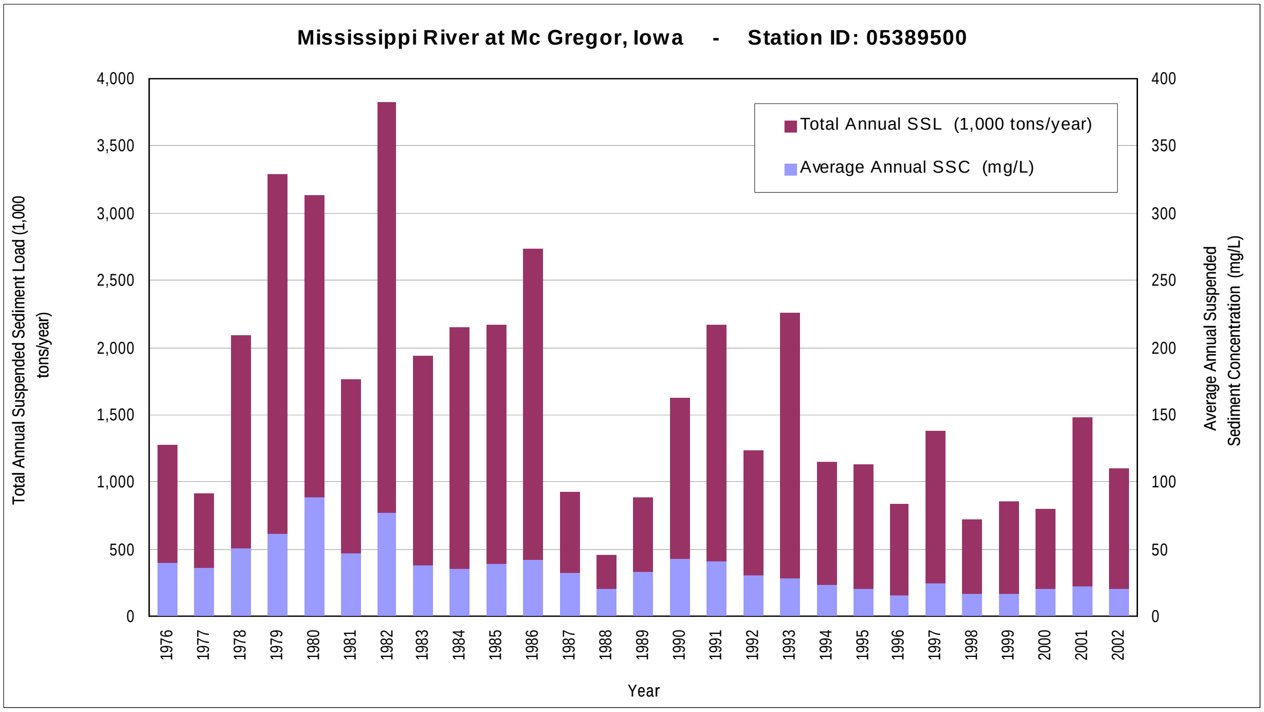

Figure 57: Suspended Sediment Discharge, in Metric Tons Per Year, at MacGregor, Iowa

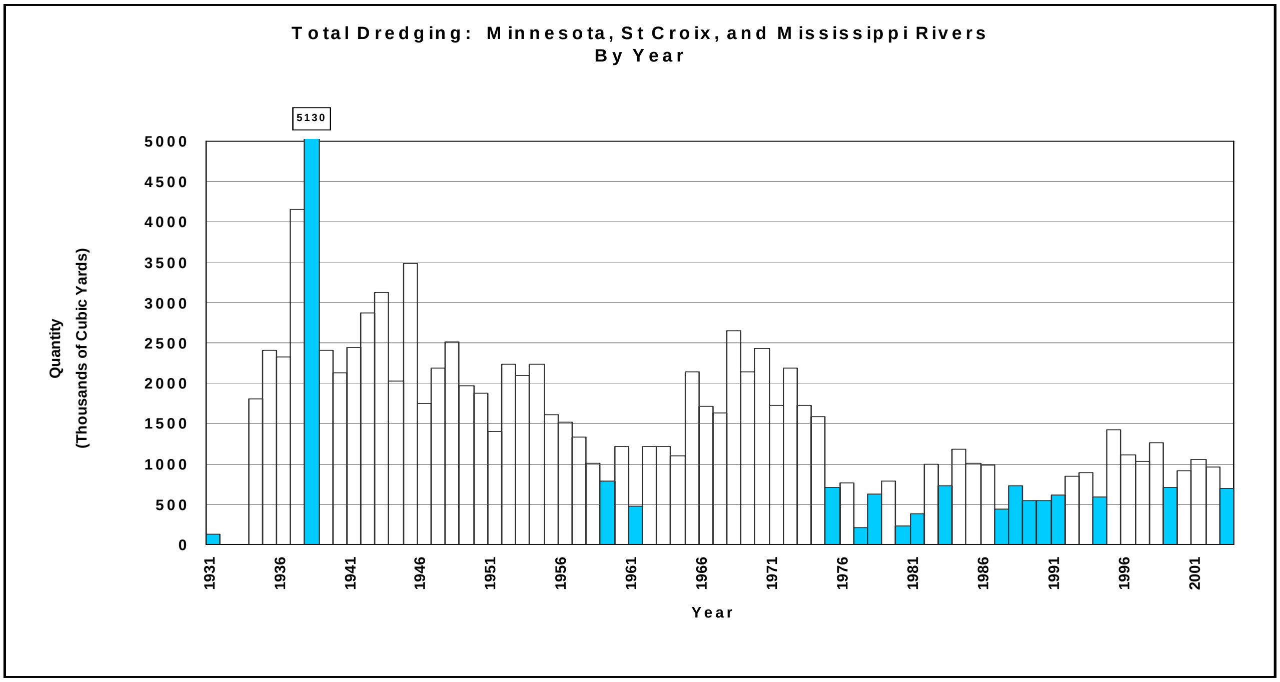

Figure 58: Historical Dredging on the Minnesota, St. Croix, and Mississippi Rivers

Figure 59 shows historical dredging conducted in the pools within the St. Louis District, between Miles 300 and 201. The average trend appears to be stable. No continual historical sediment data is available for this reach of the river.

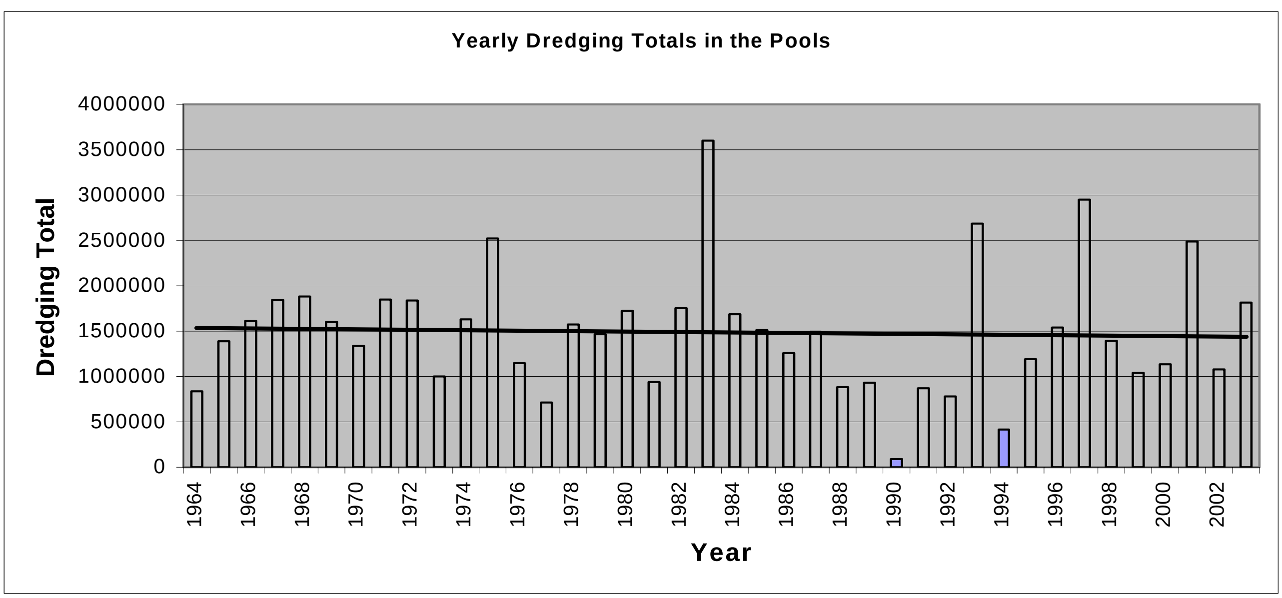

Figure 59: Historical Dredging on the Mississippi River, Miles 300 to 201

Missouri River Sedimentation Influences on the Open Reach of the Mississippi River

The Missouri River, entering the Upper Mississippi River about 10 miles upstream of St. Louis, Mo., at Mile 195.0, has a dominant influence on sedimentation trends in the open river reach of river (the open reach means that no lock or dams exist and the river flows unimpeded).

Studies have shown that approximately 75 % to 95% of the suspended sediment load that passes St. Louis on an annual basis is supplied from the Missouri River. Figure 60 is the historical histogram of suspended sediment loads collected at the St. Louis gauging station. Prior to the 1950s, the load was as high as between 250 million to 375 million metric tons per year. After completion of the Gavin's Point Missouri River Reservoir in the mid 1950s, the load has been substantially reduced to a yearly average of about 100 million to 150 million tons per year, a reduction of roughly 50 percent. This trend has remained constant over time, a parallel trend similar to Trimble's observation on the Coon Watershed in Wisconsin whereas total sediment yield changed little over time even though the individual sources and volumes of sediment changed dramatically.

This post-reservoir average load is about 50 to 100 times greater than average loads experienced in the pooled reaches above the confluence of the Missouri River. The large sediment load can be noted distinctively from the air at the junction of the Missouri and Mississippi Rivers (Figure 60). The sediment load is so dominant from the Missouri River that this sediment line can still be observed through the St. Louis Harbor, about 10 miles south of the confluence. Measured influences of this mixing line have been detected as far downstream as Chester, Illinois, about 86 miles south of the junction.

The sediments from the Missouri River tend to deposit after high flow events within the St. Louis Harbor, between Miles 192 and Miles 168. Because there are numerous fleeting facilities, dike construction is limited. Thus, this stretch of river must be maintained by dredging on a yearly basis. About 30 million cubic yards of material have been dredged in this stretch of river since 1964 (Lamm 2004).

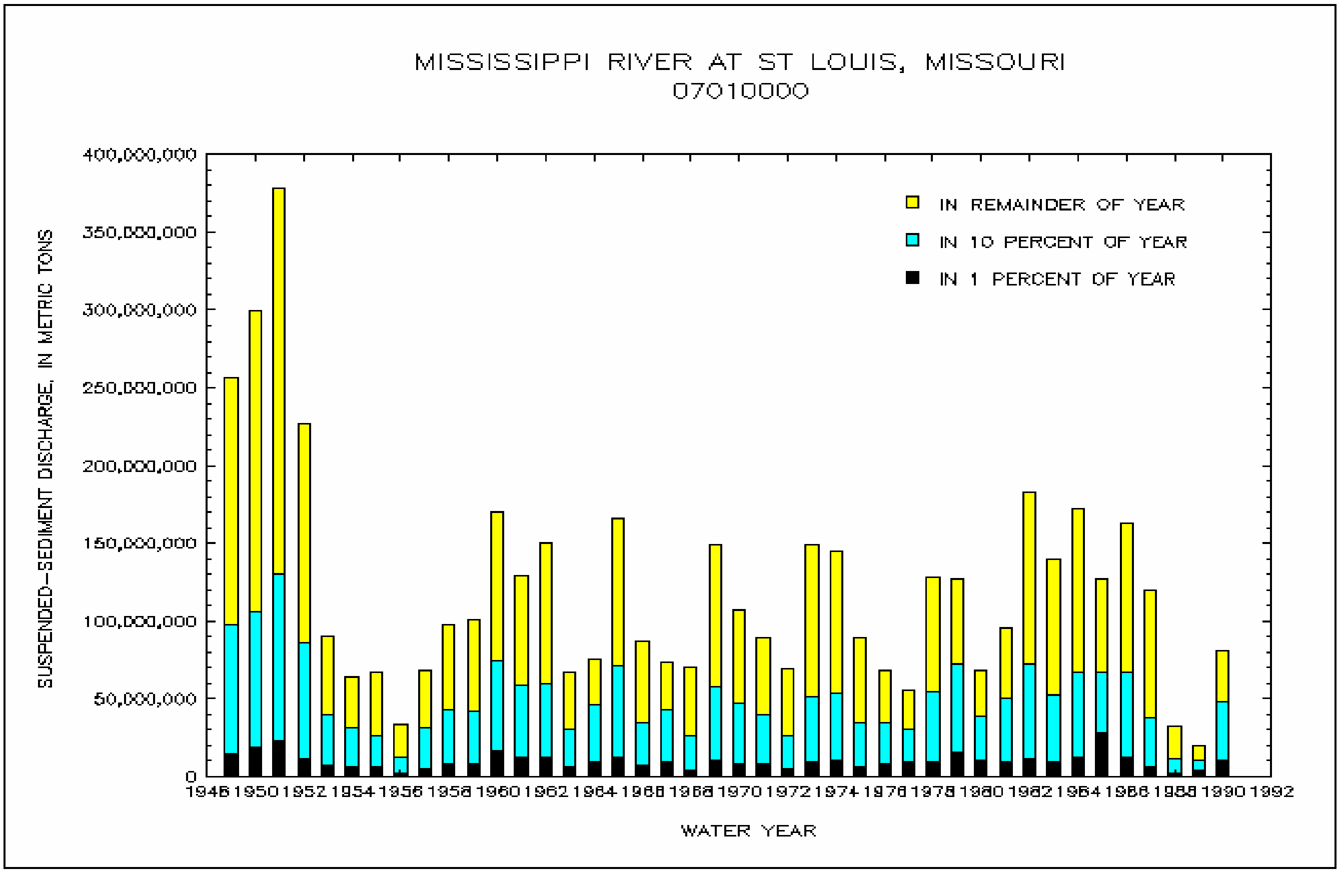

Figure 60: Suspended Sediment Discharge, in Metric Tons Per Year, at St. Louis, Missouri

Figure 61: Junction of the Missouri (Left) and Mississippi (Right) Rivers, Showing the Higher Sediment Load of the Missouri River

Dredging Trends on the Open River Reach

In addition to the dredging required in the St. Louis Harbor, the entire open river reach of the Mississippi River has required dredging to maintain a 9-foot navigation channel. Figure 62 is the historical dredging that has occurred for a 200-mile stretch of river below St. Louis (labeled as the Middle Mississippi River). An extreme drought occurred from 1988 through 1989, which brought about record low river stages at St. Louis. The navigation channel had to be maintained artificially with as many as seven dredges, well above what normally had been required. Other than this rare event, the dredging quantity trends have remained fairly constant over history.

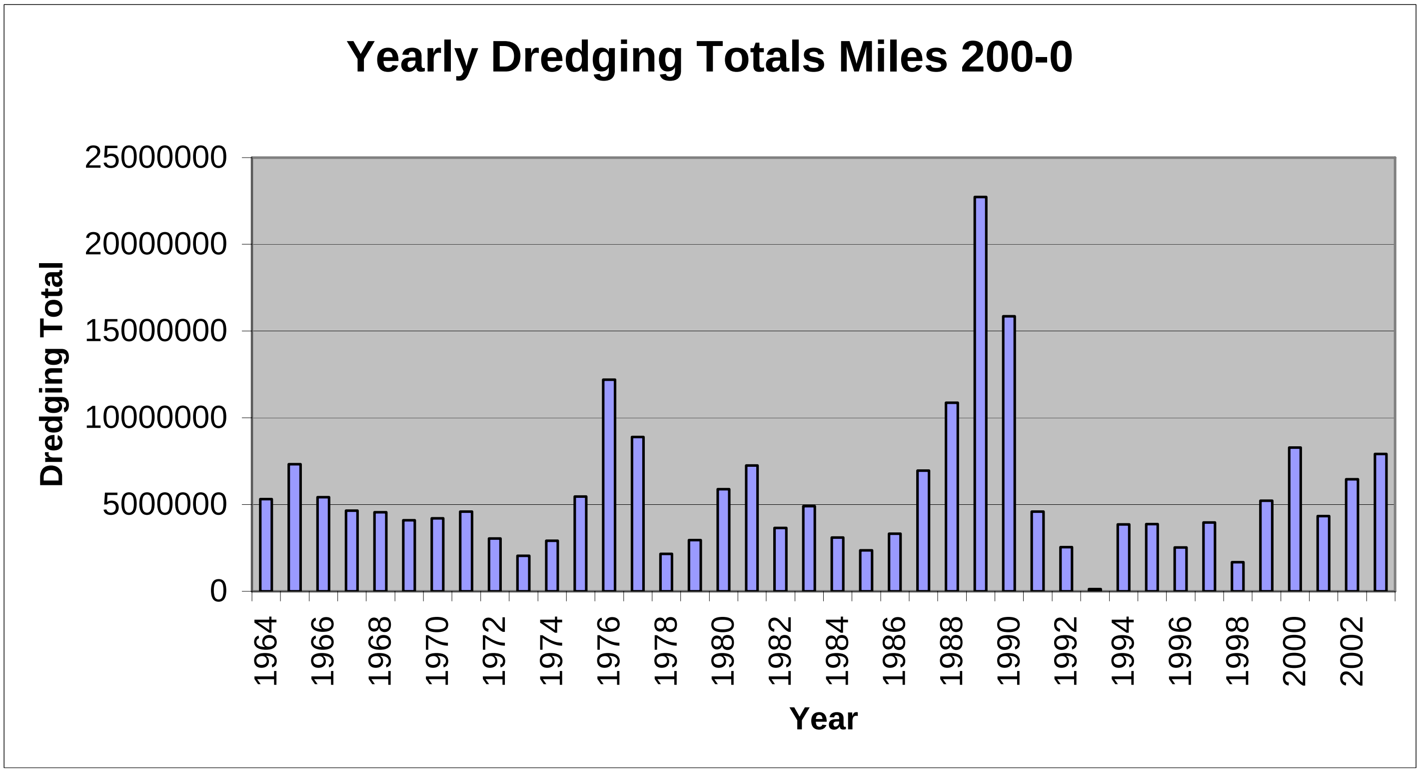

Figure 62: Historical Dredging of the Mississippi River, Miles 200 to 0

Summary of the Sedimentation Conditions of the Rivers and Streams in the Basin

The previous case studies paint a mosaic of the sedimentation conditions that are occurring on the rivers and streams in the basin. To summarize, widespread land use changes occurring in the basin in the late 1800's to early 1900's, whereby forests and prairies were converted to crops and grazing, have changed the behavior of most of the rivers and streams. After the lands were cleared, irrigation, ditching, drain tiling, and channel rerouting were conducted over a large portion of the basin. These practices dramatically changed runoff, soil structure and bulk density.

Initially, increased soil loss and sedimentation in streams was probably primarily caused by overland sheet and rill erosion. Conservation practices have greatly reduced the sediment yield from these sources over time. However, widespread downcutting (headcutting) on the tributaries also resulted from early land use changes. Excessive bank erosion was then initiated. The erosion is still observed today on many of the larger tributaries. Material from this erosion is probably the predominant source for sediment yield in the basin now, and may even be surpassing the earlier contributions of overland sheet and rill erosion (Steffen 2004). Additional sediment data in the future needs to be collected to confirm this.

The predominant river and stream types found in the basin, especially the larger rivers, would be categorized as meandering canaliforms (single channels). There are exceptions to this rule, but for the most part, the bed load is low enough (as compared to western rivers) and the floodplain material composition is resistant enough to form many of the classic meandering rivers.   Because of widespread channel downcutting, some of the canaliforms have transitioned to braided canaliforms (Figure 63).

Conversely, since the larger rivers are typically canaliforms, they tend to meander laterally across their floodplains regardless of what land use they encounter. Historical map and photo comparisons conducted on the Salt River in Northeastern Missouri, the Sangamon River in Central Illinois, and the Kaskaskia River in Southwestern Illinois (Davinroy 2003) indicated that these rivers have meandered across there respective floodplains throughout time with relative ease. Even when large tracks of riparian corridors were located in the floodplain, the river meandering was not slowed down or influenced to any observed degree. These rivers moved though forests at the same rate as they moved through cleared lands. Apparently, the channels of these rivers are deep enough that the tree roots do little to protect the toe of the bank.

On smaller streams, riparian corridors seem to play a much larger role in minimizing erosion and meandering because the size of the tree root wads are much larger relative to the size of the channel. Vegetative measures for bank stabilization therefore have a much higher success for the smaller streams.

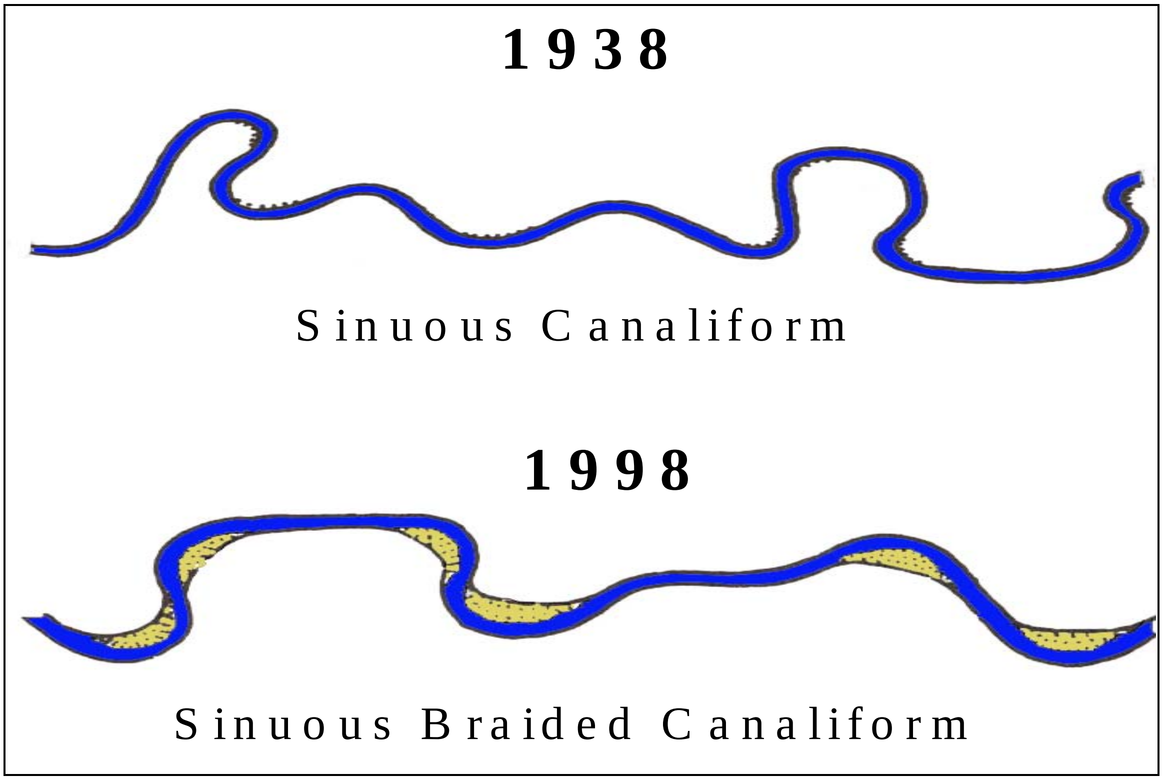

Figure 63: Observed Changes in Some of the Rivers in the Mississippi River Basin

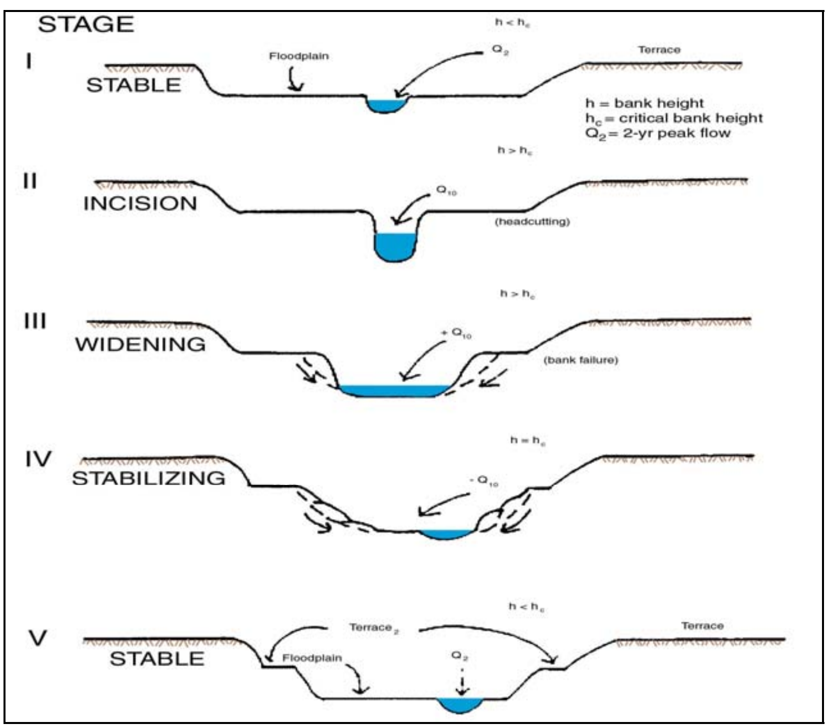

Figure 64: Schumm's Channel Evolution Model (1984) (Modified by Steffen 1994)

In 1984, Schumm, Harvey & Watson developed the Channel Evolution Model. The model gives a general indication of the stages of typical streams (Figure 64). Using this model Figure 64. Schumm's Channel Evolution Model (1984) (Modified by Steffen 1994). somewhere between stage 2 and stage 3 (Steffen, Davinroy, Rodgers, et. al 1995, 2005). As in the Kaskaskia River and some of the other larger rivers located downstream of tributary headcutting, large influxes of sediment are being introduced into the channel. Channel widening and increased bank erosion is resulting.

Another good example of what is generally happening in many sub-basins is represented by the distributed sediment budget model developed by Trimble (Figure 55). The model describes the complex sediment storage fluxes of three basin zones – tributaries (i.e. smaller creeks entering the main tributary), upper main valley, and lower main valley. The upper main valley (i.e. the upstream most reaches of the main tributary) is the most problematic zone because high banks of historical sediment are being eroded, increasing downstream sediment yield. The lower main valley continues to aggrade. The smaller creeks, called tributary zones, are becoming increasingly stable and now are often minor sediment sinks. Stabilization of isolated cutbanks in the tributary reach could be beneficial. In addition, grade control structures may be warranted if incision is still taking place. Treatment in the lower main valley, where the reach is aggrading, would require much more aggressive measures. As in the case of the Kaskaskia River and the Salt River, for example, where the river channel is aggrading and widening, dikes combined with revetments could help regain channel sinuosity, channel depth, and channel conveyance.

DECREASING SEDIMENTATION PROBLEMS IN THE BASIN

Management Strategy

It is absolutely imperative to continue to makes strides in decreasing the enormous sedimentation problems that exist throughout the basin. The effort conducted in the past by NRCS and others is commended. However, an even greater effort in the future is required if we are to ensure better conditions for future generations. Decreasing the sediment problems will not only improve the quality of life for humans, but also improve and sustain the ecosystem.

The conservation efforts that have been applied to farming practices have made significant improvements to sedimentation problems. These efforts should continue to be maintained. However, focus now must also be directed toward the rivers and streams. Attention in the past on the waterways in the United States has been almost exclusively aimed at water quality. The facts presented in this report emphasize that to improve water quality, the sediment and erosion problems in the channels must be addressed.

Clearly, the science and knowledge of what has taken place over the basin is much more advanced than it was just a few short years ago. Moreover, most scientists and professionals now understand that proper management of a river involves a holistic approach incorporating a variety of considerations including hydrology, sediment transport, geomorphology, and historical land use changes.

To achieve future success, it becomes essential that federal, state, and local agencies as well as the stakeholders become organized under a common, institutional arrangement. This common arrangement is critical in order to couple both the overland and stream problems together. This does not suggest changing or re-managing each agency. The individualism of agencies like the NRCS, the Corps of Engineers, the USGS, and others foster imagination, ingenuity, and even healthy competition. Instead, a common arrangement can integrate all of the knowledge that exists collectively among these diversified groups, especially when it comes to the art of practical application. An integrated, collaborative effort not only establishes a much more focused effort, but supplies a more cost-effective effort for the taxpayer.

One way to accomplish this integration would be to develop a collaborative sediment reduction “master plan” of the basin (Figure 65). The master plan could incorporate the use of a geographical information system (GIS) to store all pertinent information, including past studies, past measures applied, monitoring data, alternative measures, and costs. The alternatives would provide a basin-wide strategy for both land conservation and river restoration and stabilization. Measures would rely on the collaborative expertise of the group. The plan would also ensure that all groups are aware of both the required scope and sequence of work.

In the 1969 UMR Comprehensive Basin Study, Appendix G Fluvial Sediment, it was recommended that under existing Federal legislation, a UMR Basin Commission be formed to serve as a permanent body to accept responsibility and provide leadership in overcoming the sediment problems of the basin. Unfortunately, this commission was never formed, and as a result, there has been no collaborative effort on addressing the sediment problems of the basin. As a result, redundancy and/or conflicting efforts have taken place. Rather than a commission, a collaborative, interagency effort could prove just as valuable.

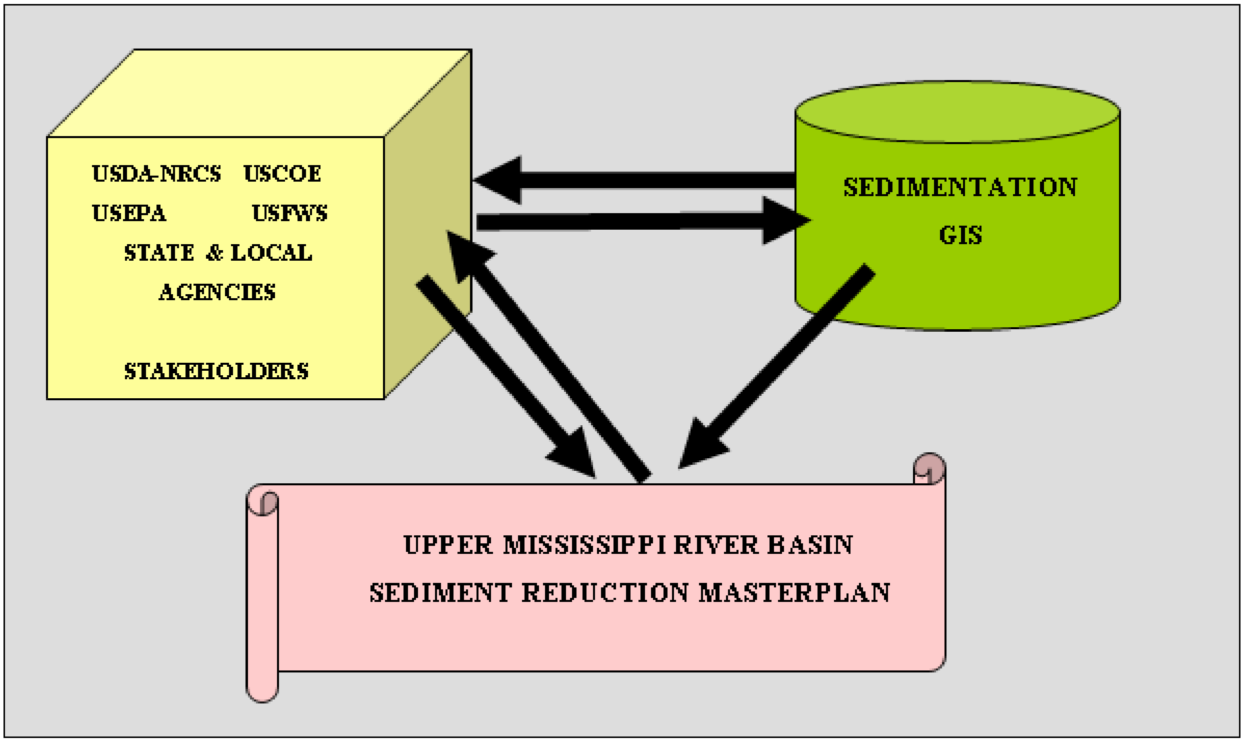

Figure 65: Simple Conceptual Model of Integrated Development of Sediment Reduction Masterplan for the Upper Mississippi River Basin

Priority Plan

All of the sedimentation problems occurring in the basin should be addressed collaboratively from a systemic view. This means prioritizing initiatives as well. Unfortunately, the sediment reduction 23or restoration projects of the past have not always been conducted based upon importance but rather upon politics. Projects have been fragmented individually over the entire basin among the various states or stakeholders. Often funding is dependent upon whoever is the most influential congressman.

Recently, large, packaged projects, such as the Everglades and the Coastal Louisiana Restoration have received congressional support and appropriations. These projects used a collaborative basin approach whereby a priority plan was identified by areas of importance. However, as Figure 66 illustrates, projects such as the Everglades have the added advantage of lying in an area containing a large percentage of federal and state land ownership. Within the Upper Mississippi River Basin, over 80 percent of the land is in private ownership. From a basin perspective then, to compete with other large projects in the nation where state and federal funds are easier to come by, it makes sense to define a priority plan.

In 1969, an interagency task force developed a priority plan based upon the computed sediment yields of the basin. The plan provided ranking of areas using a tolerable sediment yield reference. A value of 500 tons per square mile annually from a 100 square mile drainage area was arbitrarily considered the tolerable rate.

Rather than using the arbitrary tolerable rate reference, in this report the actual sediment yield values were ranked according to magnitude of sediment yield. If at least the relative difference and distribution of yields are similar today across the basin as they were in 1969, the rankings highlight some important observations.

Figure 67 is the developed priority map of the Upper Mississippi River Basin. The map serves as a guide to highlight the highest and lowest sediment producing areas of the basin. By inspection, it is obvious that the greatest sediment problems are located along the Mississippi River along the Missouri-Illinois border, the lower Illinois River, and the Des Moines River. Along the Mississippi, this would also include the lower Salt River, the Meramec River, the Kaskaskia River, and the Big Muddy River. Along the Illinois, the Sangamon River would also be included. These areas contain excessive sediment yields far greater than most of the other areas of the basin. The map serves as a planning tool not only to rank future work, but also to indicate problem areas for the possible design of future water resource projects.

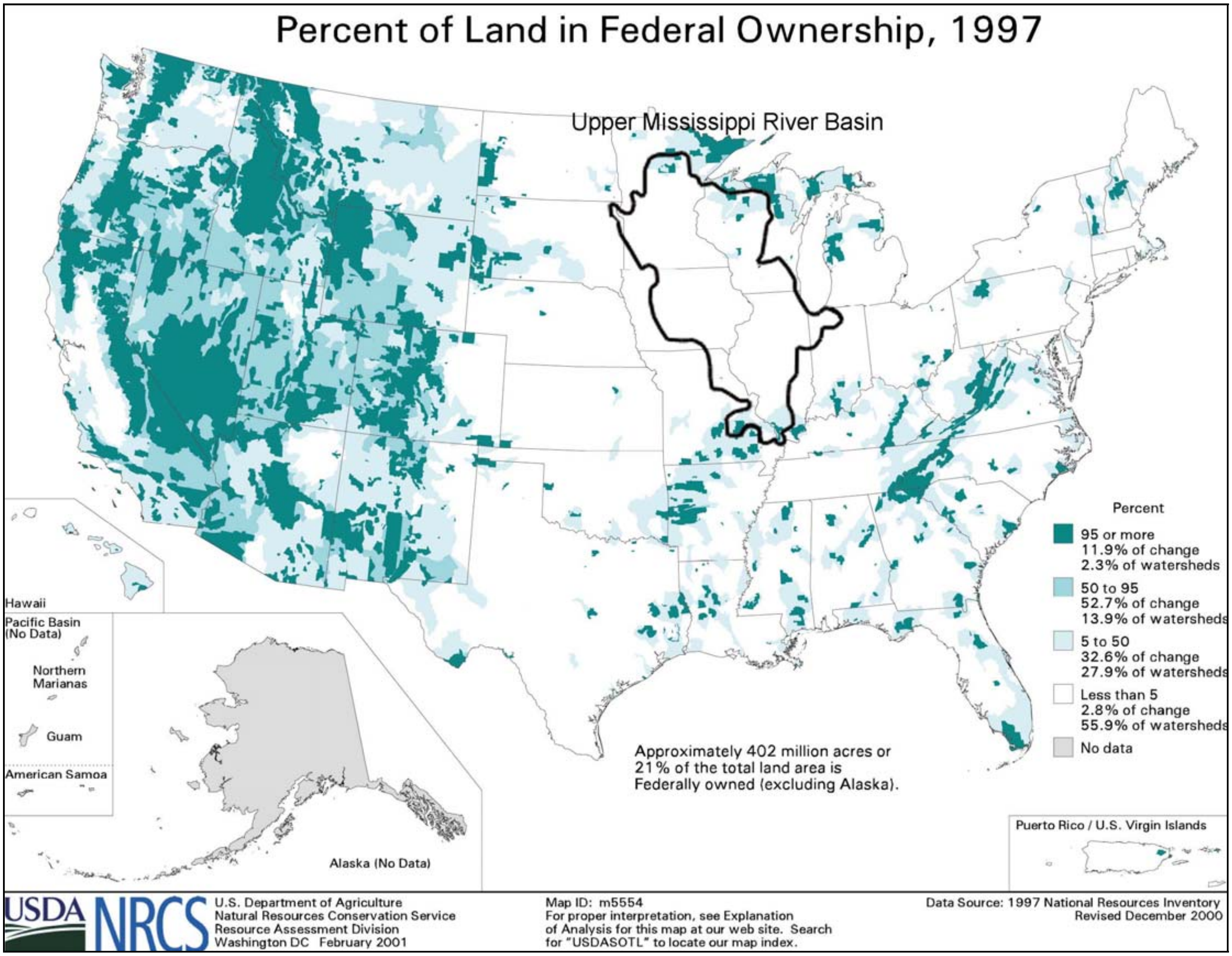

Figure 66: Percent of Land in Federal Ownership in 1997

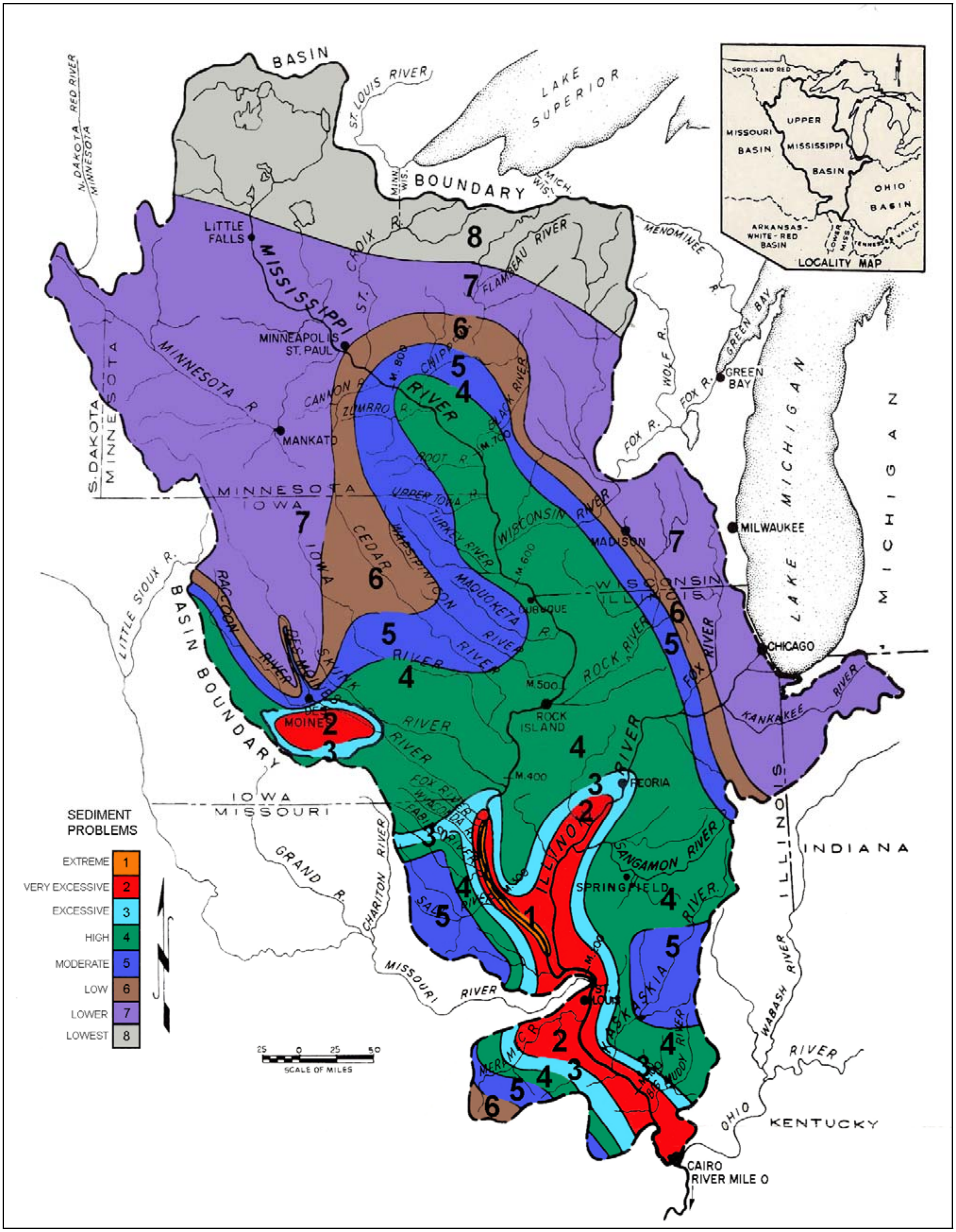

Figure 67: Priority Ranking Map of Sediment Problems in the Upper Mississippi River Basin

Public Awareness and Communication

The majority of the general public in the Upper Mississippi River Basin does not comprehend the negative impacts sedimentation has had on both the lands and waterways of the basin. Even engineers have been guilty in the past of designing water resources projects with no regard given to sedimentation.

As evident by the reduction in sediment monitoring, people have paid more attention to what has been happening with the water and less attention to what has been happening with the sediment. In the end, if more awareness does not shift toward sediment, and we continue on our present course of action, there will be insurmountable costs associated with sediment damage, far existing what presently exists.

A public awareness program must be instituted immediately to provide an outline of the nature and importance of sedimentation problems in the basin (Figure 68). This could be achieved in the form of an interagency sponsored flyer or handout, a newsletter, a series of articles submitted to newspapers and magazines, or even radio and television spots. The problem must be communicated in a manner that people will comprehend and relate to on an everyday basis.

A series of articles in the Minneapolis Star & Tribune Newspaper in 2003 and 2004 outlined details regarding watershed improvements and sediment reduction efforts in the Minnesota River, a 16,500 square mile watershed that enters the Mississippi River in the Twin Cities metropolitan area. Excerpts from these articles are as follows:

"This program consists of a $250 million conservation Reserve Enhancement Program which guarantees payments for establishing 160 square miles of grass and trees in the river watershed. It also includes $312 million spent to upgrade the basin's three largest wastewater treatment plants. Officials with the Minnesota Pollution Control Agency and the governor's office claim that the program has reduced annual runoff into the Minnesota River by 470,000 tons of sediment and 580,000 pounds of phosphorus.

However, a report by the Minnesota Center for Environmental Advocacy states that the Minnesota River remains heavily polluted despite the 10-year government commitment to make fishable and swimmable by 2002. The center concluded that the $312 million spent to upgrade the basin's three largest wastewater treatment plants reduced phosphorous by 37-percent and ammonia by 60-percent. However, the money spent on agricultural programs has shown inconclusive results. A study by University of Minnesota professor Dave Mulla concluded that sediment declined about 20-percent and phosphorous by 10-percentduring the previous 20-year period."

If one is not familiar with the nature and importance of sediment problems, then the above article excerpts will probably not make much sense when read. This is why an awareness program emphasizing education is so critical, because then articles like the one written above will be understood by more people. The more people that understand the topic of sedimentation, its ramifications on water quality, human life, and the ecosystem, the easier it will be for engineers and planners to implement future sediment reduction and restoration projects throughout the basin.

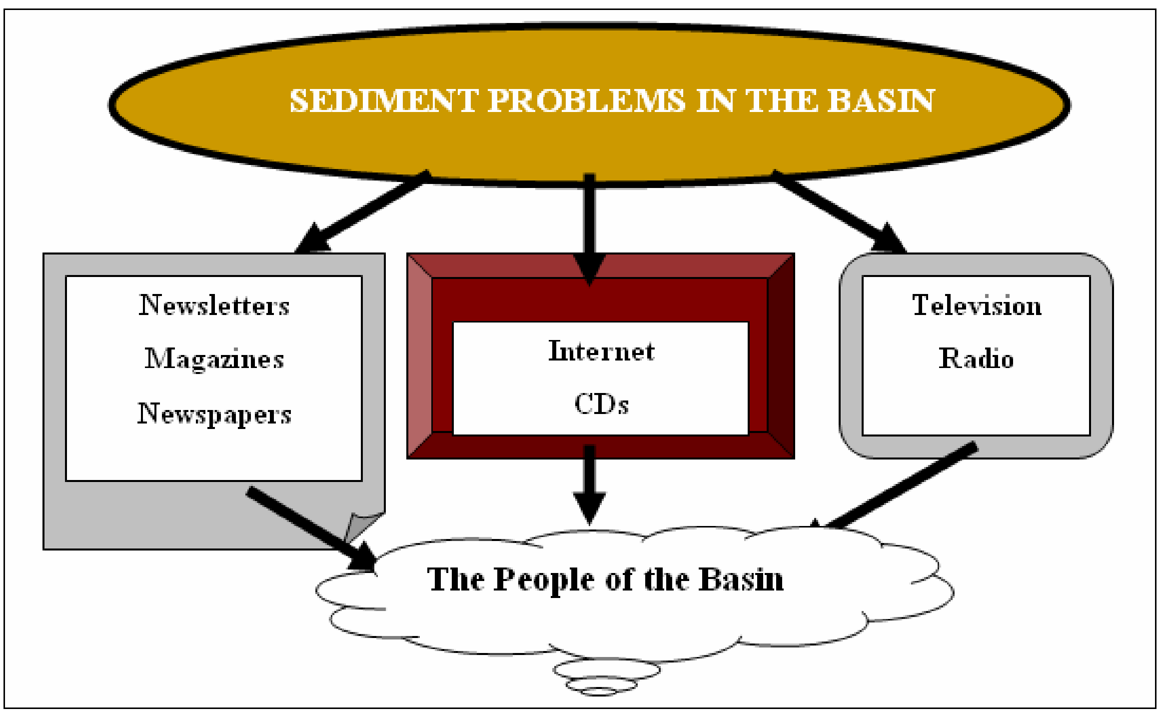

Figure 68: Spreading the Word on Sediment Problems in the Basin

Methods of Reducing Sedimentation Problems

Over the last 10 years throughout the United States, emphasis has been directed at developing new methods in conjunction with old methods of reducing sediment and erosion problems. Both old and new methods have been used in the basin. Some of these methods have been applied based upon intensive research, while others have been developed by direct field experiments. Whatever the method employed, the success of each application has depended upon the understanding of the larger problem at hand. Failures have usually resulted when the focus was directed only at the sight location and not the surrounding basin or, as in the case of rivers, when no additional focus was applied to upstream conditions.

The methods used have depended upon the cooperation of the landowner, the economic situation, the environmental impact, and the practicality of implementation.
It would be impossible to mention every method that has been used or is available for

reducing sedimentation. Therefore, this section will highlight some of the more successful methods that have been used to serve as a reference for future considerations.

Land Treatment Methods

Land treat methods can either be vegetative or structural, depending upon the problem and the costs. A combination of the two methods may also be used when possible.

Conservation Cover

This establishes and maintains perennial vegetative cover to protect soil on land retired from agricultural production.

Conservation Cropping

This method requires planting a sequence of crops to provide adequate organic residue for maintenance of soil. This practice reduces erosion by increasing organic matter. It may also disrupt disease, insect, and weed reproduction cycles thereby reducing the need for pesticides. This may include grasses and legumes planted in rotation.

Conservation Tillage

Also known as reduced tillage, this planting system maintains at least 30% of the soil surface covered by residue after planting. Erosion is reduced by providing soil cover. Runoff is reduced and infiltration into groundwater is increased, No-till, common in North America, is a conservation tillage practice (Figure 69).

Figure 69: Planting on no-till treated land

Contour Farming

Plowing, moving the earth, planting, and other management practices that are carried out along land contours or changing land contours is called contour farming. This method can reduce erosion and runoff.

Cover and Green Manure Crop

This method involves growing a crop of close-growing grasses, legumes, or grains primarily for seasonal protection and soil improvement. Usually the plants are grown for 1 year or less.

Critical Area Planting

This includes planting vegetation, such as trees, shrubs, vines, grasses or legumes, on highly erodible land.

Crop Reside

Using plant residues to protect cultivated fields during critical erosion periods can be an effective sediment reduction measure.

Delayed Seedbed Preparation

Any cropping system in which all crop residues are maintained on the soil surface until shortly before the succeeding crop is planted is called delayed seedbed preparation. This measure reduces the period that the soil is susceptible to erosion.

Diversions

Diversions involve constructing channels across a slope with a supporting ridge on the lower side. By controlling down-slope runoff, erosion is reduced and infiltration into the groundwater is enhanced (Figure 70).

Field Borders and Filter Strips

This measure considers planting a strip of perennial herbaceous vegetation along the edge of fields. This slows runoff and traps coarser sediment. This is not generally effective, however, for fine sediment and associated pollutants (Figure 71).

Figure 70: Diversion for Erosion Prevention along Cropland

Figure 71: Buffer Strip along Field

Grassed Waterways

This method entails planting grass along a swale or natural or constructed channel. The waterway may be graded and shaped to inhibit channel erosion. The grass will also serve to trap sediment that is washed in from adjacent fields (Figure 72).

Figure 72: Grassed Waterway along Edge of Field

Contour Strip Cropping

Growing crops in a systematic arrangement of strips or bands across the general slope to reduce water erosion is called strip cropping. Crops are arranged so that a strip of grass or close-growing crop is alternated with a clean-tilled crop or fallow (Figure 73).

Sediment Detention Reservoirs or Stilling Basins

Detention reservoirs or stilling basins is a method used to collect and store sediment during runoff events. Also known as a detention pond, sediment is deposited from runoff during impoundment. Basins may be formed by building dams across gullies, creeks, and stream channels (Figure 74), across upland drainage areas, or just upstream of a larger reservoir.

Figure 73: Contour Strip Cropping in Minnesota

Terracing

Terraces are constructed earthen embankments that retard runoff and reduce erosion by breaking the slope into numerous flat surfaces separated by slopes that are protected with permanent vegetation or which are constructed from stone, etc. Terracing is carried out on very steep slopes and on long gentle slopes where terraces are very broad.

Figure 74: Headcutting (Top Photo) and Small Reservoir (Sediment Detention) Measure (Bottom Photo) near Des Moines, Iowa

River and Stream Methods

As discussed throughout this report, the number one problem in the basin today is river and stream instability. Bank erosion and channel downcutting are usually the symptoms of dramatically altered runoff. To provide stabilization, as in the previous examples of land use treatments, the methods may be vegetative or structural.

<u>Rock Revetment</u>

Also known as riprap protection, rock revetment (Figure 75) has been used with tremendous success for the stabilization of banks on rivers and streams, for the stabilization of slopes, for the protection of scour around bridge piers, culverts, and many other structures associated with water movement. Although one of the most expensive methods, it also is one of the most failsafe if properly designed and correctly placed. In some portions of the pooled reaches of the Mississippi River, off-bankline revetment has been used, which involves building a dike parallel along the bank to serve as stabilization without disturbing the bank (Figure 76).

Figure 75: Revetment Being Placed along the Bankline of the Mississippi River

Figure 76: Off-Bankline Revetment in the Upper Mississippi River

Willow Plantings

Also known as natural bank stabilization or soil bioengineering, this method involves the plantings of willow shoots or stakes along the sides of the eroding bank. If the willows take root, grow, and spread, a blanket of vegetative cover becomes established. Deposition of fine sediments results, and the bank becomes stabilized. This method has worked with some success, although not recommended for larger streams and rivers. The rate of success is increased when used with a combination of other stabilization methods such as revetment (Figure 77). Caution must be taken on the possibility of increasing localized flooding because the growth of the tress can eventually add additional channel roughness and loss of channel conveyance. Soil bioengineering can also be used on the floodplain to protect against overbank scour (called “tree screens” on the Mississippi River, Figure 78), on the sides of hills, and other erosion prone areas.

Figure 77: Willow Plantings and Rock Revetment for Erosion Control

Figure 78: Tree Screens and Rock Baffles for Overbank Scour Protection at Dry Bayou on the Mississippi River (Rapp 2005)

Structures Located along Eroding Banks

Rock and/or wooden structures placed along the outside of an eroding bank are methods that have been used with success. The concept here is to redirect velocities away from the eroding bank and/or to encourage deposition between the structures. A variety of designs have been developed over the years including dikes, woven mattress, hard points, bendway weirs, groins, barbs, longitudinal peak stone, and rock vanes, to name a few (Figures 79, 80, and 81).

Figure 79: Wooden Mattress Placed along an Eroding Bank of the Mississippi River (Circa 1938)

Figure 80: Hardpoints for Bank Protection in a Side Channel of the Middle Mississippi River (Hopkins 2005)

Figure 81: Rock Vane Construction for Bank Stabilization on the Kaskaskia River

In addition, in larger rivers and streams whereby the root wads of trees provide no erosion protection along the bank, the trees may be cut down and utilized for bank protection. The key is to anchor the fallen trees perpendicular along the bank. In this manner the trees will act similar to woven mattress, encouraging the deposition of fine sediments. Figure 82 illustrates this method applied along an eroding bend of the Salt River in Missouri.

Figure 82: Anchored Cut Trees for Bank Erosion Control on the Salt River in Central Missouri (Rapp 2005)

Grade Control Structures

Rock, concrete, and wooden structures strategically place across a river or stream to prevent channel downcutting (headcutting) and to provide stability are commonly called grade control structures. Other names used are weirs, groins, drop structures, riffles, and dams. These structures can be designed high or low depending upon field conditions and the particular problem being studied (Figure 83).

Figure 83: Concrete Grade Control Measure near Iowa City, Iowa

<u>Contraction Dikes</u>

Rock and wooden pile structures designed to contract the river and encourage deposition of sediments or redirect currents are called contraction dikes. Other names that apply are wing dams, groins, vanes, spur dikes, L-head dikes, chevrons, multiple round point structures, off-channel revetment, seed islands, and bendway weirs, to name a few.

Contraction dikes have been used with great success on the Mississippi River for establishing reliable navigation channel dimensions. They have also been used for environmental river restoration, including the preservation, enhancement, or creation of side channels, sloughs, backwaters, and islands (Figures 84, 85, and 86). Dikes have also been used to alleviate sedimentation in harbors.

Contraction dikes can also be used on smaller rivers in a similar fashion as used on the Mississippi River. For example, dikes may be used to restore smaller rivers to original channel dimensions or to provide stability.

Figure 84: Creation of Islands Using Notched Dikes on the Middle Mississippi River

Figure 85: Blunt Nosed Chevrons at Bolters Bar in the Upper Mississippi River

Figure 86: Seed Island Structures, Upper Mississippi River (Hendrickson 2005)

Dredging

Dredging is the most used measure to manage sediment. It is usually repetitive in nature. In some cases, dredging has been used for diversions or the creation of new planforms, channels, sloughs, oxbows, and lakes. Dredging may involve water or land-based operations. Often times finding a place for disposal of the dredge material becomes an issue. Beneficial uses of dredge material may be considered, including beach construction, fill material, and levee construction.

Earth-Moving Methods for Restoration Measures

Recently, some streams have been restored to their original planform conditions by using earth-moving methods. The measures involve narrowing the widened, eroding condition of the disturbed stream using material from the adjacent floodplain and/or removing undesirable native vegetation (Figures 87, 88, and 89). Marshall (2003) conducted water quality and fisheries monitoring on several restored streams of the Blue Mounds Watershed in Wisconsin including the Gordon River. Compared with data collected in the 1970's and early 1990's, streams where planform restoration was achieved using earth-moving methods supported greater numbers of cold water fish including brown trout. Narrowing the channels, grading the floodplain topography, establishing natural prairie, and placing structures in the stream for habitat have made a difference in the aquatic health. In addition, sediment loads have been significantly reduced during high water events (Marshall 2005).

Figure 87: Gordon River in Wisconsin Prior to Channel Restoration (West 2005)

Figure 88: Earth Moving and Vegetation Removal of the Floodplain along the Gordon River (West 2005)

Figure 89: .Restored Planform and Floodplain of the Gordon River (West 2005)

Specific Sediment Reduction Measures Performed for Corps of Engineers Floodplain Projects

Sediment reduction measures have been performed to reduce sediment contributions from both the river and from small tributaries located in bluffs and hillsides adjacent to the floodplain. More specifically, two Corps of Engineers Environmental Management Program (EMP) projects that utilized these type measures were the Swan Lake Project (Illinois River, Mile 13 to Mile 5), and the Batchtown Project (Mississippi River, Miles 248 to 242).

The Swan Lake Project area includes a 3,100 acre lake and an adjacent 31 square mile local watershed along the lake's west shore. The site is managed by the US Fish and Wildlife Service and the Illinois Department of Natural Resources. The site is vitally important as habitat for both fish and waterfowl. However, ongoing habitat loss has reduced the habitat value of this area. The major threats to the Swan Lake complex have been: sedimentation, water level fluctuations, and wind generated waves. The lake receives substantial sediment input, not only from the flood waters of the Illinois River, but from the local watershed as well. It is estimated that two-third of the lake's sediment is from the river, and one-third is from the hillside. The projected deposition rate for the lake over the next 50 years without a project is 0.33 inches per year, resulting in a 30 percent reduction in lake surface acreage.

Sediment deposition results in a direct loss of habitat acreage over time. It also results in decreased water depth, leaving fish susceptible to temperature extremes during the summer and winter periods and to the effects of lake-freeze over during the winter. Sediment also contributes to a soft lake bottom, not conducive to plant anchorage, and contributes to high turbidity levels when agitated by wind generated waves. This increased turbidity results in reduced light penetration into the water column, causing reduced photosynthetic activity, and reduced plant production.

To control sedimentation, the project implemented at Swan Lake included a riverside levee to reduce the influx of river borne sediments, and a hillside sediment control program. A Memorandum of Agreement for the hillside program was signed between the U.S. Natural Resources Conservation Service and the St. Louis Corps District. The agreement described the terms of NRCS technical assistance to the Corps during advanced planning and implementation of the hillside features, and of the NRCS's operations and maintenance responsibilities, through successive agreements with the County Soil and Water Conservation District and landowners of the hillside program. The construction for the hillside program was cost-shared 75% federal/25% non-federal, with the cost of the O&M being a totally non-federal responsibility.
The project's objective was to try to achieve a 30% level of sediment reduction from the local watershed area. A quantification of the projects contributions in September 1998 (Table 5) indicates that the project had already far exceeded its original target.

Swan Lake Hillside Sediment Control Program Summary	
Conservation Practice	**Quantity**
Critical Area	51.2 Ac
Field Border	6.8 Ac
Filter Strip	5.8 Ac
Grassed Waterway	9.5 Ac
Pasture / Hayland Planting	12.3 Ac
Ponds	7
Terraces	4
Contour Orchard	20.0 Ac
Wetland Cells	10
WASCOB's (Water & Sediment Control Basins)	98
Concrete Block Chute	1
Rock Chute	1
Grade Stabilization Structure	5
Sediment Delivered Before	28,853 Tons/Yr
Sediment Delivered After	14,177 Tons/Yr
Sediment Reduction	14,746 Tons/Yr
Total Life Reduction	277,125

Table 5: Swan Lake Hillside Sediment Control Program Summary

The Swan Lake project represents a unique partnership arrangement that interfaces the institutional authorities of two Federal agencies—the NRCS with jurisdiction for upland watershed areas and the Corps of Engineers with jurisdiction for the floodplain area. In total it pooled the resources of many (Corps, NRCS, SWCD, and landowners) to achieve what no one entity could have accomplished alone. What makes this partnership especially important as a case study is that the most highly erodible lands in the UMRS are those located along the river bluff.

One of the lessons learned from the Swan Lake experience was that hillside features expire at a rate faster than is typical of Corps project features. Most environmental project features can be expected to remain functional for a project life of 50 years. Upland sediment control features can be expected to survive for about one-half that amount of time. Accordingly, a second application of hillside features needs to be considered at about year 25 of the project life. Even with a second application of features, the partnership approach was still found to be the most economical means for achieving the desired sediment reduction output.

Similar measures have been performed for the Batchtown Project as well under the same EMP authorities and partners. Figures 90 and 91 illustrate sediment reduction measures constructed in the upper hillsides adjacent to the floodplain. These sediment detention basins have been well accepted by the general public as they provide fishing and other recreational benefits (Thompson 2005).

Figure 90: Hillside Sediment Detention Basin, Batchtown, EMP Project (Thompson 2005)

Figure 91: Hillside Sediment Detention Basin, Batchtown EMP Project (Thompson 2005)

FUTURE NEEDS AND IMPACTS

Monitoring Needs

The USCOE, NRCS, USGS, and the States of Minnesota, Wisconsin, Iowa, Illinois, and Missouri have been reporting for several years that decreasing budgets have greatly reduced the amount of sediment monitoring conducted in the basin. This reduction has occurred on a national basis as well.

Figure 92 shows the historic year to year operation of daily sediment stations by the USGS. The USGS "sediment program" hasn't changed significantly in magnitude since the late 1990's. It is worthwhile to note that if one subtracts the Puerto Rico stations operated recently (perhaps the densest sediment data-collection program in the world with about 28 stations on the island), then the monitoring is at about the 1946-48 level, or at a two thirds century low for the 50 States (Gray 2004).

The sediment-data-collection network operated by the U.S. Geological Survey has depended on funding from local, state, and other federal agencies. Funding has usually been made available to monitor or characterize ongoing sediment problems. This has resulted in only collecting short duration sediment data primarily project related. Long-term data is usually not collected because of a lack of funding (Tornes 1986). Tornes (1986) states that suspended-sediment samples were collected by the U.S. Geological Survey from 115 sites on Minnesota streams between 1960 and 1981 (a period of 21 years). A total of 33 of these sites were daily sediment stations (i.e. stream flow and suspended sediment concentrations) with enough data to determine statistically correct sediment discharge equations, average concentrations, and sediment yields. Today, unfortunately, only one daily sediment gage site is maintained, on the Minnesota River at Mankato, Minnesota (Mitton pers. comm. 2004). Johnson (2004) states that only 12 daily sediment load sights are maintained in Illinois, and these are for short term projects as well.

Twenty years have passed since funding was provided to do a major sediment monitoring effort of tributaries to the Mississippi River. Tornes (1986) suggests that previously sampled sites could be re-sampled, for a period of 5 to 10 years, to determine if sediment-transport characteristics have changed. This could be combined with more focused sediment monitoring (e.g. bed load monitoring on the Mississippi River, efforts aimed specifically at determining the affects of watershed improvements, a resurvey of the 1935/1945 siltation surveys, and floodplain elevation surveys) to increase our knowledge base and improve future management decisions.

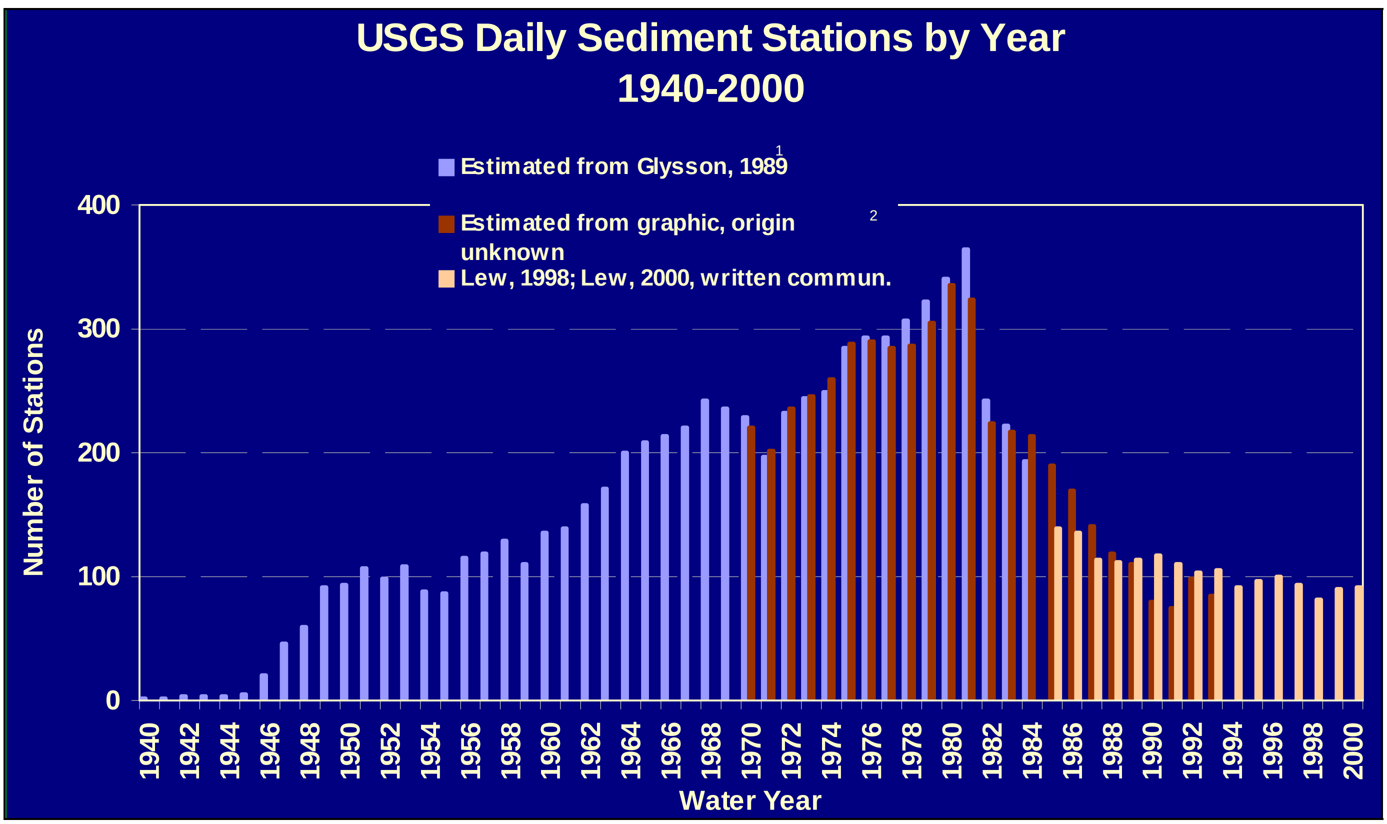

Figure 92: Historical Collection of Sediment Data of the USGS

Some of the cost of sediment monitoring could be offset by reducing or eliminating monitoring during the winter. Tornes (1986) analyzed the measured sediment load at 19 sediment stations in Minnesota and found that almost one-fourth of the annual sediment load was carried by these rivers during April and that more than 90-percent of the load was carried during the 7 months March through September. Less than 4-percent of the annual load was carried during the winter months December, January, and February. Cooper (pers. comm.) analyzed suspended sediment data on the Whitewater River and also found that March through September was the time period when most of the suspended sediment was transported.

Another way costs could be reduced is to employ the use of remote sensing technologies to measure suspended sediment data, including the Acoustic Doppler Current Profiler and airborne infrared photography. These new technologies show promise. If calibrated correctly, these methods may someday in the near future dramatically reduce the amount of labor and time required to collect and analyze sediment samples.

As discussed previously, reservoir surveys have also been substantially reduced. These surveys are more accurate in determining total load, and should be at the forefront of sediment monitoring in the basin.

Several national task force committees have been formed over the years concerning the measurement of rivers and streams in the United States, including the Advisory Committee on Water Information and the Subcommittee on Sedimentation. These committees are made up of a variety of agencies, including the Agricultural Research Service, the Bureau of Reclamation, the Federal Highway Administration, the Natural Resource Conservation Service, the Environmental Protection Agency, the U.S. Forest Service, the Corps of Engineers, and the United States Geological Survey.

In 2003, these committees drafted measures focused on maintaining and increasing the existing river and stream gage network that exists in the country. The focus was only on collecting water information, with no mention or proposal to re-establish sediment monitoring. Sediment measurements seemed to have taken a back seat, probably due to budget reductions. However, as the rivers and streams in the basin continue to experience changes, future sediment monitoring will become even more important and necessary. Monitoring will be required not only to improve our knowledge and understanding of sediment transport, but also to gage the effectiveness of applied sediment reduction and/or restoration measures. Funding must be re-established as soon as possible, or there will be a large historical data gap that will be statistically difficult to overcome.

Impacts on Flood Control Projects

As discussed previously, the physical characteristics of many of the rivers and streams in the UMR basin have dramatically changed over time. Some channels have deepened. Some channels have widened and aggraded. In both cases, the channel conveyance (water carrying capacity) has changed.

There are thousands of miles of agricultural and urban levees located along many of the waterways. In most cases, the design of the majority of these levees occurred years ago. If the river or stream channel conveyance has been reduced, then the frequency of flooding has increased, which means that the level of flood protection provided by many of these levees is far less than what was originally designed. New flood profiles must be established to account for the changed channel conditions. Levees may have to be raised, or restoration measures may have to be used in the waterway to increase channel conveyance, or a combination of measures.

These changed conditions have ramifications for the federal flood insurance program as well. Many flood insurance studies conducted along the rivers and streams in the basin are outdated because the analyses were based upon existing field surveys at the time of the study. The majority of these studies contain flood profiles and floodways that do not reflect the changed channel conveyance conditions (Stephens, Davinroy, et. al. 2005). New field surveys should be collected and new hydraulic modeling should be performed in order to establish up-to-date flood profiles. Congressional funding should be established immediately for this effort.

Impacts on the Upper Mississippi River- Illinois River Navigation System

Sedimentation trends on the main stem of the river have been for the most part stable since the 1950s, as reflected by the historical sediment gage data at St. Louis (Figure 60). However, if measures are not applied to reduce erosion and sedimentation from the tributaries, sediment entering the navigation system may actually increase and cause future navigation impacts. Large sections of bankline along critical eroding reaches such as bends have been stabilized within the Upper Mississippi River-Illinois River Navigation System. Besides increased dredging requirements, more sediment in the channel may impact these revetments. A study was recently completed on the Lower Mississippi River that showed large amounts of sediment deposits have occurred along existing revetments (Rawson 2005). These deposits influenced the development of the thalweg, which incurred additional downstream bank erosion and revetment failures. This depositional trend has not been observed above the Ohio River but may happen in the near future if sediment loads increase.

To reduce sediment loads into the Upper Mississippi River System, efforts should be aimed at reducing the overall sediment supply from the watershed and at restoring the lower tributary channels so that they transport less sediment to the mouth. Identifying the critical reaches supplying excessive sediment and achieving a more stable channel-floodplain flow regime in these identified reaches is paramount if sediment reduction is the goal. As discussed in this report, a large portion of material being introduced into the Mississippi River from the tributaries is now attributed to bank erosion. Stabilization and/or dike contraction work in these tributaries, or grade control measures, whereby restored channel sinuosity and channel width are achieved by trapping existing sediments, may be a cost effective way of reducing the overall sediment contribution to the Mississippi River. Excluding the Mississippi and Illinois Rivers, it is estimated that at least 10,000 miles of rivers and streams in the basin are disturbed to the degree that remedial measures are required (Davinroy, Myers 2005). This number may even be higher if drainage ditches and smaller rivulets are considered.

Environmental Impacts in the UMRS from Sedimentation

Increased sedimentation and changes in river and stream morphology mean that environmental impacts are certain. Eroded, fine-grain sediments carried by surface runoff severely impact water quality, fish and wildlife, and ecological habitat in the UMRS.   The sediments fill in backwater areas and increase turbidity, carry excessive nutrients into the aquatic ecosystem, and bring in pesticides and other toxic chemicals. The nitrate levels are increased. Continued sedimentation will degrade the quality of the habitat, reduce diversity, and result in a gradual aggradation of backwaters, leading to their transformation from aquatic to terrestrial habitat. The Mississippi River backwaters that presently provide fish and wildlife and plant production and nursery habitats may be lost to sedimentation and eutrophication within the next 50 to 100 years if measures are not taken.

As in the case with reducing sediment in the main channel for navigation, the key to reducing environmental impacts in sensitive areas such as backwaters and side channels in the UMRS is to focus on reducing erosion and sediment from the contributing tributaries. The Corps Navigation and Environmental Sustainability Project will focus on addressing environmental impacts within the floodplain of the UMRS. Under this effort, initiatives such as dredging, side channel structures, etc. will address backwater sedimentation. However, this will only deal with the symptom and not the source of the problem. The tributaries must eventually be addressed or the costs of performing these backwater initiatives will only increase over time.

Sedimentation Damages, Needs, and Costs

To estimate the annual damages and costs incurred by sedimentation in the basin, a very large and detailed study would be required. Damages would include personal property loss, damages to crops, increased municipal water treatment from increased phosphate loads and other pollutants, bridges and other infrastructure impacts, blockage of ports, harbors, navigation channels, and water intakes, and destruction of fish and wildlife habitat, to name a few. Needs would encompass measures to address these damages.

Because time and funds did not allow for a detailed economic study, a very qualitative estimate was outlined in this report (Table 6). It should be stressed that these estimates were qualitative and produced with the intention of providing a general understanding of the magnitude of possible costs associated with sedimentation in the basin. Some estimates were made based upon a fair amount of data and past experience with the many different corrective measures that have been initiated throughout the basin and throughout other parts of the United States. Some estimates were made with very little data. The total estimated cost, $6.6 billion dollars, is very conservative and is probably less that the actual true cost that would be provided by a detailed economic analysis study.

Description of Need or Impact	Comments	Estimated Remedial Cost	Comments
Stabilization of Waterways	Estimated at least 10,000 miles of major tributaries in distress, this number is probably much higher if all the smaller streams and creeks are included.	$2 billion	Cost based upon $2 million per mile for average size stream. (Davinroy 2005).
Habitat Restoration	See above, not inclusive of Mississippi and Illinois Rivers.	$2 billion	Cost matches engineering initiatives for stabilization.
Shoreline Protection of Reservoirs and Lakes	Based Upon 10,000 linear miles of Shoreline	$2 billion	Cost based upon $2 million per mile for average size reservoirs and lakes.
Raising of Levees for Increased Flood Protection	Based on 2000 linear miles of levees on major tributaries and streams.	$450 million	Based upon adding 1 foot of Levee per mile at a cost of $225,000 per mile.
Dredging of harbors and marina facilities, reservoirs and lakes, and sediment removal at water intakes.	Total number not known at time of the study.	$20 million	Real costs could be higher or less.
Averting Highway Bridge Scour and Failures	No way of knowing number of future bridges affected at this time.	$20 million	Cost is over 50 years and dependent upon frequency of high water events. Real costs could be higher or less.
Re-establishing suspended sediment and reservoir gages	Based upon number of gages available in the basin in the early 1970's (140)	$140 million	Cost is based upon average operation and maintenance cost of $20,000 per gage per year over 50 years (Coleman 2005).
Total Costs		**$6.6 billion**	Real costs could be higher or less, depending upon detailed economic study.

Table 6: Qualitative Estimate of Needs and Costs Associated with UMR Sedimentation

RECOMMENDATIONS

This report summarizes that commendable progress has been made on reducing sheet and rill erosion within the Upper Mississippi River Basin. However, there are still large areas of land coverage that require conservation practices. More soil conservation measures must be accomplished if there are ever any hopes of reducing the excessive sediment yield prevalent throughout the majority of the basin. In addition, there are tremendous sedimentation problems occurring in the rivers and streams, and very little effort has been initiated to date to address these problems. This ultimately affects backwaters and the main stem of the Upper Mississippi River. The following recommendations are made which highlight many of the points made in this report:

1. Continue NRCS efforts to implement soil conservation methods across the basin.

2. Re-establish sediment monitoring throughout the basin, collecting both suspended sediment load and reservoir surveys.

3. Establish funding for the formation of an interagency team and the development of an Upper Mississippi River Basin Sediment Reduction Master Plan.

4. Initiate a basin-wide public awareness program describing the sedimentation problems and the required solutions.

5. Develop a sedimentation geographical information system (GIS) of the basin.

6. Submit a sedimentation master plan to congress for approval and appropriations. This master plan should incorporate more detailed studies defining the problems and establishing the required measures. A detailed cost analysis should be prepared within this effort.

7. Implement funded measures throughout the basin using a systemic approach based upon priority and needs.

8. Continue to encourage research and development into the study of sedimentation. This should include striving to gain a better understanding of its mechanisms and developing new technologies to economically manage sediment problems, especially in rivers and streams.

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