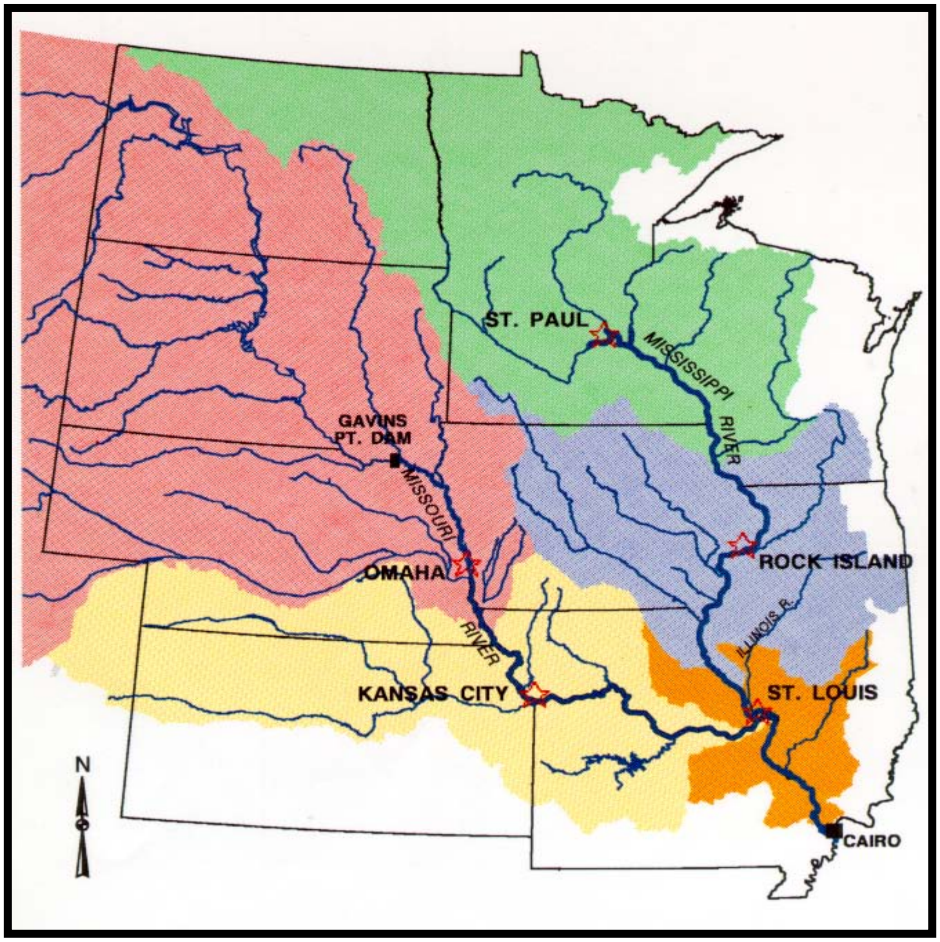
Upper Mississippi River System Flow Frequency Study



Final Report

January 2004

FOREWORD

In March 1976, the United States Water Resources Council published "Guidelines for Determining Flood Flow Frequency," identified as Bulletin 17 of the Hydrology Committee. This bulletin represented a standard for all federal agencies for flow frequency determination. Therefore, the Upper Mississippi River Basin Commission chartered a Task Force in February 1977 to use then current data and Bulletin 17 to develop flow frequency and flood profiles for the main stem reach of the Upper Mississippi River. The Task Force consisted of representatives of five states and five federal agencies. The U.S. Army Corps of Engineers completed all technical computations that were reviewed by the Task Force members and the final flood profiles from St. Paul, Minnesota, to Cairo, Illinois, were published in November 1979.

The 1979 report recognized that the results were obtained without the help of a math model or cross-sectional data and were to be used until such data or a model was available. By the late 1990's, the Corps had developed unsteady flow models (UNET) for the Illinois River, the Upper Mississippi River main stem, and the Missouri River below the Gavins Point Dam to the mouth with existing cross-sectional data. Subsequently, funds to obtain digital floodplain data for the entire reach became available. Additionally, in part due to the Great Flood of 1993, there was significant public interest by private individuals and organizations, including levee districts, supporting the update of the flood profiles for the Upper Mississippi River. When congressional funding became available for this study, the Director of Civil Works of the Corps formed a Task Force in 1997, consisting of representatives from seven federal agencies and seven states. The five Corps Districts (St. Paul, Rock Island, Omaha, Kansas City, St. Louis) conducted all of the technical investigation with general oversight from the Corps' Institute of Water Resources, Technical Advisory Group, and the Task Force members.

This effort represents the best estimates of flood profiles for the Upper Mississippi River at this time. It is recognized that the watershed and the floodplains are dynamic, including the bathymetric cross sections that are used in the study. Our knowledge of hydrologic probabilities and hydraulic modeling is also advancing steadily. When any of these factors change significantly, collaborative efforts must be made to revise these results to reflect such changes. The Task Force participants were: U.S. Army Corps of Engineers (HQ, IWR, MVD, NWD, MVP, MVR, MVS, NWK, NWO), United States Geological Survey, National Weather Service, Bureau of Reclamation, Natural Resources Conservation Service, Federal Emergency Management Agency, Tennessee Valley Authority, and the states of Minnesota, Wisconsin, Iowa, Illinois, Missouri, Kansas, and Nebraska.

S. K. Nanda
Chairman
Upper Mississippi River System
Flow Frequency Task Force

FROM THE ROCK ISLAND DISTRICT COMMANDER:

The Upper Mississippi River System Flow Frequency Study was carried out in close coordination and collaboration with other federal agencies, seven states, and the general public. It received critical guidance, direction, and review from the members of two independent technical advisory groups consisting of nationally and internationally recognized experts in their respective fields. Finally, the Corps of Engineers team that was ultimately responsible for the accomplishment of this study included many of this agency's best hydrologists and hydraulic engineers.

I have only the greatest of respect and admiration for the abilities, knowledge, experience, and commitment to excellence that these many individuals consistently demonstrated throughout the course of this study. The rigorous technical review processes they put in place to assure the quality and soundness of the study's final results were unparalleled. The products of this study, updated discharge-frequency relationships and water surface elevations for over 1,900 miles of the Upper Mississippi, Lower Missouri, and Illinois Rivers, will provide the basis for sound floodplain management, flood damage reduction planning and implementation, and environmental restoration throughout these river reaches for many years to come.

Duane P. Gapinski
Colonel, U.S. Army
District Engineer

EXECUTIVE SUMMARY

Major Upper Mississippi River Basin flooding during the last decade resulted in significant losses as well as raised questions regarding the frequency of flood events. Previous pertinent studies to assess flooding frequency for the Upper Mississippi River began with efforts reported in 1966 and extended through the "Upper Mississippi River Water Surface Profiles, River Mile 0.0 to River Mile 847.5" promulgated by the Upper Mississippi River Basin Commission in November 1979. Reevaluation or updating of the 1979 profiles became necessary to address the current questions resulting from the Great Flood of 1993 and is justified based on the availability of new topographic data, new computational techniques, and about 20 more years of recorded hydrologic data. This is generally true for the Missouri River as well. The last major effort to comprehensively determine Missouri River flow frequencies was in 1962. The additional record of more than 35 years included the major events of 1993 downstream of Nebraska City and the 1997 large volume flood in the upper reaches of the Missouri River. Thus, the Upper Mississippi River Basin Flow Frequency Study began in 1998 as the Upper Mississippi, Lower Missouri, and Illinois Rivers Flow Frequency Study and was completed as of the date of this report in 2003. The study addresses the Illinois River from Lockport to the mouth, the Missouri River from Gavins Point to the mouth, and the Mississippi River from St. Paul to the confluence with the Ohio River.

The study represents a well coordinated effort involving the Corps of Engineers; the Federal Emergency Management Agency; the Bureau of Reclamation; the National Weather Service; the U.S. Geological Survey; the Natural Resources Conservation Service; the Tennessee Valley Authority; the States of Illinois, Iowa, Kansas, Minnesota, Missouri, Nebraska, and Wisconsin; and interested private individuals who formed a public involvement group with direct access to the study team. In addition, technical advisory groups consisting of world renowned experts were formed to help address the complex issues of hydrology and hydraulics. Long-term climatological trends were assessed to the extent required to assure a sound basis for the study. The study also included comprehensive quality assurance, quality control, and independent technical reviews though several iterations and levels of review.

The technical aspects of this study relate primarily to hydrology and hydraulics. Impacts of levees, land use change, and climate variation were studied. Hydrology was accomplished with: 100 years of record from 1898 to 1998; the log-Pearson Type III distribution for unregulated flows at gages; mainstem flows between gages determined by interpolation of the mean and the standard deviation for the annual flow distribution based on drainage area in conjunction with a regional skew; flood control reservoir project impacts defined by developing regulated versus nonregulated relationships for discharges; extreme events determined by factoring up major historic events; and the UNET unsteady flow program to address hydraulic impacts. In situations where historic records were not adequate or appropriate to develop discharge frequency relationships or to verify the results, hydrologic modeling was used to create synthetic flows based on rainfall. Gage records for all streams were carefully evaluated. The computation of unregulated flow frequency relationships on the Missouri River upstream of the Kansas River required special consideration due to the combination of the two historic peak flow periods consisting of the plains snowmelt of the early spring and the mountain snowmelt and plains rainfall of the late spring/early summer. An additional concern related to the Missouri River was flow depletion due to irrigation and reservoir evaporation. Historic depletions were added to the observed flow record to help obtain unregulated flows, while historic depletions were adjusted to present level depletions for computation of the regulated flow record. The result of the hydrologic aspects of the study was a discharge and related

frequency of occurrence for stations or given cross sections located along each of the principle mainstem rivers.

A hydraulic analysis was required to establish the water surface elevation associated with each frequency discharge at each location or cross section along the river reach. The main procedures were to: use the UNET unsteady flow numeric modeling tool; use the recent channel hydrographic surveys (generally obtained for routine channel maintenance) in conjunction with recent Scientific Assessment and Strategy Team (SAST) floodplain digital terrain data collected in 1995 and 1998; and to assume levee failure at the top of existing levee grade based on an upstream and a downstream point. Typically, the hydraulic analysis involved using the HEC-RAS program to locate and develop channel and overbank cross sections for the UNET modeling. Then the UNET model was calibrated to reproduce recorded flood hydrographs for a selected period of record. The UNET model was calibrated to both stage and discharge at gaging locations primarily by adjusting roughness coefficients and estimated lateral inflows. Annual peak flows and peak stages from the period of record run of the calibrated UNET model were used to develop rating curves for each cross section location. Using these station rating curves and the station frequency flows developed during the hydrology phase, frequency elevation points were obtained for each cross section location. Connecting the corresponding points resulted in flood frequency profiles. These profiles were coordinated among the computational teams and appropriate adjustments were made to assure consistency.

Some special considerations and techniques were required to address especially complex flow reaches and levee failure impacts. The confluences of the Missouri and Illinois Rivers with the Mississippi relied primarily on development of graphical stage-probability relationships for backwater-impacted cross sections. These were created using a graphical Weibull approach. The graphical period-of-record stage-probability curves were combined to blend a consistent and reasonable profile for each probability flood. Confluences of many other smaller streams with the mainstem also exhibited backwater effects resulting in discontinuities in the profiles. A computer routine was developed to smooth the profile in these reaches so as to form a consistent, reasonable transition through the zone of backwater. The Illinois Waterway presented special problems related to backwater due to the very flat profile in the lower reaches. As a result, the general technique based on rating curves was abandoned. Profiles upstream of La Grange Lock and Dam are based on UNET modeling of pattern hydrographs based on historic records adjusted to represent various frequency events. UNET modeling of overtopped mainstem levees accounted for storage, flow through the levee cells, and/or conversion of the levee cells area to increased cross-sectional conveyance.

This study produced flood flow frequency profiles. They are presented in both graphical and tabular form. This study is based on the most current topographic mapping, the most up-to-date hydrologic data, and state-of-the-art computational techniques. It represents a large worthwhile investment of resources and provides the best estimate at this time related to future flooding. Additional data from future years of record and improved modeling techniques based on future technology will likely justify a future restudy of these vitally important relationships. However, at this time, this study answers the pertinent questions related to Upper Mississippi River Basin flooding and should serve as the basis for future related water resource planning in the basin.

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CHAPTER 1 – INTRODUCTION

It takes a major flood or disaster to remind mankind of the flood risk in our floodplains. The 1927 flood on the Lower Mississippi Valley provided a great impetus to develop battle plans for the next major flood. The Great Flood of 1993 that ravaged the Upper Mississippi River Valley was no less in its fury to provide similar incentives to the Legislative and Executive Branches of the Government.

The White House Directive of November 24, 1993, established the "Scientific Assessment Strategy Team" (SAST) to provide scientific advice and assistance to officials responsible for making decisions with respect to flood recovery in the Upper Mississippi River Basin. The interagency members of the SAST were instrumental in importing their agency data to a digital master database for many parameters in the basin. In addition, they obtained digital elevation data for the priority areas along the Upper Mississippi River.

In January 1994, the White House also created the "Interagency Floodplain Management Review Committee" headed by BG Gerry Galloway. The purpose was to make recommendations to the Administration Flood Plain Management Task Force on changes in current policies, programs, and activities of the federal government. Proposed changes should most effectively achieve risk reduction, economic efficiency, and environmental enhancement in the floodplain and related watersheds. SAST became the scientific arm of this committee.

One of the actions identified in the Galloway Report was to "….review the current standards for computing discharge-frequency relationships in light of observations from the 1993 flood and other recent large floods in the Upper Mississippi River Basin." Although, the Galloway Report was published in June 1994, funding for this effort would not come for several years.

At the same time, in November 1993, through the appropriation of Public Law 103-126, Congress also directed the Corps of Engineers to undertake "Floodplain Management Assessment" of the Upper Mississippi River. Five Corps districts participated in this effort and published the report in June 1995. This report recognized the need for flow frequency revisions for the study area, but such a task was beyond its scope. The report was completed based on existing flow frequency data.

During the Great Flood of 1993, as the rising waters of the Mississippi and Missouri Rivers were engulfing one levee district after another and the stage at St. Louis, Missouri, was approaching alarmingly close to the top of the flood wall, the need for a system-wide hydraulic model became obvious to the Corps of Engineers. There was a tremendous need to ascertain the impacts of various reservoir operations and levee failures on downstream stages. In December 1993, the Corps organized a modeling team to develop an unsteady flow model for the entire Upper Mississippi River.

By 1997, as funds became available to revise the flow and stage frequency for the Upper Mississippi River, the Corps organized a Task Force consisting of representatives from seven states, seven federal agencies, and seven Corps offices to begin this regional effort with the Rock Island District as the lead agency to manage the project and complete the task in 5 years.

The Upper Mississippi River Basin consists of 714,000 square miles with diverse hydro-meteorological settings and many flood control structures that were put in place in various time periods. The Missouri River, with major flood control reservoirs on the mainstem, is drastically different than the Mississippi River, which has none on the mainstem. The interagency federal guidelines (Bulletin 17B) lack guidance for flow frequency development for such a large basin. There were issues such as the impacts of land use change, climate change, and morphologic changes of the rivers. Existing hydrology for the Missouri River was developed in 1962, while that for the Mississippi mainstem was updated in 1979. There were also concerns as to potential impacts of revised profiles on the floodplain and levee restoration programs.

With these issues in the background, the Task Force proceeded to develop a scope of work and an organizational structure that would meet the technical and public involvement issues. Detailed description of interagency and public coordination is given in Chapter 5 of this report. The project was conceived in three phases—hydrology, hydraulics, and risk analysis. A technical advisory group was formed with nationally renowned scientists to recommend a methodology for hydrology, and another group of scientists was selected to advise on hydraulic aspects of the study. The Task Force held regular meetings to report the procedure and the progress of the study and to seek guidance and concurrence from the interagency and state representatives. A public involvement group also was formed, and their input was coordinated at the Task Force meetings. Regular newsletters also kept the public informed about the study, along with a website at the Corps' Rock Island District.

Each of the five Corps districts performed the study in their respective reaches with a common procedure, while innovations were allowed to solve site-specific, unique problems. The Corps' Institute of Water Resources (IWR) addressed land use and climate change issues. These reports are included in Appendix G. The Hydrologic Engineering Center (HEC) managed all other technical issues.

This study represents a combined effort of a multitude of scientists and engineers who utilized the most advanced concepts and technology available today. Although there were appreciable setbacks in obtaining digital elevation data, which caused some delays in the study, the unprecedented coordination among all the representatives from the federal, state, and private entities culminated in a product that was acceptable to all.

CHAPTER 2 – FLOOD DISTRIBUTION AND PROFILE ESTIMATES

2.1 Introduction

The Corps of Engineers has reevaluated flood frequency estimates for the mainstem rivers in the Upper Mississippi Basin. The motivation for the reevaluation was discussed in Chapter 1. Briefly, this motivation resulted from: (1) the significant additional period of record available since the last study (approximately 30 years of additional record); (2) the occurrence of the great flood of 1993; and (3) the potential limitations of methods in Bulletin 17B, Federal Guidelines for Determining Flood Flow Frequency (IACWD 1982), used in the earlier studies. The 17B limitation was regarding application to basins larger than 3,000 square miles. The gaged basins involved in the Upper Mississippi Basin Study are considerably larger, ranging from 8,000 to over 700,000 square miles.

Considerable data were available to perform this analysis. The gaged data were a mixture of flows from the region as the watersheds (urbanization) and channels (dams and levees) changed over time. That mixture of data necessitated developing consistent records of unregulated flows throughout the basin. The river hydraulics model, UNET, was used to develop that record. Performing a period of record simulation would ensure that the natural combinations of storms and flows occurring over such a large basin are represented.

There was also concern that climate change may have affected the historical streamflow record. Stationarity or homogeneity of the observed data is a key assumption in a flood frequency analysis. Standard statistical tests were applied to the period of record to determine if any of these influences might cause a deviation from the standard assumption.

An analytical relationship to explain unregulated flood frequencies at a gage is desirable because it can be extrapolated to larger flows in a more consistent manner than other methods. Such extrapolation is not recommended for regulated flow frequency or stage-frequency relationships directly because of potential irregularities in the curves due to regulation or floodplain geometry. Once the unregulated flow frequency relationship is obtained, it can be changed for regulated flows through the use of an unregulated vs. regulated flow relationship.

Numerous analytical flow frequency methods have been developed (Maidment 1993). The methods were developed to explain different types of data sets from low to high flows and from small to large areas. The Bulletin 17B approach recommends the log-Pearson III method. This current study evaluated several of the most appropriate methods to see if they could lend any additional insight to flood frequency calculations for the large and varied areas of the Upper Mississippi River Basin.

The study was performed with the help of a number of peer review groups. Technical advisory groups for hydrologic frequency analysis and river hydraulics were enlisted as well as an interagency advisory group. These groups provided guidance on the methods to be applied and testing criteria. The Corps of Engineers districts and divisions reviewed results and aided in making final decisions on the selection methodology. The federal/state task force was involved in the review process and provided a perspective on the regulatory requirements that any proposed methodology would need to address.

This chapter briefly summarizes the analyses performed and results obtained by the study team. Detailed explanations of this material are provided in Appendix A, as well as the district appendices.

2.2 Flow Record

The goal in establishing the database was to maximize the number of mainstem large area drainage basins available for the frequency distribution study. Maximizing the number of gages provides more opportunity to compare different frequency distributions to observed frequencies in the distribution selection procedure.

A 3,000-square-mile minimum drainage area size was established to focus both on the importance of large drainage areas on the frequency analysis problem and to examine drainage areas that exceeded those used in establishing the 17B guidelines. This minimum drainage area requirement necessarily limits the number of gages available. First, the number of large area basins that can be gaged is limited by topography and economics. Second, the records available at these gages are not homogenous for the most part, being influenced by regulation, channel modification, and land use change. Consequently, a major effort was being instituted by the Corps of Engineers to estimate the unregulated flows by accounting for these influences as part of the overall Upper Mississippi Basin Study.

Estimates of unregulated flows were developed at the locations shown in Figure 2.1 on the next page. Approximate corrections for the effects of regulation, levee failures, and land use change have been made to the observations.

2.2.1 Nature of Flooding in the Upper Mississippi River Basin

The following types of meteorological events drive major floods in the Upper Mississippi Basin:

> 1993 - Major multiple season event, caused primarily by late spring and summer convective rainfall of similar pattern to typical summer events, but of greater persistence, depth, and duration. This was the event of record on the Missouri from Kansas City to St. Louis, and from Keokuk to St. Louis on the Mississippi, and a significant event on the Missouri upstream of Kansas City to Nebraska City.
>
> 1952 - A winter snowmelt event influenced very little from precipitation. The event of record from Yankton to St. Joseph on the Missouri, and a significant event on the Upper Mississippi between St. Paul and Clinton.
>
> 1965 - A rainfall-snowmelt event occurring in late winter and early spring. The type of event expected for this region. This is the event of record on the Upper Mississippi from St. Paul to Clinton.

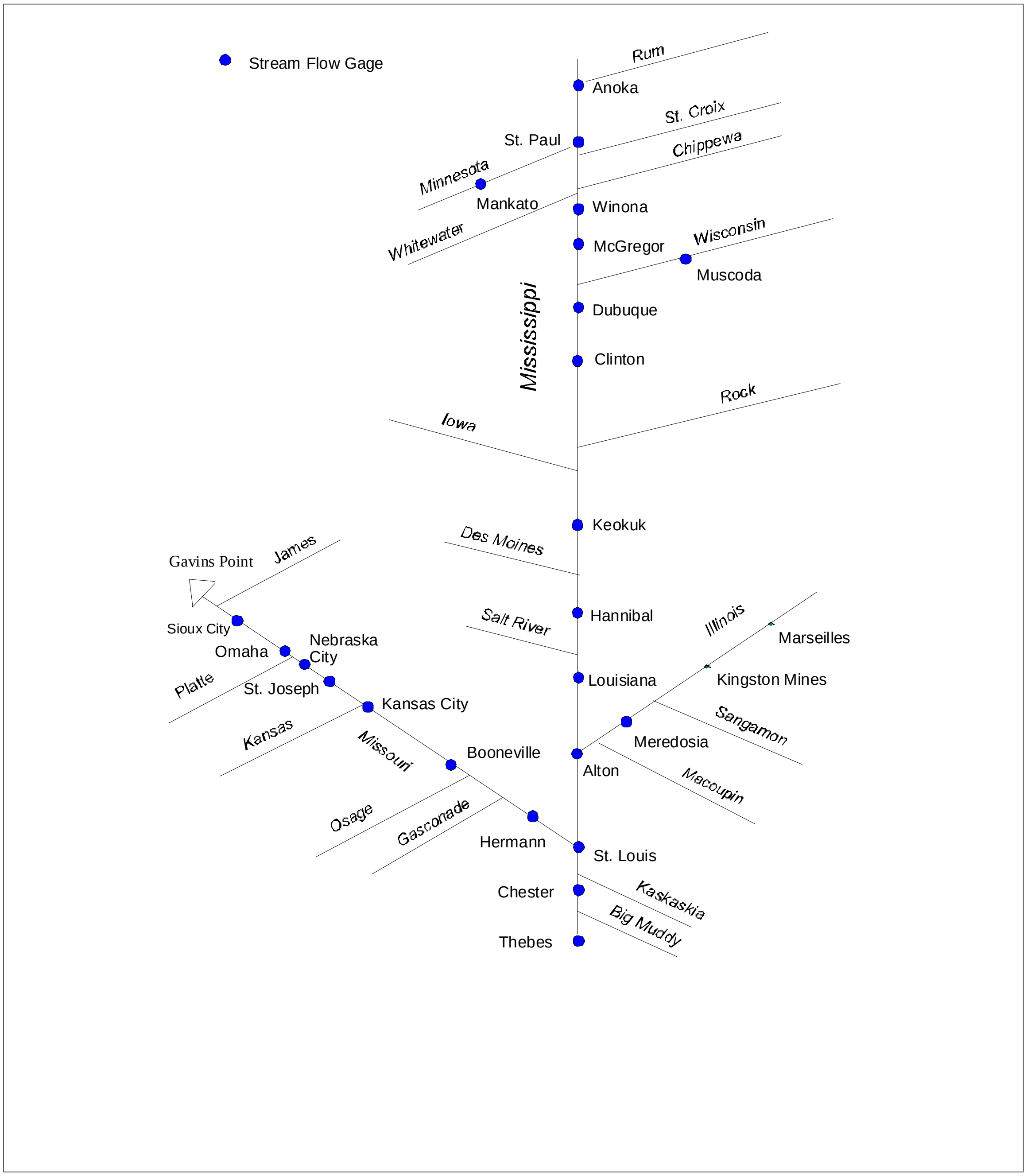

Figure 2.1: Schematic of mainstem gages where unregulated flows were developed.

Either snowmelt, rain on snow, or rainfall can cause major flooding at various locations within the study area. The inspection of major historic floods implies the following important climatologic aspects of Upper Mississippi flooding:

Location	Climatological Aspects
Upper Missouri (Yankton to Nebraska City)	Flood regime where snowmelt is an essential component of the flood. Snowmelt alone or rain and snowmelt combinations can cause major flood of record.
Transition Missouri River (Nebraska City to Kansas City)	Rainfall event or snowmelt related (snowmelt alone or rain on snow) events may cause a major flood event of record.
Lower Missouri (Kansas City to St. Louis)	Flood regime due to rainfall events.
Upper Mississippi, Northern Reach (St. Paul to Clinton)	Flood regime dominated by rain on snow events.
Upper Mississippi Transition Region (Clinton to Keokuk)	Rainfall, rain on snow may cause a major flood event.
Upper Mississippi Southern Reach (Keokuk to St. Louis)	Rainfall events cause major floods of record.

2.2.2 Selection of Study Period

The 1898-1997/1998 period of record was selected to obtain relatively stable land use conditions in the Missouri and the Mississippi Rivers. The changes prior to this time, as well as the difficulty involved in obtaining reliable flow estimates, made the use of earlier records unreliable. The most convincing evidence for selecting this period is the variation in flood statistics between Yankton and St. Joseph on the Missouri River. The channel between Yankton and Omaha has no major Federal levees and can be considered to be in a near-natural state for larger flows. Peak flows tend to attenuate in this reach of river due to the extensive floodplain storage (see section 2.5). Below Omaha, this storage is not available due to the channelization of the river and the construction of major levees, the most upstream of which are at Omaha. Consequently, much of the record existing prior to complete channelization, from the mid 1800's, is not relevant to present conditions. Kansas City and Omaha Districts constructed models that replicate channel conditions since 1898 to better estimate unregulated flows; but information does not exist to estimate the flows prior to this time. The same problem exists on the Mississippi River.

The period of 1898-1997/1998 represents the longest period where flows can be reliably estimated for flood frequency analysis. Table 2.1 provides the period of record available and locations for the gages used in the flood frequency analysis. Note that maximum annual daily flows were used for all the gages, except at St. Paul and Winona where the difference between maximum daily and peak flows were found to be significant to the frequency analysis.

Table 2.1: Upper Mississippi period of record*

Location	Drainage Area (sq mi)	Analysis Period*	Systematic Record	Historic Dates
Yankton, Missouri River	279500	1898-1997	-------	-------
Sioux City, Missouri River	314580	1898-1997	-------	-------
Decatur, Missouri River	316200	1898-1997	-------	-------
Omaha, Missouri River	322800	1898-1997	-------	-------
Nebraska City, Missouri River	410000	1898-1997	-------	-------
Rulo, Missouri River	414900	1898-1997	1885-1889, 1929-1998	-------
St. Joseph, Missouri River	420300	1898-1997	1873-1998	-------
Kansas City, Missouri River	485200	1898-1997	1873-1998	1844
Waverly, Missouri River	487200	1898-1997	1883-1998	1844
Booneville, Missouri River	505690	1898-1997	1883-1998	1844
Hermann, Missouri River	528120	1898-1997	1873-1998	1844
St. Paul, Mississippi River	36800	1898-1998	1867-1998	-------
Winona, Mississippi River	59200	1898-1998	1878-1998	-------
Dubuque, Mississippi River	82000	1898-1998	1874-1998	1828
Clinton, Mississippi River	85600	1898-1998	1874-1998	1851
Keokuk, Mississippi River	119000	1898-1998	1878-1998	
Hannibal, Mississippi River	137000	1898-1998	1879-1998	
Louisiana, Mississippi River	141000	1898-1997	-------	
Grafton, Mississippi River	171300	1898-1997	-------	
St. Louis, Mississippi River	697000	1898-1997	1861-1998	1785, 1844
Chester, Mississippi River	708600	1898-1997	-------	
Thebes, Mississippi River	713200	1898-1997	-------	
Marseilles, Illinois River	8259	1940-1998	-------	
Kingston Mines, Illinois River	15819	1941-1998	-------	
Meredosia, Illinois River	26028	1898-1997	-------	

*Peak annual flows used for St. Paul and Winona; maximum annual daily flows for all other gages.

2.2.3 Impacts of Land Use Changes

The purpose of this section is to provide a description and chronology of the changes that have occurred in the study basin. Establishing this chronology is also important for selecting the period of streamflow record that can be used to estimate the unregulated flow frequency curves.

The land use of the study area changed dramatically prior to 1900 from prairie and timber cover to agriculture as settlement from the eastern United States occurred (Table 2.2). This change is well documented by the MBIC (1969) and Schneiders (1999).

Table 2.2: Chronology of settlement and agricultural development.

Activity	Date	Description
Hunting/gathering	Prior 1870	Hunting and subsistence farming by Native Americans
Exploration	1800-1870	Exploration funded by government (e.g., Lewis and Clark), economy based on trapping and trading, river transport of goods by steamboat, some agricultural development in river valleys
Settlement	1850-1900	Migration of eastern U.S. population to develop land for agriculture in river uplands (prairies and forests), end of Civil War freed a significant population to look for more opportunity, encouraged by government programs (Homestead Act), and more desirable locations had already been settled
Agricultural economy	1900-1940	Irrigation projects spurred by government reclamation acts spurred more cultivation; government public work activities to create work during 1930's depression resulted in large water resource projects beneficial to agriculture
Agricultural industry	1940-present	Technology allows more production with less cultivated acres and labor; rural population decreases and urban areas grow

2.2.4 Impacts of Climate Change

Climatic variability is certainly a factor in the flood record over a geologic time scale. However, this variability has not been identified over time scales of engineering design interest. The gage flood record, on the order of a hundred years, is usually assumed to be approximately stationary over the design period. Still, there has been at least some discussion recently calling into question this assumption because of the influence of such factors as sea surface temperatures on climatic cycles.

Quantifying the impact of either land use change or climatic variability on the flood record, if these influences exist, is beyond the scope of this investigation.

Statistical analysis did not provide a great deal of evidence supporting a hypothesis of non-randomness in the Upper Mississippi study region as a whole. The degree of dependence between annual peak flows for the study area gages makes it difficult to assess the number of gages independently, revealing some aspect of non-randomness. However, the study area is very large, and either land use changes or climatic variability may have caused non-homogeneity or non-stationarity in the unregulated flow record. In particular, those areas in the Upper Mississippi below Hannibal exhibit a statistically significant deviation from the number of exceedances expected to occur over the past 25 years.

The study performed herein was extended by Olsen and Stakhiv (1999) to more gages using the similar approaches for studying non-randomness. They concluded (page 99):

> *There is evidence that flood risk has changed over time for sites where the 1993 flood was the flood of record, particularly at and below Hannibal, Missouri. This increased flood risk challenges the traditional assumption that flood series are independent and identically distributed random variables. This raises concerns that flood risk during the planning period will be underestimated if the entire flood record is used as the basis of projection of future flood risk.*

and:

> *It is not clear how to accommodate the change in flood risk within traditional flood frequency analysis. In the absence of viable alternatives the use of traditional Bulletin 17B procedures are warranted until better methods are developed.*

Consequently, the application of the standard flood frequency techniques over the period is recommended despite the evidence for trends in the mean annual flow identified for the lower portion of the study area.

2.3 Unregulated Flow Analysis

The methods employed to estimate unregulated flows depended on the existing regulation influencing flows in a particular reach, and to some extent the hydraulic models available for simulating floods. The analysis on the Mississippi was much simpler than that on the Missouri River because there are no significant flood control reservoirs regulating flows on the Mississippi above the confluence with the Missouri.

Different methods were used to obtain the unregulated flows for gages located on: (1) the Mississippi River between St. Paul and Hannibal; (2) the Mississippi River between Grafton and Thebes; (3) the Illinois River from Marseilles to Meredosia, and (4) the Missouri River between Yankton and Hermann. The unregulated record between St. Paul and Clinton was estimated to be equal to those reported in the gage record. Unsteady flow simulations performed by St. Paul District demonstrated no significant influence of the existing minor regulation structures. Rock Island District used an existing routing model to adjust the period of record between Clinton and Hannibal for the influence of reservoirs on the Iowa and Des Moines Rivers.

The computation of unregulated flows on the Missouri River involved estimating the influence of both the reservoirs and water supply diversions on tributaries and the major flood control reservoirs on the mainstem. Estimates of the tributary regulation and diversions were obtained by Kansas City and Omaha Districts and used as input to Omaha District's Missouri River flood routing model. Different scenarios were investigated to account for the storage and channel changes occurring in the study area over the period of record.

These computed unregulated flows were provided as inputs to St. Louis District's unsteady flow model at Hermann and Hannibal. Tributary flows between these locations and Thebes were estimated using continuous simulation watershed modeling. These tributary flows, together with inflows from Hermann (Missouri River), Hannibal (Mississippi River), and Meredosia on the Illinois, were routed to obtain Mississippi River unregulated flows between Grafton and Thebes.

The 1898-1997/1998 period of record selected to obtain the Missouri and the Mississippi River corresponds to relatively stable land use conditions. The changes prior to this time, as well as the difficulty involved in obtaining reliable flow estimates, made the use of earlier records unreliable. The same problem exists on the Mississippi River. The period of 1898-1997/1998 represents the longest period where flows can be reliably estimated for flood frequency analysis.

2.4 Flow Frequency Analysis

2.4.1 Selection of Flow Frequency Analysis Methods

The interagency and technical advisory groups (IAG and TAG, Corps of Engineers, 1997) provided recommendations for the estimation techniques to be used in inferring the distributions of peak annual stream flows. The recommendations were made without any detailed knowledge of the data available, the quality of these data, or the characteristics of the existing flood control system. Despite this, very important insights to the methods and approaches that needed to be used in inferring the appropriate frequency distributions can be gained from their recommendations. In particular, the estimation techniques recommended by the IAG and TAG to be investigated were: (1) the standard method of moments; (2) L-moments; (3) regression with censoring; and (4) expected moments with censoring. These estimation techniques were to be applied with a set of suitable probability distributions.

Distributions selected for testing corresponded to the standard two- and three-parameter distributions described in the literature: Gumbel, Generalized Extreme Value, Generalized Pareto, Generalized Logistic, log-Normal, Gamma, and log-Pearson III. Additionally, the five-parameter Wakeby distribution was selected because it has been often applied in combination with L-moment estimation procedures.

The analysis did not show any practically significant different predictions of flood quantile or exceedance estimates by the Bulletin 17B procedures and the other distribution-estimation combination methods tested. However, a particular test, forecast split sample, almost universally resulted in the selection of the log-Normal distribution-standard moment combination. This selection occurred because there is an apparent increase in the frequency of large floods over the latter half of the study area period of record. The zero-skew log-Normal distribution is favored in this case over the other distributions which were estimated to have negative skews based on the earlier part of the record.

The apparent increased risk in flooding may be due to some trend or non-homogeneity in the flood record. Nevertheless, the significance of the trend is not great enough to recommend deviation from the standard frequency analysis assumption of stationary flood records. Consequently, the recommendation is to obtain flood quantile estimates using the Bulletin 17B guidelines together with the TAG and IAG recommendations for regionalizing and smoothing distribution moments.

2.4.2 Regional Consistency

The flood-quantile estimates obtained by the application of the recommended distribution/ estimation pairing should have a regular variation along the study area river reaches to produce consistent flood profile estimates. The combined regional and at-sites estimates obtained by the method recommended are not constrained by any regularity condition. Statistical sampling error alone could cause inconsistent flood quantiles and corresponding flood profile inconsistencies. Ideally, some simple smoothing procedure should be instituted where flood distribution parameters or moments are required to vary regularly with drainage area. Finding a simple algorithm to obtain this regular variation is complicated by the influence of tributary flows that can cause apparent discontinuities in the variation of distribution statistics.

2.4.3 Regional Boundary Recommendations

Although useful in providing a general explanation for the flood regimes, the climatologic norms did not provide definitive guidance for locating the boundaries of the region. The regional boundaries for estimating flood frequency distributions can be reasonably designated given the importance of channel modifications, the influence of climate, the variation of flood statistics across the study area, and the importance of mixed distributions.

2.4.4 Unregulated Flow Frequency Computation Procedure

The period of analysis used beginning in 1898 best represents the current land use, which provides a period of record of 100 years for the gages in the study, except on the Illinois River. Regions for obtaining regular variation of flood quantiles were defined based on examination of channel characteristics, climatology, and regional variation of flood statistics. The flood frequency analysis was performed with Bulletin 17B, taking into account the regional shape (skew) factors. A mixed population analysis was used to estimate the flood distributions from Yankton to St. Joseph because of the combined rain- and snow-driven floods.

For the regional shape factors, the Missouri River is divided into three regions—Yankton to Omaha, Nebraska City to St. Joseph, and Kansas City to Hermann. The Mississippi River is considered to be one region from St. Paul to Thebes. The Illinois River gages are considered to be part of the Mississippi River Region.

To estimate flood frequencies at any point along the rivers, the regional shape areas and drainage area were used for interpolation. The Missouri River was divided into the same regions as in regional shape estimation. At-site mixed distribution estimates were used for gages between Yankton and Omaha. Separate linear regressions were used to obtain regression between Nebraska City and St. Joseph, Kansas City and Hermann. A single regression with drainage area relationship was used to obtain a regular variation of quantiles between St. Paul and Grafton. Linear interpolation with drainage area was used to estimate flows between gages on the Missouri River and between St. Louis and Thebes.

2.4.5 Estimation of Regulated Flow Frequencies

As previously noted, the unregulated flow frequency relationships are believed appropriate for extrapolation to more rare frequencies. This is necessary to meet FEMA needs for 1% (100-year) and 0.2% (500-year) floodplain inundation boundaries. Regulated flow frequencies cannot be extrapolated because of the artificial curve shapes due to reservoir operation. Thus, a relationship between regulated and unregulated flows is needed in order to translate the unregulated flow frequencies to regulated flow frequencies.

The UNET river hydraulics model was used to simulate the same period of record for current regulated conditions. The peak regulated vs. unregulated flow values are plotted and a smooth curve is fit through those points. That curve can be extrapolated to larger flow if necessary by taking ratios of the historical floods and performing the UNET simulations. The regulated vs.

unregulated relationship is then used to transform the unregulated flow frequency curves to regulated.

2.5 Flood Profile Estimates

In order to estimate inundated areas for project analysis and floodplain management, stage-frequency relationships were developed at all key locations. River hydraulics simulation models computed stages and flows throughout the river system given the river channel and floodplain geometry and hydraulic characteristics. With that model and observed river flow and stage data, a relationship between stage and flow was developed at any location. That relationship was then used to translate the regulated flow frequency curve developed in the previous section to a stage-frequency curve. In areas with major backwater, like the confluence of the Mississippi, Illinois, and Missouri Rivers, additional analyses were necessary. The UNET river hydraulics model was selected for this analysis because of its recent implementation in other studies on these rivers.

2.5.1 Selection of the UNET Model

Following the Midwest Flood of 1993, Congress tasked the Corps of Engineers to conduct a comprehensive, system-wide study to assess flood control and floodplain management practices in the areas that were flooded. That study was known as the Floodplain Management Assessment study (FPMA) (USACE 1995). It encompassed three Corps of Engineers division boundaries and five district boundaries. Participating districts included St. Paul, Rock Island, and St. Louis on the Mississippi River, and Omaha and Kansas City on the Missouri River. To accomplish the study objectives, an unsteady flow model of the Upper Mississippi and Lower Missouri Rivers was developed. Each district developed independent models that produced results that were assimilated by neighboring districts so that floodplain management alternatives could be evaluated systemically. The unsteady flow model was used to evaluate the potential impacts of various levee modification alternatives and upland watershed measures, such as reservoirs and land treatments, on the 1993 flood. The model selected for use in the FPMA study was UNET (HEC 2001). It is a one-dimensional unsteady open channel flow simulation model. UNET was subsequently employed as the kernel river hydraulics model for the development of a comprehensive real time flood forecasting system, the Mississippi Basin Modeling System (MBMS, HEC 1998). The UNET simulation model was further applied to the Upper Mississippi Flow Frequency Study to associate stage frequency with flow frequency by continuous unsteady flow simulation of historic periods of record.

2.5.2 The UNET Modeling System

UNET (HEC 2001) was the primary hydraulic analysis tool used in the FPMA and MBMS studies. It simulates one-dimensional unsteady flow through a network of open channels. One element of open channel flow in networks is the split of flow into two or more channels. For subcritical flow, the division of flow depends upon the capacities of the receiving channels. Those capacities are functions of downstream channel geometries and backwater effects. A second element of a network is the combination of flow, termed the dendritic problem. This is considered to be a simpler problem than the flow split because flow from each tributary is dependent only on the stage in the receiving stream. A flow network that includes single channels, dendritic systems, flow splits, and loops such as flow around islands, is the most general problem. UNET has the capability to simulate such a system.

Another capability of UNET is the simulation of storage areas, e.g., lake-like regions that can either provide water to, or divert water from, a channel. This is commonly called a split flow problem.

In this situation, the storage area water surface elevation will control the volume of water diverted. That volume, in turn, affects the shape and timing of downstream hydrographs. Storage areas can be the upstream or downstream boundaries for a river reach. In addition, the river can overflow laterally into storage areas over a gated spillway, weir, levee, through a culvert, or via a pumped diversion.

In addition to solving the one-dimensional unsteady flow equations in a network system, UNET provides the user with the ability to apply many external and internal boundary conditions including flow and stage hydrographs, gated and uncontrolled spillways, bridges, culverts, and levee systems.

To facilitate model application, cross sections are encoded in a modified HEC-2 (HEC 1990) forewater (upstream to downstream) format. Many river systems have been modeled using HEC-2, and those existing data files can be readily adapted to UNET format. Boundary conditions (flow hydrographs, stage hydrographs, etc.) for UNET can be input from any existing HEC-DSS (HEC 1995) database. For most simulations, particularly those with large numbers of hydrographs and hydrograph ordinates, HEC-DSS is advantageous because it eliminates the manual input of hydrographs and creates an input file which can be easily adapted to a large number of scenarios. Hydrographs and profiles that are computed by UNET are output to HEC-DSS for graphical display and for comparisons with observed data. Guidance for numerical modeling of river hydraulics is given in the Corps of Engineers Engineering Manual on *River Hydraulics* (USACE 1993).

2.5.3 Developments to UNET

Several new capabilities were added to UNET in previous studies to meet the needs of this river system. Those capabilities include levee breaching algorithms and navigation dam operation algorithms.

2.5.3.1 Levee Algorithms

The leveed areas along the Mississippi-Missouri River systems are substantial. Breaching of levees, as shown in Figure 2.2, results directly in flooding of areas meant to be protected by the levees. The water that floods those areas is stored for later return to the river. The modeling of this exchange and storage of water resulting from levee breaches is an important aspect of UNET. This feature is included in HEC-UNET Ver. 4.0.

Figure 2.2: Levee Breach (North Central Division, 1994).

The UNET approach to simulation of the impact of levee overtopping and/or breaching on flood characteristics prior to the 1993 flood event considered the area behind the levee to be a storage area. That is, it fills and empties through a levee breach or overtopped area, but does not convey water in the downstream direction. This concept of storage areas is used to approximate a blend of one-dimensional and two-dimensional approaches to river modeling. For most confined locations and for overbank floods less than that of 1993, this has been an adequate assumption.

A simple linear reservoir routing algorithm is used in the existing UNET model to compute the flow through the levee breach; the linear routing coefficient can be fitted to observed data. This description of levee breaches and the associated hydraulics is simplified.

As a result of the 1993 flood on the Missouri River, a new capability for simulating the effects of levee breaches was added to UNET. During 1993, virtually all of the agricultural levees along the Missouri were overtopped, resulting in significant overbank conveyance. This situation poses a peculiar modeling problem. For flows below a certain transition discharge, the levee interior acts as a storage cell which communicates with the river through a breach, or breaches, in the embankment. When flow exceeds the transition discharge, the area behind the levee no longer acts as a storage cell but becomes part of the river, conveying flow. Therefore, there are two situations that must be modeled—a storage cell and a flowing river. An algorithm was developed that allows the overbank storage areas to change to conveyance areas (and back) based upon a triggering river flow or stage. Consequently, the conveyance and storage of the levee cells is described by traditional cross-sectional data rather than with a lumped routing coefficient.

Note, however, that these techniques do not directly predict the location, size, or timing of a levee breach. Once these parameters are known or estimated, however, the impacts of the levee breach on upstream and downstream flows and stages can be computed.

Implementation of the UNET levee breach algorithms developed for the Upper Mississippi River System Flow Frequency Study and related studies requires specification of a water surface elevation in the river at which the levee begins to breach. Historic observations, levee design parameters, and geotechnical research indicate that levees may withstand some degree of overtopping prior to initiation of substantial breach development. Initiation of breaches with water surfaces lower than the levee crest is also possible due to wind waves, vegetation, local subsidence, etc. Selection of a consistent breaching criterion was addressed in the formulation of study parameters - "*A consensus* (being) *reached where federal levees would be modeled to fail when the water surface elevation exceeds the top of levee…*" (Appendix A.3).

2.5.3.2 Navigation Dam Algorithms

A major effort was undertaken to provide the ability to simulate lock and dam operations (as shown in Figure 2.3) with the UNET system (Barkau 1996). The capability to use operating rule curves at navigation dams as internal boundary conditions was developed and implemented. The district offices accomplished preparation of the input data necessary to describe these rule curves.

Figure 2.3: Melvin Price Lock and Dam.

Two types of navigation dam operation can be simulated with UNET:

- **Control Point within the Navigation Pool.** For this type of operation, the navigation pool is adjusted to maintain a constant elevation at a control point in the navigation pool. This procedure is also called hinge pool operation because the pool conceptually tilts about the control point. The hinge pool operation was devised to minimize the amount of flooded land that had to be purchased by the Government in the upper reaches of the pool. The operation of a hinge pool is defined by an operating curve (essentially a rating curve) at the dam. The operating curve is usually derived from experience. Operating curves are a set of functions which relate control point elevation to pool elevation at constant flow. An example of the operation criteria that can be prescribed by input data for a hinge pool is shown on Figure 2.4. Figure 2.4 portrays a hinge pool operation as used by the St. Louis District. In this case, the instruction to the lockmaster is to maintain a target pool elevation.

- **Control Point at the Dam.** This is the simplest regulation procedure for a navigation dam. The navigation pool is maintained at a target elevation at the dam. When the tailwater elevation plus the swellhead through the structure exceeds the target elevation, the pool is no longer controlled by the dam and the dam is in open river condition. The target elevation can change with the seasons. Figure 2.5 reflects a general operation as performed by the St. Paul District. For high flows, tailwater controls (open river condition) and the difference between the pool and tailwater is the loss at the structure (swellhead). For lesser flows, gates are set to maintain a constant pool elevation. For low flows, the pool level is increased to maintain an upstream navigation depth. In this case, the lockmaster is given gate settings. Flexibility must be provided to allow for seasonal variations (ice, wind, etc.) and local requirements.

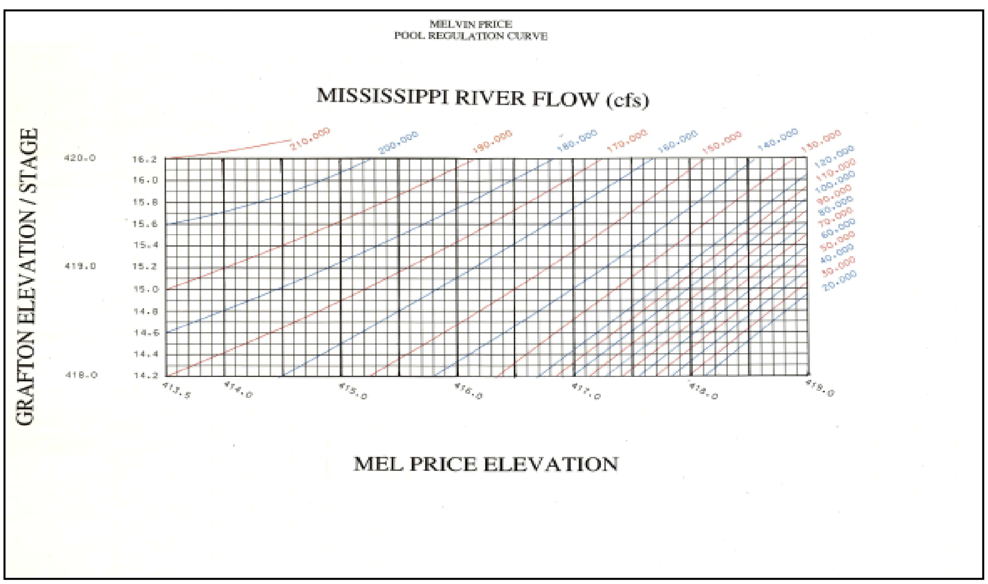

Figure 2.4: Melvin Price Lock and Dam hinge pool operation.

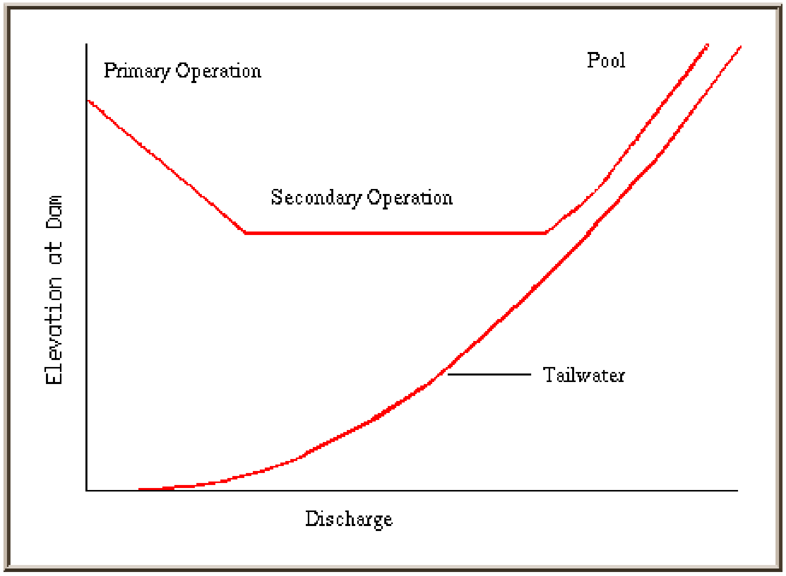

Figure 2.5: St. Paul District lock and dam operation.

2.5.4 UNET Calibration

The primary parameter that is adjusted during UNET calibration is the channel conveyance. Adjustment of channel conveyance is considered to be the equivalent of adjusting Manning's *n* (assuming that gross channel geometric properties do not change through scour, deposition, or avulsion). The general steps used to achieve calibration are:

1. Adjust conveyance to match simulated flows and USGS gaged flows (base calibration).
2. Estimate ungaged inflows/outflows using the UNET null internal boundary condition (Barkau 1995; HEC 2001).
3. Calibrate stages to intermediate gages.
4. Estimate, for locks and dams, the ungaged inflow between gages.
5. Calibrate to secondary gages.
6. Fine tune by adjusting to the individual event using the discharge-conveyance change factors.

Descriptions of the data, methodology, and adjustments for calibration of UNET are described in Appendices B through F.

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2.5.5 Geographic Coverage

The area modeled using UNET is extensive—from Anoka, Minnesota, to Thebes on the Mississippi River; from Gavins Point Dam on the Missouri River to St. Louis (confluence with the Mississippi); and from Lockport Lock and Dam to Grafton on the Illinois River. Portions of numerous smaller tributaries in the basin are also modeled as unsteady flow routing reaches. Figure 2.6 is a schematic representation of the system showing key locations that are referred to later in this report. Note that this is the same area analyzed for flow frequencies.

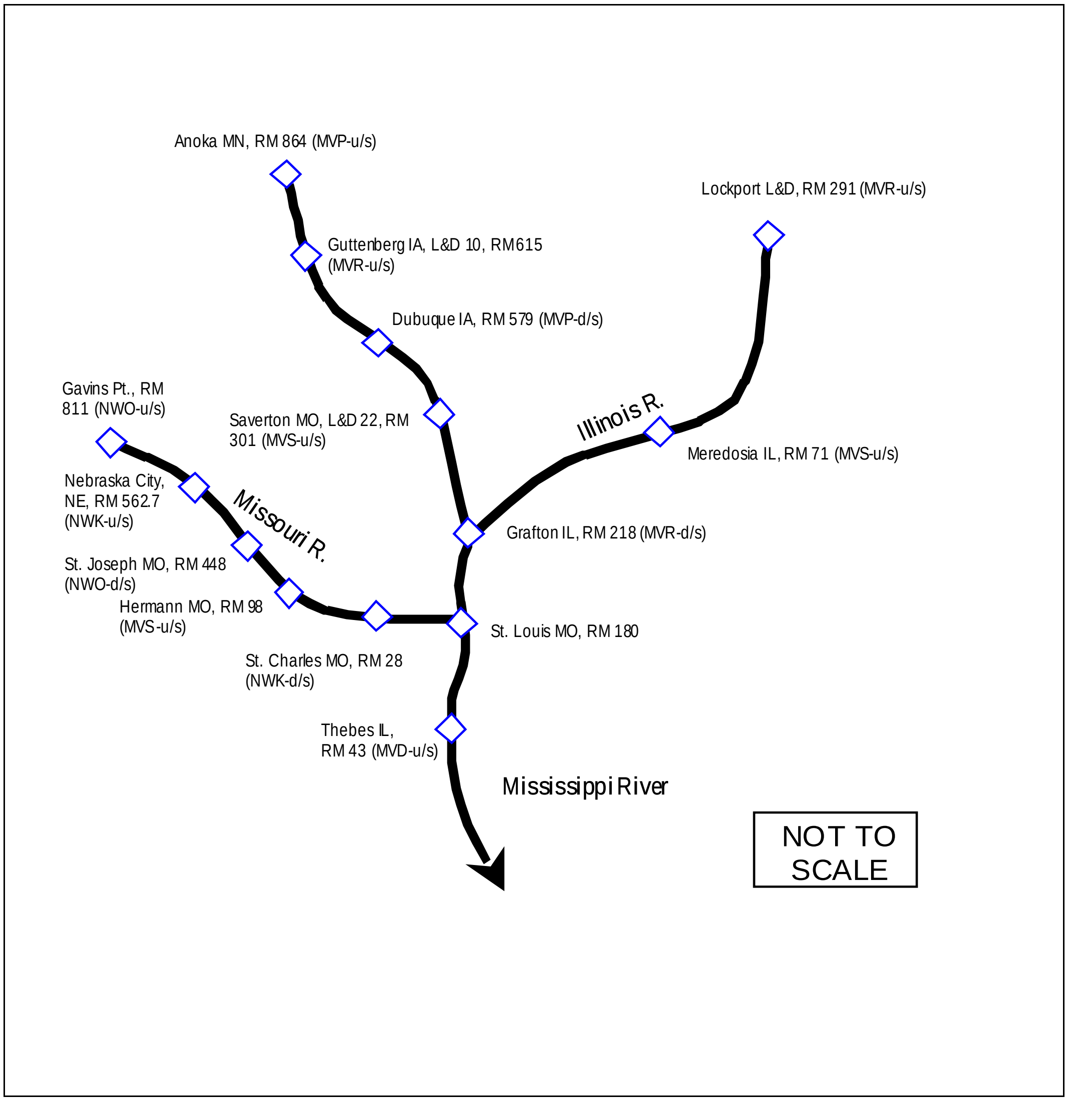

Figure 2.6: Schematic diagram of UNET geographic extent.
u/s = upstream location of UNET boundary condition
d/s = downstream location of UNET boundary condition

2.5.6 Flow vs. Stage Relationships

The continuous period of record analysis is performed with the calibrated UNET model. The analysis uses daily flow data for all inflow hydrographs. The purpose of the POR analysis is to generate 100 years of stage-flow data at all UNET model cross section locations by simulating the observed flow record. Annual maximum flows and stages are produced by UNET.

The POR UNET analysis stores the simulation output data in a HEC-DSS file. Files created with this method contain the annual maximum stage and annual maximum flow values at all locations. The POR analysis determines the annual maximum flow and stage that would occur for the current condition model using 100 years of observed historical flow data. The output from the POR analysis is a set of data files that can be used by further analysis to determine stage-frequency relationships at all locations.

In most cases, the POR does not include flows and stages as large as desired in the flow frequency analysis, e.g., the 0.2% or 500-year recurrence flood. In order to extend that flow vs. stage relationship, ratios of the POR flows were used.

2.5.7 Stage-Frequency from UNET Results

Stage-frequency relationships may be determined at all model cross-section locations using the output from the UNET and the previous flow frequency results. The flow vs. stage relationships from UNET are used to translate the regulated flow frequency curves to regulated stage-frequency curves. The "profile" produced is a line connecting stages corresponding to equal flow exceedance at that location. Tables 2.3 through 2.5 are the result of the flow frequency and stage analyses for major locations along the main rivers. Detailed results for these and other locations are provided in the appendices.

Note that the results of this current study are compared to previous study results. In most cases, an increase in flow corresponds to an increase in stage, and vice versa. In some locations, that logical result does not occur because of possible changes in channel and floodplain geometry or differences in assumptions about flow confluences. In the older analyses, only steady flow computations were made that did not take into account the actual timing of flows on the mainstem and the tributaries. The current UNET unsteady flow analysis simulates the actual timing of mainstem and tributary flows and stages over the period of record, which together with the flow frequency analysis produces the new results.

In river reaches immediately upstream of tributaries, the backwater effect from the confluence causes increased variability in the stage-flow relationship. Stage upstream of a confluence is not simply a function of flow; it is a function of the stage in the other river and the stage immediately downstream. Typically, a family of rating curves is developed to determine the stage in a backwater-influenced area. The stage-frequency software used in this study develops a single stage-flow relationship at each location by best fitting a curve through the combination of ranked stage versus ranked flow data. Since the resulting stage-flow relationship does not represent all the possible stages which could occur for a given frequency flow, discontinuities in the computed stage-frequency profiles may occur across the confluence. The discontinuities are simply smoothed out in the final profiles, using the same distance-weighted average smoothing technique applied everywhere along the river.

The Grafton, Illinois, location on the Mississippi River required a different analysis because of its special backwater situation—it lies immediately below the confluence with the Illinois River and just above the confluence with the Missouri River. Also, large flows on the Missouri cross over the divide and enter the Mississippi upstream of the normal confluence with the Missouri. This situation produces a very irregular stage vs. flow relationship at Grafton. Thus, it was necessary to use a graphical frequency analysis of the UNET-simulated period of record stages at Grafton and then adjust the frequency of the largest flows based on flow-frequency results at nearby locations upstream and downstream of Grafton (see Appendix D).

Table 2.3: Comparison of old and new 1% chance (100-year) water surface elevations and discharges for the Missouri River.

Location	River Mile	OLD 100-year 1% NGVD 1929	NEW 2003 Study 100-year 1% NGVD 1929	Difference* (feet)
Omaha District		**1978 Study****		
Decatur, NE	**691.0**	1047.6	1046.3	**-1.3**
Near Blair, NE	**648.3**	1007.1	1008.6	**1.5**
Omaha, NE	**616.0**	982.8 *190,000 cfs*	982.6 *174,700 cfs*	**-0.2**
Plattsmouth, NE	**591.5**	962.4	966.3	**4.0**
Nebraska City, NE	**562.7**	931.0 *221,000 cfs*	934.3 *236,600 cfs*	**3.3**
Brownville, NE	**535.3**	902.4	904.5	**2.0**
Kansas City District		**1962 Study*****		
Rulo, NE	**498.0**	861.7 *241,000 cfs*	863.3 *252,200 cfs*	**1.6**
St. Joseph, MO *USGS Gage*	**448.2**	815.1 *270,000 cfs*	819.4 *261,000 cfs*	**4.3**
Kansas City, MO *USGS Gage*	**366.1**	748.5 *425,000 cfs*	749.5 *401,000 cfs*	**1.0**
Waverly, MO *USGS Gage*	**293.5**	677.6 *445,000 cfs*	677.5 *424,000 cfs*	**-0.1**
Booneville, MO *USGS Gage*	**196.6**	599.9 *550,000 cfs*	601.9 *573,000 cfs*	**2.0**
Hermann, MO *USGS Gage*	**97.9**	518.4 *620,000 cfs*	518.6 *673,000 cfs*	**0.2**

* Negative value means a decrease in 100-year (1%) flood event water surface elevation.
** U.S. Army Corps of Engineers, 1978. 'Flood Hazard Information, Missouri River, Gavins Point Dam to Rulo, Nebraska,' Volumes I and II, 1978-1979, Omaha District.
*** U.S. Army Corps of Engineers, 1962. 'Missouri River Agricultural Levee Restudy Program – Hydrology Report,' Missouri River Division, Omaha District, Kansas City District.

Table 2.4: Comparison of old and new, 1% chance (100-year) water surface elevations and discharge for the Illinois River.

Location	River Mile	OLD* 1992 100-year 1% NGVD 1929	NEW 2003 100-year 1% NGVD 1929	Difference** (feet)
Rock Island District				
Interstate 55	277.9	**511.7**	**511.5**	**-0.2**
Morris, IL	263.5	**502**	**503.6**	**1.6**
Seneca, IL	252.7	**495**	**496.7**	**1.7**
Marseilles, IL *Marseilles USGS Gage*	246.5	**479.4** *107,000 cfs*	**480.3** *114,000 cfs*	**0.9**
Ottawa, IL	239.7	**472.3**	**473.7**	**1.4**
La Salle, IL	224.8	**463.3**	**465.1**	**1.8**
Spring Valley, IL	218.4	**461.3**	**462.7**	**1.4**
Henry, IL	196.0	**459.7**	**461.4**	**1.7**
Chillicothe, IL	180.3	**459.1**	**460.3**	**1.2**
Peoria (Interstate 74)	162.7	**458.8**	**459.7**	**0.9**
Pekin, IL	152.9	**457.3**	**457.6**	**0.3**
Kingston Mines, IL *Kingston Mines USGS Gage*	145.4	**456** *101,000 cfs*	**455.6** *97,900 cfs*	**-0.4**
Havana, IL	119.6	**453.5**	**453.2**	**-0.3**
Beardstown, IL	87.9	**451.1**	**451.1**	**0**
La Grange, IL	80.2	**450.3**	**449.6**	**-0.7**

Table 2.4 (continued)

Location	River Mile	OLD* 1992 100-year 1% NGVD 1929	NEW 2003 100-year 1% NGVD 1929	Difference** (feet)
St. Louis District				
Meredosia, IL	70.8	**446.8**	**447.9**	**1.1**
Meredosia/Valley City USGS		*133,000 cfs*	*132,000 cfs*	
Valley City, IL	61.3	**445.4**	**445.6**	**0.2**
Florence, IL	56.0	**444.5**	**444.5**	**0**
Pearl, IL	43.2	**442.6**	**442.1**	**-0.5**
Hardin, IL	21.6	**440.7**	**440.2**	**-0.5**
Grafton, IL	0	**440.7**	**439**	**-1.7**

* U.S. Army Corps of Engineers, 1981. 'Illinois River Water Surface Profiles, River Mile 0 to 80,' St. Louis District.
** Negative value means a decrease in 100-year (1%) flood event water surface elevation.

Table 2.5: Comparison of old and new 1% chance (100-year) water surface elevations and discharges for the Mississippi River.

Location	River Mile	OLD* 1979 Study 100-year 1% NGVD 1929	NEW 2003 Study 100-year 1% NGVD 1929	Difference** (feet)
St. Paul District				
Prescott, WI	**811.40**	691.1	691.1	**0.0**
Prescott, WI USGS Gage		*194,800 cfs*	*192,00 cfs*	
Red Wing, MN	**790.97**	684.0	683.9	**-0.1**
Wabasha, MN	**759.92**	678.2	677.4	**-0.8**
Winona, MN	**725.70**	659.9	659.5	**-0.4**
Winona, MN USGS Gage		*240,600 cfs*	*239,000 cfs*	
La Crosse, WI (C.P. 8)	**696.85**	642.6	642.3	**-0.3**
McGregor, IA	**633.60**	629.4	628.7	**-0.7**
McGregor, IA USGS Gage		*249,500 cfs*	*251,000 cfs*	
Guttenberg, IA	**615.20**	622.4	622.4	**0.0**
Rock Island District				
Dubuque, IA	**579.3**	611	**610.5**	**-0.5**
Dubuque, Iowa Corps of Engrs Gage		*281,000 cfs*	*274,000 cfs*	
Dam 13 Pool (near Clinton, IA)	**522.5**	593.8	**592.8**	**-1**
Clinton, Iowa USGS Gage		*295,000 cfs*	*283,000 cfs*	
Camanche, IA	**512**	586.9	**587.8**	**0.9**
Dam 14 Pool (near Le Claire, IA)	**493.3**	576.5	**577.3**	**0.8**
Dam 15 Pool (near Quad Cities)	**482.9**	565.5	**565.8**	**0.3**
Fairport, IA	**463.1**	559.3	**558.9**	**-0.4**
Muscatine, IA	**455.2**	557.3	**556.6**	**-0.7**

Table 2.5 (continued)

Location	River Mile	OLD* 1979 Study 100-year 1% NGVD 1929	NEW 2003 Study 100-year 1% NGVD 1929	Difference** (in feet)
Keithsburg, IL	**428**	544.7	**544.6**	**-0.1**
Burlington, IA	**403.1**	533.7	**534.2**	**0.5**
Dam 19 T/W (near Keokuk, IA)	**364.2**	500.8	**501**	**0.2**
Keokuk, Iowa USGS Gage		*351,000 cfs*	*366,000 cfs*	
Quincy, IL	**327**	486.1	**486.8**	**0.7**
Hannibal, MO	**309**	475.3	**477.1**	**1.8**
Hannibal, Missouri Corps of Engrs Gage		*374,000 cfs*	*440,000 cfs*	
Dam 22 Pool (Saverton, MO)	**301.2**	471.8	**472.8**	**1**
St. Louis District				
Louisiana, MO	**282.9**	462.4	**463.2**	**0.8**
Louisiana, Missouri Corps of Engrs Gage		*410,000 cfs*	*443,000 cfs*	
Confluence with Illinois River				
Grafton, IL	**218.6**	440.7	**439**	**-1.7**
Grafton, Illinois USGS Gage		*510,000 cfs*	*488,000 cfs*	
Confluence with Missouri River				
St. Louis, MO	**179.6**	427	**426**	**-1**
St. Louis, Missouri USGS Gage		*1,020,000 cfs*	*910,000 cfs*	
Chester, IL	**109.9**	389.3	**389**	**-0.3**
Chester, Illinois USGS Gage		*1,120,000 cfs*	*948,000 cfs*	
Thebes, IL	**43.7**	346.7	**345.4**	**-1.3**
Thebes, Illinois USGS Gage		*1,140,000 cfs*	*950,000 cfs*	

* U.S. Army Engineer District, Rock Island, 'Upper Mississippi River Water Surface Profiles, River Mile 0.0 to 847.7,' Upper Mississippi River Basin Commission, in cooperation with St. Paul District, North Central Division, and St. Louis District, November 1979.

** Negative value means a decrease in 100-year (1%) flood event water surface elevation.

CHAPTER 3 – QUALITY CONTROL

The Upper Mississippi River System Flow Frequency Study (UMRSFFS), initiated in 1998, encompassed a study area of five U.S. Army Corps of Engineers districts, two U.S. Army Corps of Engineers divisions, and seven states. An Interagency Task Force Team was assembled to utilize the expertise of federal agencies, state agencies, and independent technical advisors. The Quality Control Plan (QCP) for this study was critical to ensuring that the nation-wide level of expertise was coordinated and efficiently utilized.

The study was essentially divided into two phases—hydrology and hydraulics. Hydrology and hydraulics are two related but unique fields of science, with each field being represented by specialized experts. A Technical Advisory Group (TAG) was assembled for each phase (hydrology and hydraulics) utilizing the available nationally and internationally renowned expertise in both fields of science. The two phases of the study were each subject to five independent levels of review. An outline of the QCP for the UMRSFFS is shown below, followed by a description of each segment of the plan.

3.1 UMRSFFS Quality Control Plan

I. Quality Control Plan Communication

   A. Monthly and Bi-Monthly Conference Calls
   B. Task Force Meetings
   C. Public Information
      1. Public Information Group Meetings
      2. Newsletters
      3. Website

II. Hydrology and Hydraulic Review

   A. Independent Technical Review (ITR)
   B. Quality Control Review Team (QCRT)
   C. Center of Expertise Review (HEC/IWR)
   D. Interagency Group (IAG)
   E. Technical Advisory Group (TAG)

3.2 Quality Control Plan Communication

All Project Delivery Team (PDT) members and reviewers were responsible for reading all written documents related to the project. Regularly scheduled project meetings were held during the project life and were used as a forum to discuss issues related to the product quality. The PDT held monthly and bi-monthly conference calls to communicate the status of work, technical issues, and general concerns. Issues and concerns from the conference calls were elevated to the experts of the TAG for resolution when necessary. During the 5 years of the study, the PDT and the Interagency Task Force Team met four times to discuss methodologies, assumptions, and study progress.

Coinciding with the six Task Force meetings, a Public Involvement Group was assembled of local interest groups, public citizens, levee and drainage district representatives, and landowners associated with the study area. This group participated in the study by developing report requirements to meet the needs of the public, voicing opinions and concerns to the PDT, and verifying data and information gathered by the PDT. The public, as well as the Public Involvement Group, was kept informed between Task Force meetings with six newsletters and a website displaying information about the study.

3.3 Hydrology and Hydraulics Review

Independent Technical Review (ITR)

An ITR Team was composed of team members having expertise and technical background in the fields of hydrology and hydraulics in order to provide a comprehensive district level review. ITR team members were selected from those having the required expertise but were not directly involved with the development of the report. The ITR Team's function was to review the product from a technical aspect and critique the results. Comments from the ITR Team were formally written and distributed to the PDT for response. The PDT then incorporated changes and submitted changes, corrections, and responses to the ITR Team for concurrence. Formal concurrence was then sent to the PDT and recorded after the Independent Technical Reviewers were satisfied with the response by the PDT.

Quality Control Review Team (QCRT)

A QCRT was composed of regional Corps team members having expertise and technical background in the fields of hydrology and hydraulics in order to provide a comprehensive regional level review. QCRT members were selected from those having the required expertise but were not directly involved with the development of the report. The team's function was to review the product from a technical aspect and critique the results. Comments from the QCRT were formally written and distributed to the PDT for response. The PDT then incorporated changes and submitted corrections and responses back to the QCRT for concurrence. Formal concurrence was then sent to the PDT and recorded after the QCRT members were satisfied with the response by the PDT.

Center of Expertise Review (HEC/IWR)

The Center of Expertise Review team's function was to review the product from a technical aspect and critique the results. Comments from the Center of Expertise Review team were formally written and distributed to the PDT for response. The PDT then incorporated changes and submitted changes, corrections, and responses back to the Center of Expertise Review team for concurrence. Formal concurrence was then sent to the PDT and recorded after the Center of Expertise Review team members were satisfied with the response by the PDT.

Interagency Group (IAG)

In order to provide a comprehensive review, the IAG Review Team was composed of seven federal agencies and seven states represented by team members having expertise and technical background in the fields of hydrology and hydraulics. The IAG Review Team's function was to review the product from a technical aspect and critique the results. Comments from the IAG Review Team were formally written and distributed to the PDT for response. The PDT then incorporated changes and submitted corrections and responses back to the IAG Review Team for concurrence. Formal concurrence was then sent to the PDT and recorded after the IAG Review Team members were satisfied with the response by the PDT. The seven states represented on the IAG were: Illinois, Iowa, Kansas, Minnesota, Missouri, Nebraska, and Wisconsin.

The Federal Interagency Technical Experts consisted of:

Ken Bullard, Bureau of Reclamation
Ming Tseng, Earl Eiker, Jerry Webb, Corps of Engineers
Leslie Julian, Geoffrey Bonnin, National Weather Service
William Kirby, U.S. Geological Survey
Frank Tsai, Bill Blanton, Federal Emergency Management Agency
Don Woodward, John Werner, Natural Resources Conservation Service
Gregory Lowe, Tennessee Valley Authority

Technical Advisory Group (TAG)

The TAG participated throughout the study by advising and critiquing methods utilized in the study and critiquing the results. The TAG was consulted numerous times for guidance on unresolved issues. The TAG included some world-renowned experts.

The Hydrology Group consisted of:

Jon Hoskings, IBM Watson Research Center
William Lane, Bureau of Reclamation, retired
Kenneth Potter, University of Wisconsin
Jery Stedinger, Cornell University
Wilbert Thomas, U.S. Geological Service, retired, consultant with Michael Baker, Jr., Inc.
(Several members of this panel have served as members of committees for the National Research Council for the National Academy of Sciences)

The Hydraulics Group consisted of:

Tony Thomas, Corps of Engineers, retired
Danny Fread, President, Mobile Boundary Hydraulics, PLLC

SECTION 4 – PUBLIC INVOLVEMENT

Public involvement is the exchange of information with various segments of the public. The Public Involvement Program for the Upper Mississippi River System Flow Frequency Study provided the interested public the opportunity to become engaged in and informed about the study through various avenues of communication—newsletters, Citizens' Public Involvement Group meetings, study website, and a series of public open houses. In addition, this final report will be made available to the public via the study's website.

Public involvement activities are described in detail in Appendix H, Public Involvement.

CHAPTER 5 – INTERAGENCY COORDINATION

When a regional study of such magnitude is undertaken, it is important to partner with all agencies and stakeholders to develop the plan of action and to seek problem solutions that are acceptable to all. The study area involves five Corps districts in two Corps divisions and seven states. Seven federal agencies have an interest in the results of this study. The technical challenges need to be addressed by scientists with national reputations and the technical study process needs to be explained to the lay public. A Task Force staff and structure was developed to address all of these coordination tasks as follows (only the most recent members are listed):

Task Force Chairman – S. K. Nanda, appointed by the Director of Civil Works, Corps of Engineers; directs all aspects of the study and coordination of the Task Force

Lead Corps District – Rock Island District; all coordination was conducted from this district

Project Manager – Jerry Skalak, appointed by the Rock Island District for project execution

Study Coordinator – Andrew Leichty, budget, schedule, funds allocation, and study progress

Public Involvement Coordinator – Suzanne Simmons, newsletters, home page, Task Force and public meeting arrangements, point-of-contact for general public questions

Technical Coordinator – David Goldman, facilitate all technical problem resolution, recommend technical advisory groups, develop methodologies – formerly Hydrologic Engineering Center, Corps of Engineers

Technical Liaison to Public Involvement Coordinator – Arlen Feldman, explanation of technical processes to Public Involvement Group

Technical Advisory Group – Nationally renowned scientists to recommend methodologies and review results

The Hydrology Group consisted of:

Jon Hoskings, IBM Watson Research Center
William Lane, Bureau of Reclamation, retired
Kenneth Potter, University of Wisconsin
Jery Stedinger, Cornell University
Wilbert Thomas, U.S. Geological Service, retired, consultant with Michael Baker, Jr., Inc.

The Hydraulics Group consisted of:

Tony Thomas, Corps of Engineers, retired
Danny Fread, President, Mobile Boundary Hydraulics, PLLC

Interagency Advisory Group – Task Force Members from seven federal agencies

Corps of Engineers

Jerry Webb, Corps of Engineers, HQ, Washington DC
Greg Ruff, Bob Occhipinti, Mississippi Valley Division
Pat Foley, Gregory Eggers, Stuart Dobberpuhl, St. Paul District
Marv Martens, Shirley Johnson, John Burant, Rock Island District
Dennis Stephens, Ron Dieckman, Rich Astrack, St. Louis District
Al Swoboda, Northwest Division
Dan Pridal, Roger Kay, Omaha District
Rebecca Allison, Gordon Lance, Allen Tool, Kansas City District
Rolf Olsen, Eugene Stakhiv, Institute of Water Resources (IWR)
Michael Gee, Hydrologic Engineering Center (HEC)

Ken Bullard, Bureau of Reclamation
Geoffrey Bonnin, National Weather Service
William Kirby, U.S. Geological Survey
Bill Blanton, Federal Emergency Management Agency, HQ, Washington DC
Ken Hinterlong, Federal Emergency Management Agency, Region V
Rich Leonard, Federal Emergency Management Agency, Region VII
John Werner, Natural Resources Conservation Service
Gregory Lowe, Tennessee Valley Authority

State Advisory Group – Task Force Members from seven states

Ogbazghi Sium, Minnesota DNR
Bob Watson, Daniel Baumann, Wisconsin DNR
Jack Riessen, Bill Cappuccio, Iowa DNR
Don Vonnahme, Marty Stralow, Illinois DNR, Vernon Knapp, Illinois State Water Survey
Charlie DuCharme Missouri DNR, George Riedel, Buck Katt, Missouri SEMA
Julie Grauer, David Pope, Kansas Dept. of Agriculture, Matt A. Scherer, Kansas Water Office
Brian Dunnigan, Nebraska DNR

Public Involvement Group – General public with interest in the study.

Task Force Members were briefed once or twice a year regarding the methodology, assumptions, and the study progress. The Public Involvement Group also met concurrently and provided input to the Task Force. Quality control was accomplished by the Independent Technical Review process at the district level, the Quality Control Process Team for the overall study, HEC level review for inter-district transition, and by oversight of the Interagency Advisory group and State Advisory group members. Public workshops were held at eight different locations to explain the study results. Periodic conference calls and meetings took place among the five districts on technical problem resolutions and study accomplishments.

GLOSSARY

acre-foot	A measure of volume equal to an acre of land uniformly flooded to 1 foot in depth.
channel slope	The change in elevation of the channel bottom divided by the distance between the measured elevations.
coefficient of variation	The standard deviation divided by the mean.
cubic feet per second (cfs)	Unit of flow.
discharge	The volume of water passing a location in the river per unit time (e.g., cubic feet per second).
drainage area	The surface area of the watershed contributing runoff to a particular location on the river system.
exceedance frequency	The exceedance probability multiplied by 100, sometimes interpreted as the number of exceedances per 100 years on the average (e.g., the 1% exceedance frequency flood is the 0.01 exceedance probability multiplied by 100).
exceedance probability	The probability that the annual flood will exceed a specified value in a year (e.g., the 0.01 exceedance probability flood has a 1/100 chance of being equal or exceeded in any year).
flood distribution	A function or graphical curve expressing the relationship between exceedance probability and annual maximum flow (e.g., the log-Pearson III distribution is typically used by federal agencies to represent the peak annual flood distribution).
flood frequency curve	See flood distribution.
flood population	The hypothetical collection of all possible annual floods at a site. The observed flood record is assumed to constitute a random sample from the population. The true population can never be known, but its properties (or characteristics) are estimated from the sample.
hydrograph	The variation of river discharge with time at a particular cross section, usually for some period corresponding to a flood event.
flood rank	The position in an ordered list from largest to smallest of the observed annual maximum floods (e.g., the largest flood has rank equal to one, the smallest has rank equal to the number of observed floods).

operating rule	The procedures to be followed and/or actions to be taken by dam operators given both reservoir inflows and downstream flow conditions.
plotting position	An estimate obtained of flood exceedance probability from the observed record of annual maximum flow values independent of an assumed distribution. Various plotting position formulas exist for estimating plotting positions (e.g., Weibull annual maximum flood plotting position = flood rank/(number of observations + one)).
probability	A number in the range 0 to 1 representing the likelihood of occurrence of a specified event. For example, the probability of heads on the flip of a fair coin is 0.5.
quantile	The probability distribution quantity corresponding to a particular exceedance probability (e.g., the 0.01 exceedance probability flood is 100000 cfs, where 100000 is the quantile).
rating curve	The relationship between discharge and river stage.
regulated flows	River flows affected by the presence of reservoirs and operation of dam outlets (a significant portion of the study area observed period of record was influenced by reservoir regulation).
regulated flood frequency curve	See "regulated flood distribution."
regulated flood distribution	A flood distribution expressing the relationship between exceedance probability and regulated flows. Generally very non-linear and not describable by an analytic flood distribution, such as the log-Pearson III distribution.
regulated vs. unregulated relationship	A relationship between the discharge that would occur without the influence of reservoirs to that occurring with present day reservoir operations.
river basin	See "watershed."
river cross section	The area of river defined by the channel bottom, and possible levees, at right angles to the flow.
river main channel	The portion of river cross section carrying flow under normal circumstances (see "river overbank").
river overbank	The portion of the river cross section conveying additional flow to the main channel during flood periods.
sample estimate	A quantity derived from the observed data used to approximate the unknown population value (e.g., sample mean, sample standard deviation, sample skew coefficient, sample flood distribution).

sample mean An estimate of the central tendency of the data. The average (the sum of the observed values/number of observations).

sample skew coefficient A measure of the asymmetry of the distribution, for the same mean and standard deviation, a positive value results in a greater 1% exceedance frequency flood than a negative value. The average of the cube deviations from the mean divided by the standard deviation cubed.

sample standard deviation Both a measure of the range of the observed data and the width of the flood distribution the square root of the average of the sum of squared deviations from the mean of the observations.

unregulated flows River flows unaffected by the influence of reservoir regulation (a major effort was undertaken by the Corps districts to adjust the observed records for the influence of reservoir regulation).

unsteady flow The variation of stream flow with time, a condition always present within a river (note that although flow within a river is always unsteady, the change is gradual enough to be considered approximately steady for analysis purposes).

volume duration frequency curves Curves a set of flood distribution for various annual maximum defined for different durations at a particular location (e.g., flood distributions estimated from the observed 1-day, 3-day, 7-day, 10-day and 30-day maximum flood volumes obtained from the period of record).

watershed A closed boundary describing the land surface area contributing runoff to a particular location on a river.

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