

The Illinois River Decision Support System (ILRDSS)

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Contents

	<i>Page</i>
Abstract.....	1
Introduction.....	3
Physical Setting.....	3
Illinois River Issues.....	3
Soil Erosion and Sedimentation in the Illinois River Watershed	6
Water-Level Fluctuations.....	7
Navigation.....	10
The Integrated Management Plan (IMP) for the Illinois River Watershed	13
Rationale – The Need for a Decision Support System	15
The Illinois River Decision Support System	17
Background Information.....	17
Structure and Components of Decision Support Systems	17
Decision Support System Applications in Water Resources	18
Development of the Illinois River Decision Support System.....	19
Identification of Users and Issues	19
Identification of Decision Support System Structure and Database Framework	20
Identification of Necessary or Desired Analytical Tools and Models.....	20
Identification of Necessary or Desired Data Acquisition and Processing	21
Identification of Graphic User Interfaces and Visualization Tools	21
General Structure	22
Application Protocol.....	22
Initial Developments and Applications.....	25
Hydrology	25
Hydraulics.....	25
Future Developments and Applications.....	26
Collaboration with Other Scientists and Agencies	26
Collaboration within the Water Survey	28
Collaboration with Scientific Surveys and University of Illinois Scientists.....	28
Collaboration with State and Federal Agencies.....	28
Resource Needs.....	28
Acknowledgments.....	29
References.....	31
Appendix: Review of Precipitation-Runoff Models for the Illinois River Decision Support System	35

List of Figures

	<i>Page</i>
Figure 1. Location of the Illinois River watershed	4
Figure 2. Sediment budget of the Illinois River.....	5
Figure 3. Volume of water in Peoria Lake at normal pool	6
Figure 4. Shrinkage of area in Peoria Lake with water depth greater than 5 feet between 1903 and 1985	8
Figure 5. Average annual stage hydrographs for the Illinois River at Havana for different periods.....	9
Figure 6. Profile of the Illinois Waterway	10
Figure 7. Processes and transitions involved in Decision Support System development.....	19
Figure 8. Schematic for the Illinois River Decision Support System.....	23
Figure 9. Observed and simulated water-level fluctuations in the LaGrange Pool during the summer of 1997.....	27

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Abstract

The Illinois River has become the focus of state and federal agencies interested in integrated management of watersheds. Issues related to habitat restoration, floodplain management, navigation, erosion and sedimentation, water quality, and point and nonpoint source pollution are all being discussed at the watershed level. One major result of these discussions is the Integrated Management Plan (IMP) for the Illinois River Watershed (Kustra, 1997). The plan includes 34 recommendations that are in the process of being implemented by different agencies at different paces and levels of intensity.

The Illinois State Water Survey has played a major role in the development of the IMP and is actively participating in implementation of the plan. The implementation phase of the IMP involves questions and answers on a watershed-wide basis and is not limited to local or regional issues. Currently, there is no integrated tool to evaluate and predict hydrological and water quality responses to changes in the physical environment of the Illinois River basin. To fill this gap, the Water Survey has initiated the development of the Illinois River Decision Support System (ILRDSS) for use in assessing and evaluating the effectiveness of different projects undertaken under the IMP as well as the consequences of other natural or human-induced changes in the watershed.

The ILRDSS will integrate and expand existing databases and models for segments of the Illinois River and portions of the watershed into an integrated decision support system (DSS) for the entire watershed. New databases and models also will be created for the entire watershed and to address important water quantity and quality issues. Links and interfaces will be developed that interconnect various databases and model components. Once developed and tested, the ILRDSS will enable decision-makers to answer “what-if” questions during the implementation phase of the IMP or other programs within Illinois River system. The scenarios that can be evaluated using the ILRDSS may include climate shifts and fluctuations, land-use changes, and changes in regulations and water management practices. Using various combinations of these variables as input, the ILRDSS will generate output on potential hydrological and water quality responses of the Illinois River system for different temporal and spatial scales.

Introduction

The Illinois River is the single most important river in the State of Illinois. Approximately 95 percent of the urban areas and half of the agricultural lands in the state are located within the Illinois River basin. The Illinois Waterway, which consists of the Illinois River, Des Plaines River, and the Chicago Sanitary & Ship Canal System, is the only inland waterway that links the Great Lakes to the Mississippi River and thus the Gulf of Mexico. The Illinois Waterway is therefore an important commercial waterway.

Because of its strategic location in the state and because it is downstream of the Chicago metropolitan area, the Illinois River has experienced significant human influences over the years. The most significant influences have been related to commercial navigation, municipal and industrial waste discharges, and agricultural practices in the watershed. Because of the lack of a basin-wide comprehensive management plan, many environmental and ecological problems in the Illinois River basin have not been addressed adequately over the years. The most serious and difficult problem facing the Illinois River is sedimentation in the river channel and backwater lakes. Many backwater lakes have lost more than 72 percent of their capacities to sediment accumulation and have a limited life expectancy unless appropriate rehabilitation and management techniques are implemented in the near future. Problems in the Illinois River basin are not, however, limited only to sedimentation. Issues such as water quality, nonpoint source pollution, flooding, degradation of aquatic habitats, and water-based recreation need to be addressed. It is therefore important that an Integrated Management Plan (IMP) developed for the Illinois River basin treats the river, its valley, and watershed as an integrated system and also deals with all the basin's ecological, environmental, and economic problems.

Physical Setting

The Illinois River, one of the major tributaries to the Mississippi River in the central United States, has a drainage area of 28,906 square miles or mi^2 (75,156 square kilometers or km^2) that covers portions of Illinois, Indiana, and Wisconsin (Figure 1). Except for about a 4,000 mi^2 (10,360 km^2) area in Indiana and Wisconsin, the Illinois River watershed is located in Illinois. As a result of repeated leveling by glaciers, most of the Illinois River watershed is flat and covered with fine loess soil, making it one of the best agricultural regions in North America. More than 80 percent of the Illinois River basin is presently used for agricultural purposes. Most of the significant rivers in the state such as the Des Plaines, Fox, Kankakee, DuPage, Vermilion, Mackinaw, Spoon, Sangamon, and LaMoine Rivers all drain into the Illinois River.

Illinois River Issues

Important issues that are relevant to the Illinois River range from climate, hydrology, hydraulics, water quality, and sediment quality to ecology, economics, and social issues. There is a need for developing and discussing all of these issues. At the present state of development for the ILRDSS, we have only included those issues highlighted in the Integrated Management Plan (IMP); namely, sedimentation, water-level fluctuation, and navigation. As we continue to

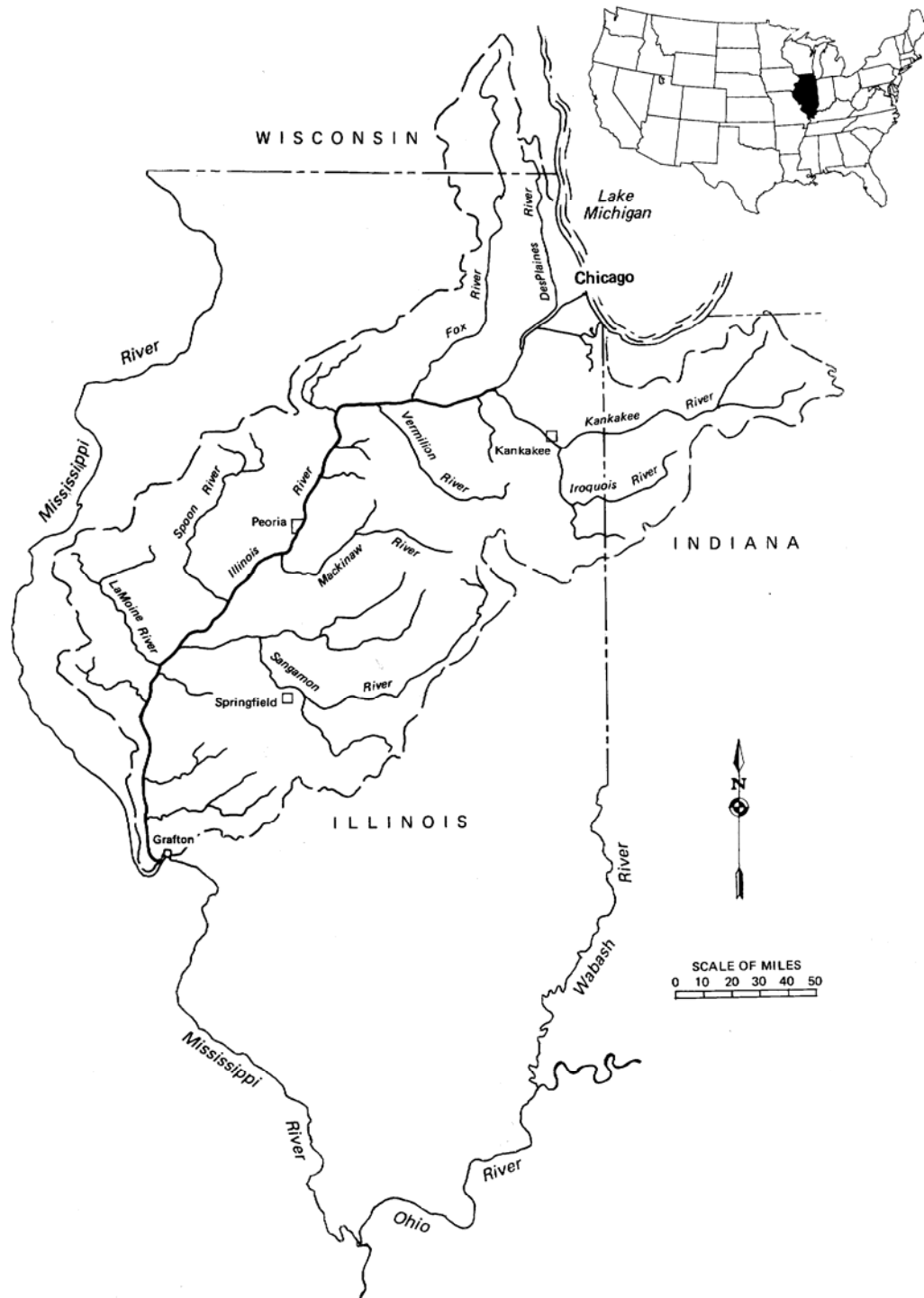


Figure 1. Location of the Illinois River watershed

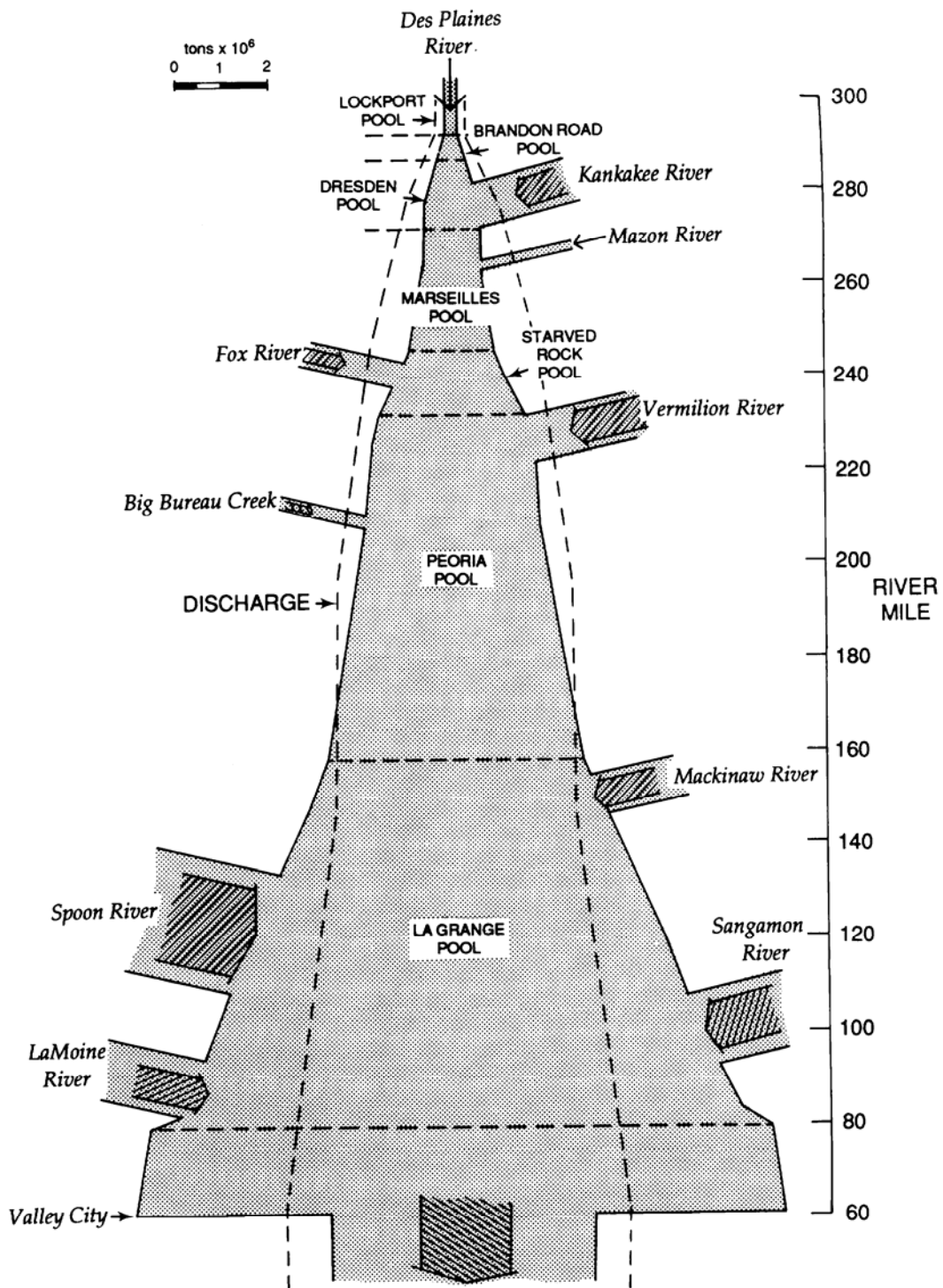


Figure 2. Sediment budget of the Illinois River

develop the ILRDSS, expanded discussions on other issues such as water quality, ground water, and influence of climate, habitats, and ecology will be developed and included in the report.

Soil Erosion and Sedimentation in the Illinois River Watershed

Erosion and sedimentation have long been recognized as the principal causes for most of the environmental and ecological problems in the Illinois River valley. Sediment delivery calculations based on suspended sediment data collection in recent years show that tributary streams on the average deliver 13.8 million tons of sediment into the Illinois River valley, of which 5.6 million tons is discharged to the Mississippi River and 8.2 million tons is trapped in the Illinois River valley (Demissie et al., 1992). Figure 2 shows the relative sediment contribution of the major tributary streams. This conservative estimate does not include contributions from bank and bluff erosion along the Illinois River that were not calculated as part of tributary stream loads. This recent rate of sediment delivery is estimated to be greater than the rate in the late 19th and early 20th centuries. Because of the absence of long-term erosion and sediment load data, the only way to estimate the long-term trend of erosion and sediment delivery is based on sedimentation rates in the bottomland lakes in the valley. For example, Figure 3 shows the long-term reduction in lake volume due to sediment accumulation for 1903-1985 in Peoria Lake, the largest bottomland lake in the Illinois River valley. This figure illustrates that the rate of sedimentation, as measured in volume loss, in more recent years starting around the 1960s is greater than during the early 1900s. However, it is still difficult to determine when the rate of sedimentation started to increase because of the lack of lake sedimentation data between 1903 and 1965.

Sedimentation has long been identified as a major problem for bottomland lakes in the Illinois River valley since most of them have been filling up with sediment (Lee and Stall, 1976, 1977; Bellrose et al., 1983; Illinois Division of Water Resources, 1987; Demissie et al., 1992).

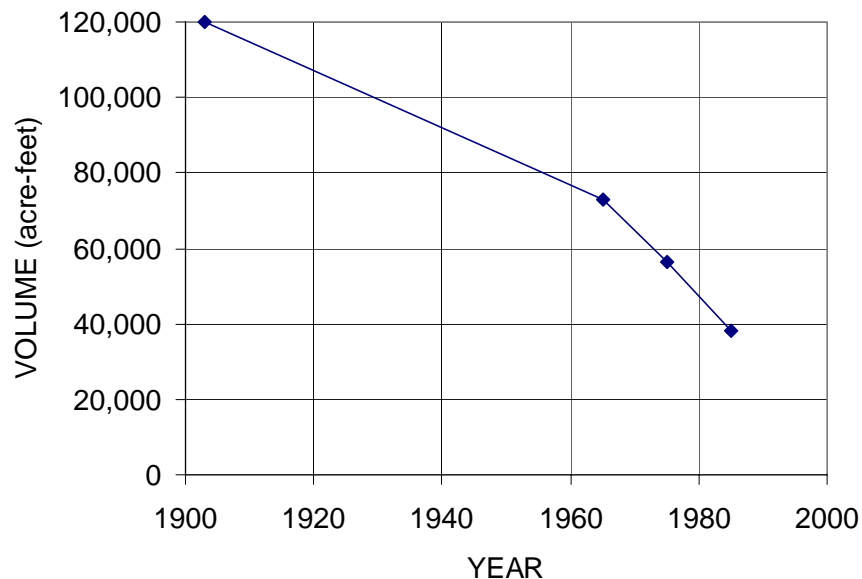


Figure 3. Volume of water in Peoria Lake at normal pool

Bottomland lakes along the Illinois River are important ecological, recreational, and economical resources of the State of Illinois. Because of a combination of natural geologic conditions and human-made hydraulic controls, there are numerous bottomland lakes along the Illinois River valley. Under normal flow conditions, most of the lakes are connected to the main river by narrow outlet channels (Demissie and Bhowmik, 1986; Division of Waterways, 1969).

Demissie et al. (1992) estimated that on the average the bottomland lakes in the Illinois River valley had lost 72 percent of their water storage capacity to sedimentation by 1990. Some lakes have completely filled with sediment. In addition to the loss of capacity, there is concern about the quality of sediment in the lakes. As the lakes become shallower, waves generated by wind and river traffic continuously resuspend the bottom sediment. If contaminants are stored in the sediment, they may be resuspended along with the sediment and become available to aquatic biota in the water column.

The impact of sedimentation on the bottomland lakes is clearly illustrated by what has happened to Peoria Lake, the largest, deepest lake in the Illinois River valley. The overall impact of the sedimentation pattern in Peoria Lake is the shrinking of the deeper parts of the lake as illustrated in Figure 4, which compares that portion of the lake deeper than 5 feet during 1903 and 1985. Much of the lake would have been deeper than 5 feet in 1903 under present-day normal pool conditions, while much of the lake was shallower than 5 feet in 1985, with a narrow navigation channel in the middle of the lake. As sedimentation continues and the shallow flat areas start supporting vegetation, much of the lake will be transformed into seasonally flooded wetland area. Development of the ILRDSS will provide the capability to evaluate erosion and sedimentation in a more systemic manner and provide better tools to assess potentials and impacts of restoration along the Illinois River valley.

Water-Level Fluctuations

Water-level fluctuation is one of the important hydrologic factors in an aquatic environment that controls biological productivity and diversity. Water-level fluctuations in a natural aquatic environment are controlled by the hydrologic cycle of the region and the storage and carrying capacity of stream channels, floodplains, and wetlands within the watershed. The resulting ecosystem evolves from the adaptation of different species to different hydrologic conditions that include high water levels during floods and low water levels during droughts. In regulated aquatic environments, in addition to naturally occurring floods and droughts, human-induced factors such as dams, levees, and water diversions have a significant impact on water-level fluctuations. The Illinois River is such a system where both natural and human-induced factors have played major roles in the history of water-level fluctuations along the river. Under present conditions, low water levels in the Illinois River are regulated by a series of locks and dams along the river for navigation purposes. During flood events, the locks and dams in the lower part of the river do not control water levels. However, levees that constrict the floodplain affect water levels during floods.

The significant changes in water levels include step jumps in low water levels due to diversion of water from Lake Michigan into the Illinois River, maintenance of navigation pool elevations after the construction of locks and dams at different times, and water-level

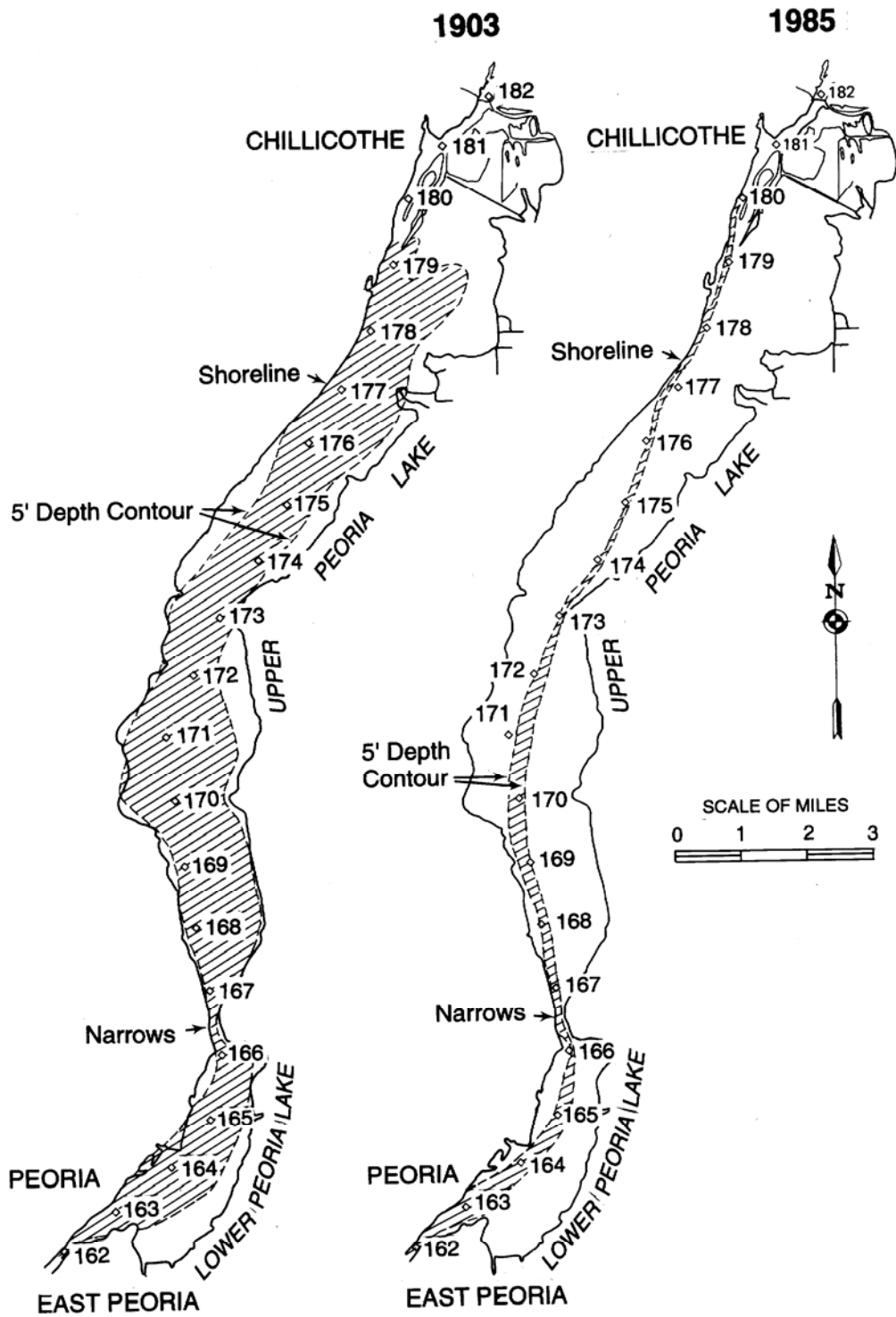


Figure 4. Shrinkage of area in Peoria Lake with water depth greater than 5 feet between 1903 and 1985

fluctuations associated with the operation of the locks and dams. For example, Figure 5 shows the changes in average daily water elevations for different periods in the Illinois River at Havana. In a historical perspective, construction of the old LaGrange Dam in 1888 raised water elevations from 3 to 4 feet at Havana. Water levels were further raised by about 1 foot due to Lake Michigan water diversion starting in 1900. When the diversion was reduced in 1939, water levels were lowered by more than a foot. In addition to these shifts in average water levels, short duration water-level fluctuations have significantly increased after construction of the new LaGrange Lock & Dam in 1939. Changes in water elevations at different locations along the Illinois River are different depending on their location with respect to lock and dams. To synthesize and evaluate the changes along the whole stretch of the Illinois River, a hydraulic model that is calibrated using historical data needs to be developed and applied. Once the model is developed, it will be possible to evaluate the impact of changes in the past and potential future water-level management alternatives on water-level fluctuations at any point along the Illinois River. This addresses one of the major recommendations of the IMP dealing with the causes of natural and unnatural water-level fluctuations in the Illinois River (Kustra, 1997).

Understanding the historical changes in water levels and the factors that brought about the changes is a fundamental requirement in the development of a restoration plan for the Illinois River. The proposed hydrologic and hydraulic modeling components of the ILRDSS will provide the capability to analyze historical changes and simulate the impacts of alternative scenarios for the management of the Illinois River watershed by decision-makers in the state.

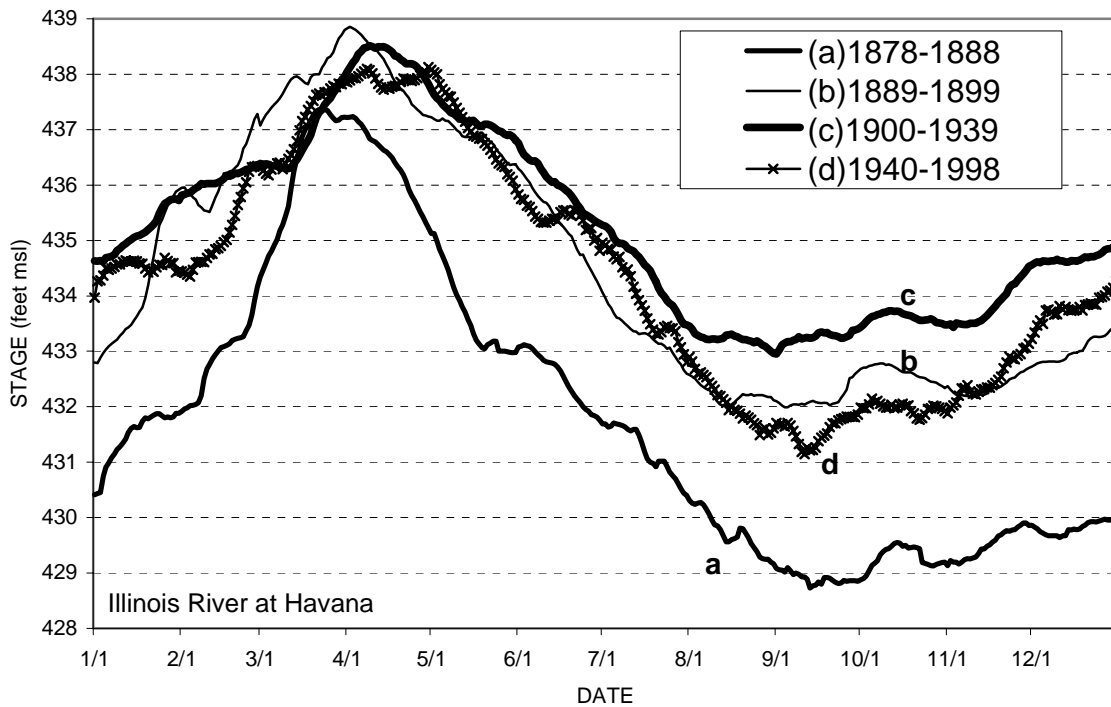


Figure 5. Average annual stage hydrographs for the Illinois River at Havana for different periods

Navigation

Navigation and waterborne commerce in Illinois have a long history and have played a significant role in the agricultural and industrial development of the state. Most of the major cities of the state are located along these navigable waterways. The greater Chicago metropolitan area, with a population of more than 5 million, and the cities of Joliet, Ottawa, LaSalle-Peru, Peoria, Havana, Beardstown, and Grafton are all located along the Illinois Waterway. Illinois ranks third among the 50 states, behind Alaska and Louisiana, in domestic waterborne commerce.

The Illinois Waterway, a major component of the Upper Mississippi River System, serves the State of Illinois exclusively and carries more waterborne cargo than the Mississippi River upstream of its junction with the Illinois River. The Illinois Waterway consists of the Illinois River from Grafton to Channahon, the Des Plaines River, the Chicago Sanitary & Ship Canal, the Cal-Sag Channel, and the Calumet River. Eight locks and dams on the Illinois Waterway provide the necessary water depth and lift to make navigation possible from Lake Michigan to the Mississippi River, as shown in Figure 6. Most of the locks and dams are located in northeastern Illinois where the natural gradient of the streams is steeper than that of the lower Illinois River.

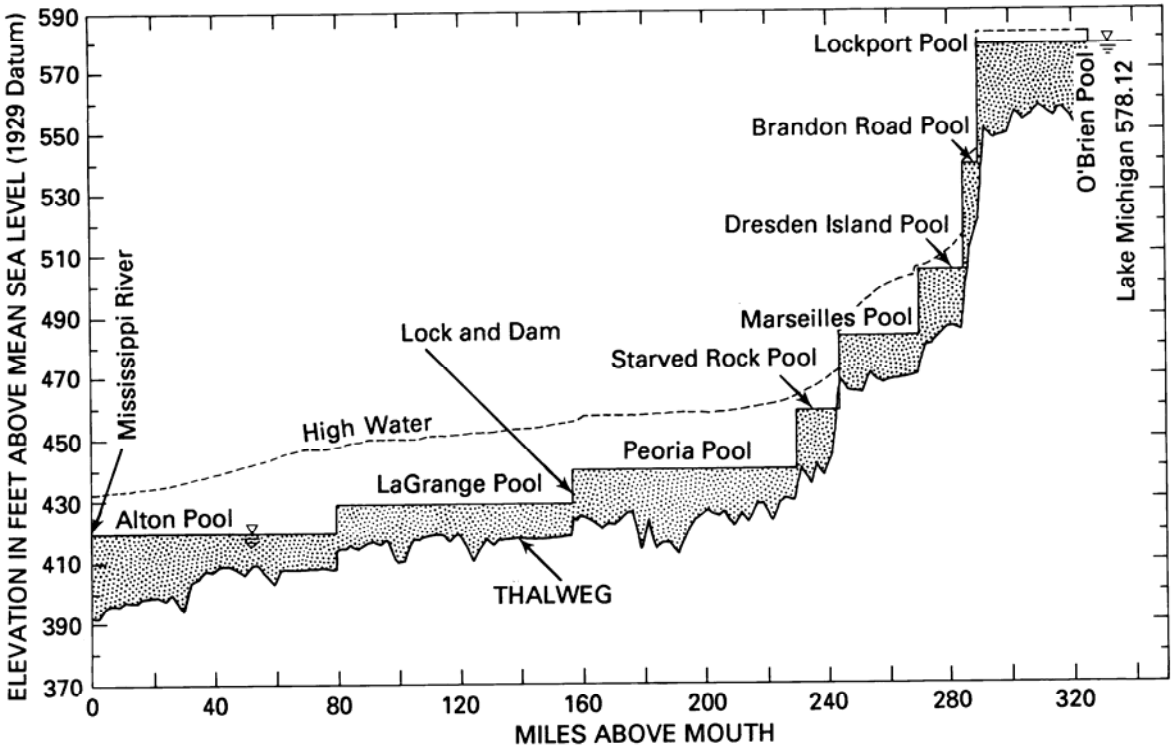


Figure 6. Profile of the Illinois Waterway

Any management plan for the Illinois River has to acknowledge the importance of navigation to the state and incorporate the needs of the navigation industry in the plan. The U.S. Army Corps of Engineers is in the process of completing their Upper Mississippi River and Illinois Waterway System Navigation Study to evaluate the feasibility of navigation improvements to the waterways. Some of the options being considered include replacing the old locks and dams with new and larger ones. Implementation of these types of changes could have a significant impact on the hydraulics of the river and its ecosystem. A fully developed ILRDSS should provide detailed hydrologic, hydraulic, and ecological information as a basis for decision-making.

The Integrated Management Plan (IMP) for the Illinois River Watershed

After extensive discussions of the problems facing the Illinois River, the State of Illinois has produced an Integrated Management Plan (IMP) for the Illinois River Watershed as a long-term plan to improve the Illinois River and its watershed (Kustra, 1997). The management plan was prepared by the Illinois River Planning Committee under guidance of the Illinois River Strategy Team created by Lt. Governor Bob Kustra in 1994. The Management Plan consists of 34 recommendations that were selected from a list of 93 recommendations prepared by six Action Teams.

Of the 34 recommendations, the following 12 deal with hydrologic, hydraulic, and sediment issues (Kustra, 1997):

- 1) Encourage beneficial use of sediments through three options for use of dredge materials.
- 2) Implement backwater lake and side-channel sediment management measures at selected locations.
- 3) Assess the feasibility of implementing a temporary drawdown in conjunction with scheduled maintenance of the navigation system to dry out and compact deposited sediments.
- 5) Complete the ongoing work to determine the extent of shoreline erosion on the Illinois River due to boat-generated waves and pursue recommended controls or remedies accordingly.
- 7) Identify the causes of unnatural and natural water-level fluctuations, disseminate results, and implement solutions as appropriate.
- 8) Establish water-level management programs throughout the watershed for sediment management, waterbanking, and flood crest reduction.
- 9) Provide incentives for selective dechannelization of tributaries on a voluntary basis.
- 10) Stabilize unstable streams in rural and urban areas, particularly streams where the rate or magnitude of erosion yields abrupt or progressive changes in location, gradient, or pattern because of natural or human-induced changes.
- 11) Implement all actions called for in the *Great Lakes Memorandum of Understanding*.
- 12) Improve monitoring of water and sediment of Illinois streams.
- 13) Build wetlands and other water retention capacity in urban and rural areas in the Illinois basin, in collaboration with appropriate public landowners and volunteering private landowners.
- 32) Reduce runoff rates throughout the watershed during the next 15 years through remedial and preventive efforts.

Rationale – The Need for a Decision Support System

The rationale for developing the Illinois River Decision Support System (ILRDSS) is based on the type of questions that are being asked as we move into the implementation phase of the Integrated Management Plan (IMP) for the Illinois River watershed. Most of the questions require a system-wide analysis of the hydrology of the Illinois River watershed and the hydraulics of the Illinois River. For example, one of the recommendations in the IMP is to identify the causes of unnatural and natural water-level fluctuations in the Illinois River and to implement appropriate solutions to solve the problem. This type of recommendation requires a thorough understanding of the Illinois River hydrology and application of the appropriate hydrologic and hydraulic models to assist in identifying causes and evaluating alternative solutions. Without a basin-wide analysis, conclusions and recommendations will be limited to selected sites and a broad application of the results will be impractical. Other recommendations, such as establishment of water-level management programs throughout the watershed for sediment management, waterbanking, flood crest reduction, building wetlands and other retention capacity in urban and rural areas, and reducing runoff rates throughout the watershed, require the same type of detailed analysis for the entire river basin.

The issues that need to be examined on a watershed basis for the Illinois River are not limited to hydrology and hydraulics but also include a whole gamut of issues related to water quality, sediment transport, ground-water/surface water interaction, impact of climate change or fluctuation, ecosystem restoration, and economic and societal impacts. There is a need for the development of an integrated decision support system (DSS) that can help decision-makers in addressing these issues on a watershed basis. The ILRDSS will attempt to fulfill this need.

The Illinois River Decision Support System

Background Information

Although there is considerable literature concerning decision support systems (DSSs), there is no clear, standard definition of what they are. Watkins and McKinney (1995) provide a useful definition for most applications in the field of water resources: “A DSS is an integrated, interactive computer system, consisting of analytical tools and information management capabilities, designed to aid decision makers in solving relatively large, unstructured problems.” However, to encompass all types of applications, Loucks (1995) suggests that a broader definition is necessary, defining a DSS as simply an “interactive computer-based information provider.” Thus, there is more than one type of DSS. The common objective of all DSSs, as described by Loucks, is to “provide timely information that supports human decision makers – at whatever level of decision making.”

Structure and Components of Decision Support Systems

Simonovic (1996a) describes three basic structural or architectural DSS types: 1) the functional approach, 2) the tool-based approach, and 3) the intelligent decision support approach, which is an integration of the first two types. The functional approach is usually based on an expert or knowledge-based system, and explicitly does not incorporate either modeling or data retrieval. These systems are often developed to address a specific problem, usually in a non-quantitative manner. The tool-based approach normally contains database and modeling components, as discussed below. The intelligent decision support approach includes both modeling and knowledge-based decision-making, and is presented by Simonovic (1996a) as a more complete, mature method for decision support. Relatively few DSS applications have used a complete, intelligent decision support approach. However, it is important to note that most DSS applications described in the literature are dynamic, growing systems, in which new capabilities, problems, and analytical tools are continually being added to the existing structure.

Most applications in water resources have been tool-based. A tool-based DSS can be model-centered or database-centered. The model-centered DSS normally takes a specific analytical model and develops supportive software to present model results for use by modelers and decision-makers. The supportive software typically includes interactive capabilities, database retrieval, Geographic Information Systems (GIS), and/or visualization tools. The database-centered DSS develops comprehensive data sets in a common framework that can be used to support a variety of analytical processes and models.

A DSS can contain many different components and capabilities, depending on the structure and comprehensiveness. Some relatively common components and capabilities listed by Loucks (1995) and Simonovic (1996a) are:

- Analytical models or algorithms (simulation and/or optimization)
- Database module(s) and data retrieval processes
- Graphics and visualization tools
- Spatial analysis – GIS

- Prediction and evaluation of consequences based on hypothetical (what-if) scenarios
- Expert systems, or other decision-process techniques
- Use of artificial intelligence
- User-friendly computer interactions or interfaces
- Flexibility to respond relatively quickly to posed questions
- Identification and formulation of problems
- Dialogue generation

Decision Support System Applications in Water Resources

As stated earlier, most DSS applications in water resources have been tool-based. Included in the category of model-centered DSSs are a number of deterministic hydrologic models for which database, graphics, and visualization tools are being developed to make the model output more useful to decision-makers. Database-centered systems often have modeling components but normally provide a broader base for multi-disciplinary analyses. Some examples of water resources DSSs are given as follows. Most of these applications are directed towards some aspect of watershed management.

Knowledge-based approach:

- Evaluation of drainage practices (Bingner et al., 1998)
- Water, nutrient, and pesticide management of farms (Ascough et al., 1998)
- Providing advice to watershed managers about land management and land treatment decisions (NSCU-WQG, 1999)
- Stage-discharge rating curve development (DeGagne et al., 1996)

Model-centered approach:

- Reservoir management and operation (Huang and Yang, 1998; Simonovic, 1996b)
- River forecasting (Matthews et al., 1998)
- Surface water quality modeling, nonpoint sources (Rodda et al., 1999)

Database-centered approach:

- Watershed and reservoir management (Lins and Frevert, 1998)
- Water use and allocation planning (Malers et al., 1998; Larson et al., 1998)

Intelligent decision support approach:

- Collaborative planning of water resource projects (Simonovic, 1996b)

sufficient hydrologic/hydraulic information. It is expected that the full evolution of potential DSS issues, and design of additional DSS modules and capabilities, will not be fully realized until the hydrologic/hydraulic capabilities of the DSS have been developed and results displayed to potential additional users of the system, with the intent of recruiting additional partners. It is expected that the eventual uses of the system will include climatic, water quality, environmental/biological, economic, and many other aspects of watershed management. Certain issues, such as the impacts of climate variability on water resources and some water quality issues, potentially could be formulated as the framework of the DSS is under development. In its first years, we expect that DSS users will be scientists and professionals within agencies, including those who will be formulating DSS components. As the ILRDSS evolves and grows in future years, and knowledge-based components are added to aid in decision-making processes, system users will increase to include a broader range of decision-makers.

Identification of Decision Support System Structure and Database Framework

The development of the ILRDSS will be an iterative and ever-improving process. The ultimate goal is that the ILRDSS will develop into an intelligent DSS, including knowledge-based management algorithms along with database and modeling components. In its initial stages, however, we see the ILRDSS as adopting a database-centered approach. It is essential that this database framework be designed to potentially support the use of a variety of modeling applications and other algorithms. We also see the need to integrate different modeling applications, such as large-basin and small watershed models, or climate and basin models. For this, we envision an all-encompassing modular approach to modeling, one in which certain problems may require the conjunctive use of several different modeling components.

To make the most of our resources, we have to rely upon what others have developed in establishing the database and modeling framework. Many federal agencies and their contractors have developed support systems for their watershed management and modeling applications. Two examples of database and modeling frameworks already established for use in watershed management and hydrologic modeling are the Modular Modeling System (USGS, 1998) and the Watershed Modeling System (WMS) from the U.S. Army Corps of Engineers Waterways Experiment Station (Brigham Young University, 1997). Various existing support systems will be examined to determine which systems will best fit the needs for the ILRDSS. Concerns to be addressed in the choice of a support framework for the ILRDSS will include its expected level of future support and product development, flexibility, and accessibility; potential for supporting many modeling applications as well as knowledge-based algorithms; and the capability for customized applications.

Identification of Necessary or Desired Analytical Tools and Models

The development of basin-wide hydrologic and hydraulics models of the Illinois River will be essential to address most of the issues developed in the Illinois River IMP. The identification of additional tools will occur as DSS issues continue to be developed and with the addition of new players/collaborators. As the DSS is developed in future years, it is expected that

the system will also incorporate water quality modeling at some scale and interface with climate models to address additional issues. Potential ideas for future additions to the DSS could include the WASP5 Water Quality Analysis Simulation Program (Ambrose et al., 1993) and the use of SPARROW or SPATial Referenced Regression On Watersheds (Smith et al., 1997; Preston et al., 1998) for regional analysis over the entire watershed. Other research in the Illinois River watershed will continue to pursue the use of physically based deterministic models for small watersheds, with the potential to expand to model major tributaries to the Illinois River. The ILRDSS databases will continue to be developed in future years to support such modeling efforts. It is also expected that future modules will be integrated into the DSS to provide the capability to assess the water resource impacts of climate variability/change.

Identification of Necessary or Desired Data Acquisition and Processing

It is envisioned that the ILRDSS will provide a clearinghouse for water resources and environmental data on the Illinois River. The ILRDSS databases will contain not only the data required for a variety of analytical models, but also what is expected to be a wide spectrum of other data and information on the river and its watershed. This will initially include basic data on water quantity and quality issues, such as sediments, nutrients, dams and lakes, and river stages, and existing GIS databases, such as those for land cover, soil type, river bathymetry, watershed boundaries, and hydrography. Links to other significant databases, such as climate data, will also be established. The ILRDSS databases will also include a bibliography of studies done on the Illinois River and its watershed covering a broad range of water resources and biological/ecological subjects. It is envisioned that all data will eventually be accessible via the Web.

Identification of Graphic User Interfaces and Visualization Tools

The use of graphic user interfaces (GUIs) and visualization tools in modeling and DSSs provide two primary advantages. First, they are essential communication tools that provide the user with the mechanisms to process a greater amount of complex information, and can be particularly useful for conveying technical information to decision-makers. Second, they can speed the process used to formulate and respond to specific issues, primarily by reducing the time spent in processing data for model input and analyzing output. The use of Geographic Information Systems (GIS) is viewed as an important tool in visualization and data management for the ILRDSS. However a range of additional graphics capabilities will be needed, particularly in association with the use of analytical models.

The development of GUIs and visualization tools for a DSS and/or modeling system can require a tremendous investment in resources. To reduce development costs and avoid “reinventing the wheel,” we may choose to adopt an ILRDSS structure that will allow the adoption of GUIs and visualization tools currently used by other DSSs and modeling systems. In particular, it would be useful to adopt tools that have been developed and will continue to be supported by other agencies and/or major research groups. The choice of the DSS structure and framework, discussed earlier, will have a significant impact on the visualization capabilities available with the ILRDSS. The visualization packages associated with the Watershed Modeling

System (Brigham Young University, 1997), Modular Modeling System (USGS, 1998), and/or other alternatives should be examined for possible ILRDSS use.

General Structure

Once developed, the ILRDSS will be a tool that can be used to facilitate the analyses and evaluation of different water resources management scenarios being considered to address issues identified in the IMP or the consequences of other natural or human-induced changes in the Illinois River watershed. Based on the above discussion about the steps for the development of the ILRDSS, it is envisioned that the ILRDSS will be based on a database-centered framework, using relational database technology and a suite of models. Figure 8 shows a schematic of such a system in which the different datasets and models will be linked through a DSS that could provide GUIs and other advanced modeling aids. The DSS will also need to provide easy access to model output and graphical tools required to present the analytical results to planners and managers, and meet the objective of integrated watershed management. The appropriate DSS development tools will be evaluated and adapted for the ILRDSS.

Application Protocol

The development and application of ILRDSS will be an iterative and evolving process. Once the basic structure is developed, the system will be used to answer questions. While attempting to answer the initial set of questions, the system may be modified and improved; additional user interface and process modeling capabilities may be added. This process of identifying questions, answering these questions using the existing capability of the ILRDSS, and gradually improving and adding more capabilities to answer more related questions will be a relatively long and on-going exercise.

Along the long-term path of developing and applying the ILRDSS, the following sub-steps will be followed in applying the ILRDSS to address each question. One iteration of the following steps will be needed for each question.

Step 1: Question Formulation

Although some general questions related to the hydrology and hydraulics of the Illinois River have already been asked, these questions will be made more specific and relevant during the implementation of the IMP. Discussions between the ILRDSS developer/user and the agencies responsible for implementing the IMP are necessary so that each question includes adequate relevant technical detail. Only when adequate technical details are included in the question and are understood by all sides will potentially meaningful answers be generated using the ILRDSS.

Step 2: Translation of Question to Modeling Scenario

For questions that can only be answered with additional information generated by models, the ILRDSS developer/user needs to translate the formulated question to modeling

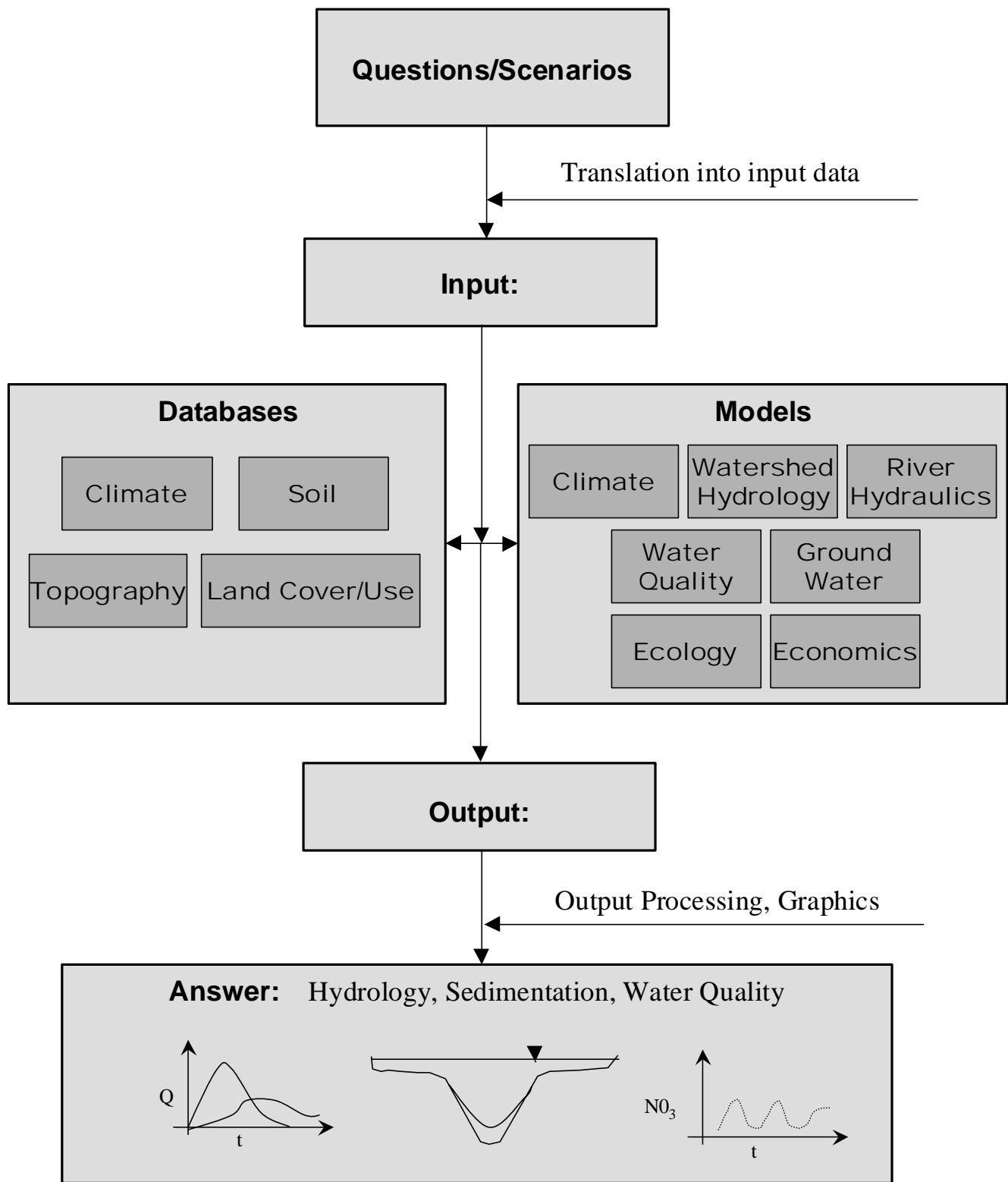


Figure 8. Schematic for the Illinois River Decision Support System

scenarios so that models in the ILRDSS can be run to generate results and answers. Sufficient details must be included in the formulation of the question to allow construction of these modeling scenarios. For other questions that can be addressed using information already in the database, this step may be skipped.

Step 3: Evaluation of Adequacy of Data and/or Modeling Capabilities

For questions that may be answered by using information already in the database, the ILRDSS developer/user examines the adequacy of the data, in terms of spatial and temporal scales and resolutions, to determine the necessity of additional data collection and/or modeling.

For questions requiring additional modeling, the ILRDSS developer/user examines the existing capabilities of the ILRDSS to determine if they are sufficient for carrying out the simulation runs of the required modeling scenarios. If not, additional modeling capabilities are added to the ILRDSS.

Some parameters of the modeled processes may need to be calibrated using site-specific data. At this step, the available data in the database are also examined to see if they are adequate for the calibration of these parameters. If not, additional data collection is recommended.

Step 4: Input File Preparation, Calibration of Parameters, and Model Runs

If additional modeling is necessary, during this step, input data files are prepared, calibration runs are performed to calibrate the models, and scenarios are modeled. If additional modeling is not necessary, this step may be skipped.

Step 5: Data Processing and Response Formulation

Output files from scenario runs and/or data files already included in the database are processed to generate statistics and graphics, which can be used to respond to the question posed. In formulating the response, however, some judgement by the ILRDSS developer/user may have to be made in interpreting the modeling results. This is necessary because of the uncertainties involved in the parameter values, and consequently the input and output data, and the limitations of the models used. These judgement calls, uncertainties contained in results and limitations of the ILRDSS, need to be considered and included in formulating the response. In most cases, these uncertainties and limitations should be communicated to and discussed with the agency posing the question early in the process.

Step 6: Evaluation, Feedback, and Improvement

At this final step in using the ILRDSS to answer individual questions, meetings may be held between the ILRDSS developer/user and the agencies interested in the specific question. These meetings will be convened to evaluate the steps followed, to discuss the feedback received on the answers provided, and to plan for the improvement of not only the process followed, but also the database and modeling capabilities of the ILRDSS. Additional monitoring or modification of the existing monitoring activities may also be recommended and discussed at this stage.

The above outlined steps form one iteration of the development and application of the ILRDSS. As more questions are formulated and answered, more iterations are completed. The modeling capabilities of the ILRDSS and the monitored and simulated data series contained in the ILRDSS will gradually increase. This iterative, gradual development and application procedure will also promote increasing confidence in the ILRDSS by user agencies.

Initial Developments and Applications

Hydrology

One of the most important modeling components of the ILRDSS will be a precipitation-runoff model for the entire Illinois River watershed. The purpose of the model will be to compute streamflows into the Illinois River for use in evaluating watershed and river management issues influenced by water quantity. To accomplish this effort in a reasonable time with limited resources, the selected model will initially use a coarse watershed segmentation to compute volume of flow. Such a coarse segmentation, or “lumped” approach, will be sufficient for computing inflow conditions into the Illinois River and for evaluating general land-use practices, but will not be sufficient to address water management issues in sub-watersheds that will require detailed water routing and storage modeling.

After developing the overall model with coarse segmentation, more detailed precipitation-runoff models that incorporate channel routing and storage processes will be developed for the major sub-watersheds in the basin. In some cases, existing models for various sub-watersheds could be incorporated into the ILRDSS to take advantage of previous studies.

Since there is no existing precipitation-runoff model for the entire Illinois River watershed, a thorough review of hydrologic models for large river watersheds has been conducted before selecting the one most appropriate for the ILRDSS. A summary of the review is included in the appendix of this report

Hydraulics

The Illinois River is the main artery for the Illinois River watershed. It carries the runoff, sediment, nutrient, and pollutants from all tributary streams down to the Mississippi River. River hydraulics have been modified by numerous water resource management practices and decisions over the last century. Changes in river hydraulics affect the river’s capacity to transport sediment, nutrients, and pollutants. It also affects water levels and flow velocities that are important parameters for aquatic and wetland habitats.

To answer questions related to water-level fluctuations, flooding, and transport capacity along the Illinois River, a hydraulic model of the river is required. Fortunately, there also exists a one-dimensional unsteady flow hydraulic model for the Illinois River that was developed by the U.S. Army Corps of Engineers-Rock Island District. The model has been applied by the Illinois State Water Survey for two projects dealing with the evaluation of floodplain management and water-level fluctuations (Akanbi and Singh, 1997; Xia and Demissie, 1999).

The model is based on the UNET model (One-Dimensional Unsteady Flow Model through a Full Network of Open Channels) developed by the Hydrologic Engineering Center or HEC (1995).

Figure 9 illustrates the adequacy of the model to evaluate causes of water-level fluctuations in the Illinois River where the impacts of the operation of the Peoria Lock & Dam on water-level fluctuations in the LaGrange Pool were evaluated using the one-dimensional model. Water-level data collected during the summer of 1997, when the Peoria Lock & Dam was being repaired, provided valuable data to verify the capability of the model to simulate water-level fluctuations in the Illinois River during low-flow conditions. Figure 9 compares the measured water level and that simulated by the model. As shown in the figure, the model reproduces the observed fluctuations adequately. Water-level measurements are made at a limited number of observation points, and thus cannot provide reliable information at other locations without some form of modeling. Once the model is developed, it is possible to determine water-level fluctuations that could be caused by different factors at any cross section in the LaGrange Pool.

With minor modifications and additional calibrations, the Illinois River hydraulic model based on the UNET model will be adequate to answer most of the issues related to water-level fluctuations and regulations. However, it should be recognized that it is a one-dimensional model and could not provide detailed information on river hydrodynamics that are three-dimensional in nature.

For more detailed hydraulic analysis, the Water Survey has applied a two-dimensional hydrodynamic model (Surface Water Modeling System or SMS) to segments of the Illinois River in the Peoria and LaGrange Pools. Thus, if more detailed hydraulic analysis is required for selected areas, the SMS model can be used in conjunction with the UNET model to generate the necessary information.

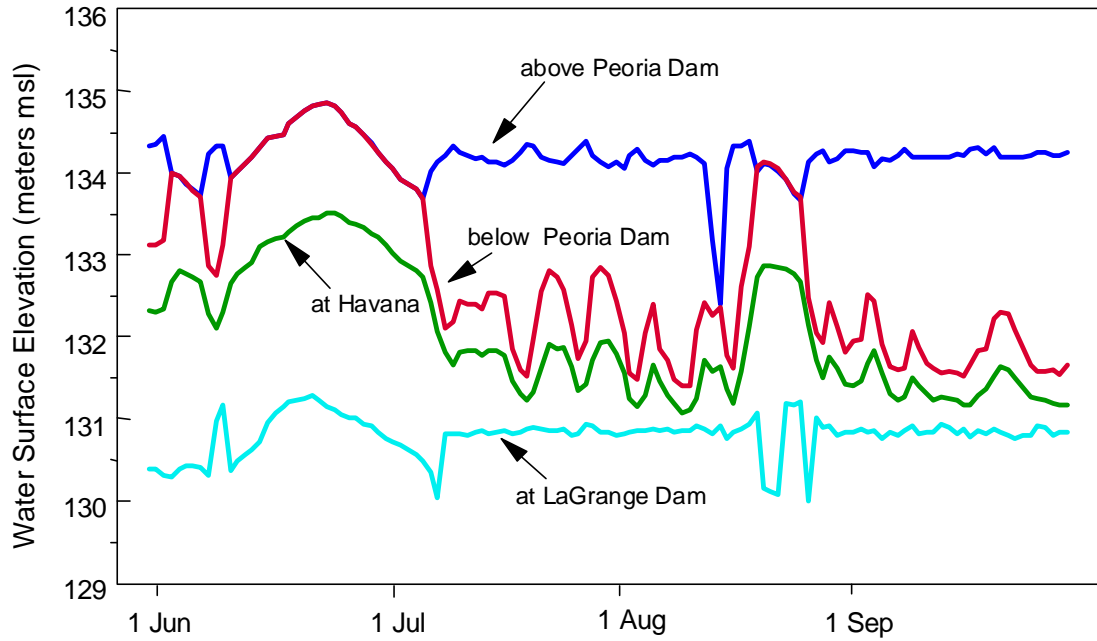
Future Developments and Applications

In the initial phase of the development of the ILRDSS, we have focused on developing the hydrologic and hydraulic components because these are primary issues highlighted in the IMP. However, it is our full intention to incorporate additional databases and models as appropriate. We plan to include components on ground water, water quality, sediment, and climate all within the capabilities of the Water Survey scientists and ecological and economic components in collaboration with scientists from other Surveys and the University of Illinois.

Collaboration with Other Scientists and Agencies

Once the hydrologic and hydraulic components are developed, the plan is to incorporate other databases and models as appropriate. This will require collaboration within and outside the Water Survey with scientists from the other Scientific Surveys and the University of Illinois. This process will be initiated as soon as the basic structure for the ILRDSS is formulated.

Illinois River Hydrographs, Summer 1997
(Actual Gage Data)



Illinois River Hydrographs, Summer 1997
(Modeling Results)

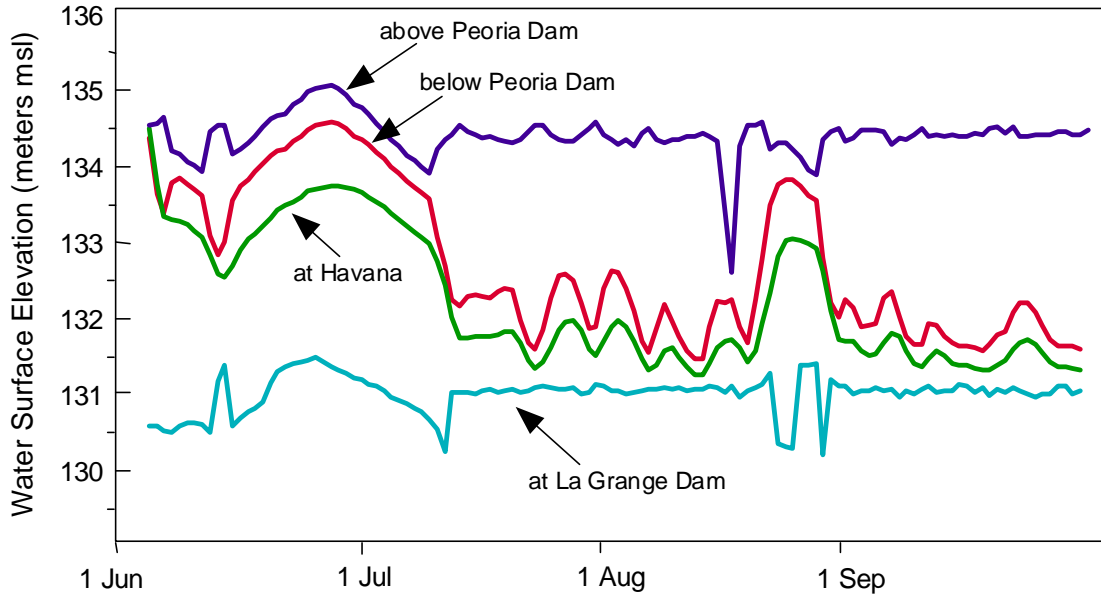


Figure 9. Observed and simulated water-level fluctuations in the LaGrange Pool during the summer of 1997

Collaboration within the Water Survey

The Water Survey has expertise in several areas that are extremely important and relevant to the development of a comprehensive watershed management plan for the Illinois River. The expertise includes climatology, hydrology, hydraulics, ground water, water quality, sediment transport, sediment chemistry, and sedimentation. Experts in these areas will be invited to participate and develop databases and models applicable to the Illinois River watershed.

Collaboration with Scientific Surveys and University of Illinois Scientists

In areas where expertise does not exist within the Water Survey, collaboration will be initiated with the other Scientific Survey and University of Illinois scientists. Areas of potential collaboration include geology, hydrogeology, sediment quality, ecology, and economics.

Collaboration with State and Federal Agencies

The Water Survey alone cannot fully develop a comprehensive ILRDSS. It will require collaboration with state and federal agencies. The primary agencies that will be interested in supporting the development of the ILRDSS include the Illinois Department of Natural Resources (IDNR), Illinois Environmental Protection Agency (IEPA), Illinois Department of Agriculture (IDOA), and The Nature Conservancy. Once the basic framework for the ILRDSS is developed with demonstrable results, these agencies will be approached for collaboration and support to fully develop the ILRDSS.

Proposals will be developed for the different ILRDSS components. For example, the IEPA may be interested in supporting the development of the water quality component and the IDOA may be interested in supporting the ground-water and soil erosion components. We plan to invite any of the agencies interested in the ILRDSS to become full partners in the development of databases and models.

Resource Needs

As mentioned earlier, the Water Survey cannot fully support the development of the ILRDSS without major programmatic shifts. Therefore, collaboration and funding from outside sources will be required to fully develop the ILRDSS. In addition to continuing to submit funding for new initiatives through IDNR, proposals will be prepared for the different components of the ILRDSS. Proposals will be prepared that continue and expand work on hydrology and hydraulics; initiate work on water quality, sediment transport, ground-water/surface water interaction; and influence of climate fluctuation on the Illinois River. Opportunities for preparing other proposals with lead Principal Investigators from other Scientific Surveys and University of Illinois scientists on issues related to ecology, geology, and economics will be pursued.

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Appendix: Review of Precipitation-Runoff Models for the Illinois River Decision Support System

Review of Precipitation-Runoff Models for the Illinois River Decision Support System

1. Introduction

The backbone of the Illinois River Decision Support System (ILRDSS) will be the centralized database coupled with the watershed precipitation-runoff models and the one-dimensional hydrodynamic model of the Illinois River. The precipitation-runoff model transforms precipitation into surface runoff by simulating the processes of infiltration, evapotranspiration, surface runoff, and erosion and sedimentation. The hydrodynamic model takes tributary inflow from the precipitation-runoff model and simulates in detail the flow, stage, and velocity variations along the Illinois River. River water quality models may be developed to study the interaction of various water quality constituents within the Illinois River. Ground-water models can be used to study the interaction between ground water and Illinois River or tributary river flows, and the influence of land-use modifications on ground-water levels, and ground-water quality.

A number of precipitation-runoff models or modeling systems containing precipitation-runoff models were reviewed in order to select those most appropriate for ILRDSS. The review was carried out in two stages. At stage 1, all available models and modeling systems were searched and briefly reviewed. Several suitable ones were selected for a more in-depth review at stage 2. At the end of stage 2, a recommendation was formed on the basis of a comparison of the pros and cons of the selected models.

The modeling packages reviewed in the first stage included: AgNPS and AnnAgNPS, AHPS-NWSRFS, HEC-HMS, WES-WMS, CASC2D, MMS, and HSPF. Those selected for the second stage review were AHPS-NWSRFS, MMS-PRMS and HSPF. This appendix documents the findings of this review process. Section 2 provides a brief description for each of the reviewed packages. Section 3 summarizes the recommendations from stage 1 review. Section 4 contains more information about the three seemingly suitable modeling packages, while Section 5 presents the final recommendation from stage 2 review.

2. Brief Description of Available Modeling Packages ***AgNPS and AnnAgNPS***

The Agricultural Non-Point Source (AgNPS) pollution model was developed by the Agricultural Research Service (ARS) of the U.S. Department of Agriculture (USDA) in cooperation with the Minnesota Pollution Control Agency and the Soil Conservation Service (SCS) of the USDA (Young et al., 1989, 1994). The model was developed to analyze and provide estimates of runoff water quality from agricultural watersheds. The AgNPS model is event-based. The model simulates runoff, sediment, and nutrient transport from agricultural watersheds. The nutrients considered include nitrogen and phosphorus. Basic model components include hydrology, erosion, and sediment and chemical transport. The model operates on a cell

basis. Cells are uniform square areas subdividing the watershed, allowing analyses at any point within the watershed. Pollutants are routed through cells from the watershed divide to the outlet in a stepwise manner so that flow at any point between cells may be examined.

The event-based hydrology in the AgNPS model is very simplistic. Runoff volume is calculated using the SCS curve number method, and peak runoff rate for each cell is estimated using an empirical relationship. A modified form of the Universal Soil Loss Equation is used to estimate upland erosion for single storms. Soil loss is calculated for each cell of the watershed, and detached sediment is routed from cell to cell through the watershed to the outlet. Streambank, streambed, and gully erosion are accounted for by using estimated values as point sources. Sediment from these sources is added to upland sediment and considered in the transport phase of the model.

Several states have used the AgNPS model to prioritize watersheds for the potential severity of water quality problems, to pinpoint critical areas within a watershed contributing to pollution, and to evaluate the effects of applying alternative management practices.

The continuous simulation Annualized Agricultural Non-Point Source (AnnAgNPS) pollution model is a replacement of the AgNPS model (Cronshey and Theurer, 1998; Geter and Theurer, 1998). This model simulates the movement of sediment and chemicals (nutrients and pesticides) in the surface water on a watershed over a user-specified period of time using a daily time step. The pollutant loading can be expressed as quantities for a runoff-producing event in selected stream reaches and as source contributions from a watershed component (i.e., specific land area, stream reach, feedlot, gully, or point source) to the watershed outlet over the simulation period. Unlike the AgNPS model, the cells in the AnnAgNPS model can be of various sizes either square-shaped or amorphous (hydrologically based), provided each cell can be represented by single land use, land management, and soil type. This model still uses the curve number method to estimate runoff.

The AnnAgNPS model can run on any computer platform that has a FORTRAN 90 compiler. A graphic user interface (GUI) and editor have been developed to aid users in the selection of appropriate input parameters to run the model.

AHPS – NWSRFS

The Advanced Hydrologic Prediction System (AHPS) is being developed by the National Weather Service (NWS) of the National Oceanic Atmospheric Administration or NOAA (Fread, 1995). The planned AHPS will be capable of producing hydrologic forecasts with lead times of a few days to several months. It will provide river forecasts accounting for not only precipitation already on the ground, but also estimates of future precipitation. This advanced prediction will greatly improve the nation's capability to take timely actions to mitigate the impact of major floods and droughts. In FY1999, NOAA proposes to begin AHPS implementation in the Upper Midwest, concentrating on the Red River of the North, and the Pacific Northwest, focusing on the Columbia River basin (National Weather Service, 1999).

The AHPS will build upon the following components:

1. Partnerships with other water cooperators (federal, state...).
2. The existing NWS hydrologic forecasting infrastructure, including 13 NWS River Forecast Centers (RFCs) and the NWS River Forecast System (NWSRFS), a very large software system used by RFC hydrologists to produce forecasts of time series of discharges and stages at selected locations along the nation's rivers.
3. The NWS Modernization, which is providing enhanced scientific and technological components including Advanced Weather Interactive Processing System equipment, and NEXRAD Doppler radar coverage.
4. The Water Resources Forecasting System initiative, which will provide additional resources to:
 - Make critical software enhancements to the NWSRFS.
 - Develop a NOAA Hydrologic Data System.
 - Increase the use of short- to long-range weather and climate forecasts within the NWSRFS through appropriate hydrometeorological coupling algorithms.
 - Calibrate and field implement the AHPS within the NWSRFS.
 - Implement a snow estimation and updating system that provides gridded estimates of snow water equivalent.

The existing NWSRFS can run on Unix workstation and includes the entire Illinois River drainage basin.

HEC-HMS

The Hydrologic Modeling System (HEC-HMS) developed by the U.S. Army Corps of Engineers' (USACOE) Hydrologic Engineering Center is a Windows-based single event precipitation-runoff simulation program (U.S. Army Corps of Engineers, 1999). The HEC-HMS provides a variety of options for simulating precipitation-runoff processes and is comprised of a GUI, integrated hydrologic analysis components, data storage and management capabilities, and graphics and reporting facilities.

The basic framework of the HEC-HMS for simulating basin runoff is similar to that in HEC-1. In addition to unit hydrograph and hydrologic routing options similar to those in HEC-1, capabilities currently available include a linear-distributed runoff transformation that can be applied with gridded (e.g., radar) rainfall data, a simple "moisture depletion" option that can be used for simulations over extended time periods, and a versatile parameter optimization option. Future versions will have capability for continuous moisture accounting and snow accumulation and snowmelt simulation.

The HEC-HMS can run on computers with MS Windows 95, or MS Windows NT version 3.51 or higher.

WES-WMS

The USACOE's Waterways Experiment Station (WES) has developed a Watershed Modeling System (WMS) software package that provides interfaces to five models: HEC-1, TR-20, CASC2D, Rational method, and National Flood Frequency or NFF (U.S. Army Corps of Engineers, 1999). Traditionally, HEC-1 and TR-20 models are developed from a topologic representation, or tree diagram of a watershed. Nodes or icons for each component, such as outlet points, confluences, basins, diversions, and reservoirs are linked together according to the underlying stream network of the watershed. Using the WMS, tree diagrams can be established automatically from Triangulated Irregular Networks (TINs) by inputting digitized data, either from digital topographical maps or from manually digitized data, and triangulating the points. Once a TIN is created, a continuous surface is modeled by interpolating between the corners of the triangles. After the surface is modeled, the WMS automatically defines the stream network on the user's screen and calculates the contributing drainage area to each of the user-defined stream junctions. The WMS employs NEXRAD radar information in assessing precipitation intensities, durations, and distributions.

The WES-WMS can run with MS Windows or UNIX systems.

CASC2D

The CASC2D is a physically based, distributed-parameter, raster (square-grid) hydrologic model for simulating the hydrologic response of a watershed subject to an input rainfall field (Ogden and Senarath, 1997). Major components of the model include: continuous soil moisture accounting, rainfall interception, infiltration, surface and channel runoff routing, and soil erosion and sediment transport. Development of CASC2D was initiated in 1989 at Colorado State University. This model was selected by the WES as its premier two-dimensional surface water hydrologic model, and is one of the surface-water hydrologic models supported by the WES.

The model is fully spatially varied at a user-specified resolution (typically 30 – 200 meters) and therefore requires considerably more input data (Julien et al., 1998). Spatially distributed modeling offers the capability of determining the value of any hydrologic variable at any grid point in the watershed.

The model has numerous input and output options. The WMS interface for CASC2D can be used for input file formatting, model set-up and option selection. The model relies on the GRASS ASCII data format for storing all spatially distributed variables. The WMS interface can directly access data from both ARC/INFO and GRASS GIS systems and export data to the CASC2D.

MMS-PRMS

The Modular Modeling System (MMS) is an integrated system of computer software that has been developed to provide the research and operational framework needed to support physical process model development and application (Leavesley et al., 1996). The MMS supports the development, testing, evaluation, and application of a wide range of modeling capabilities needed to address the issues associated with basin-scale water management. A Geographic Information System (GIS) interface, the GIS Weasel, has been integrated with MMS to support model development, application, and analysis. The MMS has also been coupled with RiverWare, an object-oriented reservoir and river system modeling framework, using a shared relational database. The development of MMS began as a cooperative research effort between the U.S. Geological Survey (USGS) and the University of Colorado's Center for Advanced Decision Support for Water and Environmental Systems. As the MMS took shape, many other agencies became interested. Now the development and application of decision support systems (DSSs) comprised of the MMS, databases, and other modeling systems are the major objectives of a cooperative effort by the USGS and the U.S. Bureau of Reclamation (USBR) under the Watershed and River Systems Management Program.

The MMS uses a master library that contains compatible modules for simulating a variety of water, energy, and biogeochemical processes. A model is created by selectively coupling the most appropriate process algorithms from the library to create an optimal model for the desired application. Where existing algorithms are not appropriate, new algorithms can be developed.

One of the alternatives for rainfall-runoff modeling within the MMS framework is the Precipitation-Runoff Modeling System or PRMS (Leavesley et al., 1983). The PRMS is a modular design, deterministic, distributed-parameter modeling system developed to evaluate the impacts of various combinations of precipitation, climate, and land use on streamflow, sediment yields, and general basin hydrology. Basin response to normal and extreme rainfall and snowmelt can be simulated to evaluate changes in water-balance relationships, flow regimes, flood peaks and volumes, soil water relationships, sediment yields, and ground-water recharge. The PRMS allows spatial distribution of model parameters by partitioning the watershed into hydrologic response units (HRUs). Each HRU is assumed to have uniform physical and hydrologic characteristics.

Although the MMS has been developed for UNIX-based workstations and uses X-windows for a GUI, a DOS version of PRMS is also available.

HSPF

The Hydrological Simulation Program – FORTRAN (HSPF) is a comprehensive, conceptual, continuous watershed simulation model designed to simulate all the water quantity and quality processes that occur in a watershed, including sediment transport and movement of contaminants (Bicknell et al., 1996). Although the HSPF is usually classified as a lumped model, it can reproduce spatial variability by dividing the basin into hydrologically homogeneous land segments and simulating runoff for each land segment independently, using different

meteorologic input data and watershed parameters. The model includes fitted parameters as well as parameters that can be measured in the watershed.

The HSPF has its origin in the Stanford Watershed Model developed by Crawford and Linsley (1966) and has undergone numerous modifications and additions. The present form of the HSPF is distributed by the U.S. Environmental Protection Agency's Center for Exposure Assessment Modeling (CEAM) and is comprised of a set of computer codes that can simulate the hydrologic, and associated water quality, processes on pervious and impervious land surfaces and in streams and well mixed impoundments. It is more comprehensive than most existing hydrological modeling systems. The HSPF uses continuous rainfall and other meteorologic records to compute streamflow hydrographs and pollutographs. The HSPF simulates rainfall interception, soil moisture, surface runoff, interflow, baseflow, snowpack depth and water content, snowmelt, evapotranspiration, ground-water recharge, dissolved oxygen, biochemical oxygen demand, temperature, pesticides, fecal coliforms, sediment detachment and transport, sediment routing by particle size, channel and reservoir routing, constituent routing, pH, ammonia, nitrite-nitrate, organic nitrogen, orthophosphate, organic phosphorus, phytoplankton, and zooplankton. The HSPF can simulate one or many pervious and impervious unit areas discharging to one or many river reaches or reservoirs. The HSPF is generally used to assess the effects of land-use change, reservoir operations, point or nonpoint source treatment alternatives, flow diversions, etc.

The software program GENeration and analysis of model simulation SCeNarios (GENSCN) was developed as the pre- and post-processor for use with the HSPF. The GENSCN modules can create and store a potentially large number of modeling scenarios for a given watershed. Specific sets of input data for various locations within the watershed can be selected by clicking on map locations and edited through menus, cut and pasting, etc. Spatial data can be shared with GIS tools such as ArcView or ArcInfo. The interface also provides capabilities to plot, compute statistics for, and analyze model output.

The HSPF is available for MS DOS systems.

3. Recommendations from Stage 1 Review

The ILRDSS will have the capability to assemble input data files from various databases with as few user manipulations as possible, and to efficiently display and analyze model outputs. Thus, the capabilities of pre- and post-processing model input and output data are a major consideration in selecting a precipitation-runoff model for the ILRDSS. At the same time, the ILRDSS must be able to answer many questions raised in the implementation stage of the Integrated Management Plan (IMP) for the Illinois River. Continuous simulation, sediment detachment and transport modeling, for example, are required to answer some of the questions. Thus, the precipitation-runoff model's capability to simulate all these related processes is yet another important consideration.

The AgNPS and AnnAgNPS models are obviously not appropriate for the ILRDSS because of their simple hydrology. The AnnAgNPS model can only use a fixed daily time step, which may be inappropriate for the ILRDSS to answer some of the questions. The runoff

generation and routing procedures used in the AgNPS and the AnnAgNPS models are the simplest, because the models focus on agricultural nonpoint source pollution.

The HEC-HMS and WES-WMS are quite attractive because of their advanced GUIs. However, the HEC-HMS currently supports only hydrologic calculations similar to those in HEC-1, although there are plans to further develop their hydrologic routines. The WES-WMS merely interfaces to the HEC-1, TR-20, and CASC2D models, and the Rational Method. The hydrology represented in the HEC-1 and TR-20 models and the Rational Method is too simple for the ILRDSS.

At the other extreme, the CASC2D is a state-of-the-art hydrologic model that describes the full details of the hydrologic processes. However, it is not suitable for the ILRDSS either because the CASC2D model is designed for use on small watersheds where detailed data related to land uses, soils, and topographies are available, and baseflow and interflow components are insignificant. For the ILRDSS, the watershed is so large that either detailed input data are not available or it is impractical to assemble a model of such areal extent and yet still maintain such high spatial resolution. The physically based approach used in the CASC2D model is superior when the modeler is interested in runoff process details at small scales within the watershed. Discussions with one of the CASC2D developers, Dr. Fred Ogden, confirmed that the CASC2D model is not appropriate for large watersheds.

The three remaining candidates are the NWSRFS, MMS-PRMS, and HSPF. Watershed models are available as a part of NWSRFS from the NWSRFC in Minneapolis for the entire Illinois River watershed. The MMS has been used by the USGS and the USBR to develop DSSs for large watersheds in the west. Use of the MMS will result in significant savings in the development of model input and output interfaces, GIS interfaces, and database structures for the ILRDSS, since the MMS was developed for similar purposes. The PRMS within the MMS can be used to evaluate the impacts of various combinations of precipitation, climate, and land use on stream flow, sediment yields, and general basin hydrology, which may be sufficient to answer most of the questions that may be raised.

The HSPF is the most comprehensive precipitation-runoff model. As a result, it requires the largest amount of input data. Some of the input data required may not be available for some parts of the watershed. The training needed to run the model properly is also the highest. Nevertheless, the comprehensiveness of the HSPF may make it the only choice for the ILRDSS to address some of the more technically involved questions for the Illinois River watershed. Thus, the NWSRFS, MMS, and HSPF are recommended as candidates for stage 2 review.

4. More Information Gained at Stage 2 Review

NWSRFS

The NWSRFS is a collection of interrelated software and data capable of performing a wide variety of hydrologic and hydraulic functions related to river stage and discharge prediction. It is comprised of three major systems: the Calibration System, the Operational Forecast System, and the Extended Streamflow Prediction System. The Calibration System is

used to generate time series based on historical data and to determine model parameters. The Operational Forecast System uses calibrated parameters to generate short-term river and flood forecasts, and to maintain model state variables. The Extended Streamflow Prediction System uses current model states, calibrated parameters, and historical time-series to generate probabilistic forecasts extending weeks and months into the future. For use in the ILRDSS, only the Calibration System of NWSRFS is of interest. However, the Calibration System software is intended for use on just one segment of a river system at a time. A major river system is calibrated an area at a time, with a typical calibration run spanning several years of historical data (Smith et al., 1996). In contrast, the Operational Forecast System operates on an entire river system, but for comparatively short time periods. Thus, for the purposes of developing the ILRDSS, the Calibration System would have to be modified to simulate the hydrologic responses from multiple segments.

Currently, an Antecedent Precipitation Index (API) procedure is used in the NWSRFS for soil moisture accounting (National Weather Service, 1999). The original API procedure is applied on a storm event basis. Although a continuous API model has been developed for continuous simulation, the NWSRCs are modifying their systems to switch from the API-based approach to the use of the Sacramento Soil Moisture Accounting model, which is more physically based and compatible with continuous simulation.

Consistent with their objectives of forecasting flows at major river cross sections, spatial input data used in the NWSRFS are lumped to a higher degree than may be desired in ILRDSS (Smith et al., 1996). For example, calibration preprocessor programs are available to compute mean areal values of precipitation, temperature, etc., from point values.

In summary, the NWSRFS is a huge software system centering around the task of forecasting flows for medium to large watersheds. Erosion, sedimentation and water quality processes are not included in the NWSRFS. The need to modify the system for use in the ILRDSS, to wait for the conversion to Sacramento Soil Moisture Accounting model, and to add erosion, sedimentation, and water quality modeling capabilities preclude the use of the NWSRFS for the ILRDSS. However, it may be possible to derive some data from the existing NWSRFS input files for the Illinois River.

MMS-PRMS

The MMS is a part of the database-centered development tools currently being developed jointly by USGS and USBR. The DSSs are being developed for San Juan River basin in the four-state area of Utah, Arizona, Colorado, and New Mexico; Gunnison River basin in Colorado; Yakima River basin in Washington; and the Upper Rio Grande River basin in New Mexico (Lins and Frevert, 1998). The approximate drainage areas of the San Juan River, Gunnison River, Yakima River, and Upper Rio Grande River are 23,000, 10,000, 6,100 and 30,000 square miles, respectively. The DSSs are being developed to assist resource managers to achieve an equitable balance among the following uses: municipal water supply, fish and wildlife, agricultural, recreational, hydropower generation, and water quality maintenance. Each DSS being developed for the four river basins has three components: MMS, HDB and RiverWare. The MMS is used to

create watershed hydrologic models. HDB stands for Hydrologic Database and is a relational database storing observed and simulated streamflow, reservoir operation, and precipitation data. RiverWare is a general purpose hydropower and reservoir systems model (Zagona et al., 1998). It can be used to develop short-term reservoir operations and scheduling, mid-term operations and planning, and long-term policy and planning.

According to Dr. George Leavesley, senior author of the MMS, the MMS now has a Beta version for channel erosion/sedimentation. Although the MMS currently is Unix- and motif-based, version 2 of the MMS is being developed using Java and will be platform free. Version 2 MMS will be ready for testing in Fall 1999. There are plans for the inclusion of water quality modeling capabilities into the MMS. Currently, the AnnAgNPS model can be run under the MMS framework. With these enhancements, the MMS has all the modeling capabilities needed for the development of the ILRDSS.

Continuous soil moisture calculations are performed in the MMS using the Green-Ampt equation. Soil moistures are conceptualized as being stored in two reservoirs: upper soil layer and lower soil layer. The Green-Ampt model is physically based with measurable parameters that can be easily estimated from soil texture data, which makes it appropriate for evaluating changes in runoff resulting from agricultural practices and urbanization. A contributing area approach can be used for overland flow routing under daily mode simulation while the kinematic wave approach can be used for overland flow routing under storm mode simulation.

HSPF

The HSPF is a widely tested and well-accepted watershed hydrologic model. The current version is Release 11 from the USEPA. A detailed review of HSPF was still not attempted with the understanding that if all other simpler models fail to meet the requirements of the ILRDSS, the HSPF would be essentially the only choice.

The HSPF is the most comprehensive watershed hydrologic model. Its comprehensiveness can be appreciated by taking a look at how it considers soil moisture. To estimate the storage of moisture and the associated storage and transport of agricultural chemicals, soils of a watershed are divided into four layers: surface layer, upper layer, lower layer, and ground-water layer. A modified version of the Philip equation is used for infiltration calculations. The infiltration capacity, the maximum rate at which soil will accept infiltration, is considered as a function of both the fixed and variable characteristics of the watershed. Fixed characteristics include primarily soil permeability and land slopes, while variable characteristics are soil surface conditions and soil moisture content. Fixed and variable characteristics are allowed to vary spatially over the land segment. A linear probability density function is used to account for areal variation.

The comprehensiveness is desirable when all the necessary input data are available. According to Dr. Jeff Holland of the WES, an interface for the HSPF is being developed within the WES-WMS.

5. Recommendations from Stage 2 Review

It became clear at the end of stage 2 review that the MMS and HSPF are the only two viable choices for use in the ILRDSS. The advantages and disadvantages of the two models are discussed here.

The advantages of using HSPF are that it is well-known and well-accepted. The comprehensiveness of the HSPF will probably eliminate future programming needs to add more modeling capabilities. The disadvantages of using the HSPF are the extensive input data requirements and greater efforts needed to set up and calibrate the model. If addition to or modification of the HSPF does become necessary, the cost involved will be greater because the HSPF is not as modularly designed as the MMS.

The advantages of using the MMS are that it is easier to set up because it is simpler than the HSPF. For portions of the watershed, the AnnAgNPS model running under the MMS framework may be used to examine nonpoint pollution resulting from agricultural activities. Furthermore, the modular structure allows relatively easier addition of more process modeling capabilities. More importantly, MMS has been used to develop similar decision support systems, and as a result, the companion HDB and data management interfaces can be used directly.

The disadvantages of the MMS is that it currently does not include water quality modeling capabilities and the erosion and sedimentation modeling capabilities of the MMS have not been extensively tested.

Overall, to make the maximum use of technology that has already been developed, and to avoid the unnecessary time and resources required to set up the HSPF model for the entire Illinois River watershed, it is recommended that the MMS-PRMS be used initially for the development of the hydrologic model for the entire Illinois River watershed. Later on, when it is necessary, other models or modeling packages can be incorporated into the MMS framework and used to answer specific questions or for portions of the Illinois River watershed.

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