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Water Supply Assessment For Kaskaskia River Watershed Development: Phase I Technical Report

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WATER SUPPLY ASSESSMENT FOR KASKASKIA RIVER WATERSHED DEVELOPMENT: PHASE I TECHNICAL REPORT

by

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Abstract

This document was prepared for the Kaskaskia Basin Water Supply Planning Committee to aid their development of a plan for meeting the future growth of water supply demands within the basin. It contains background information to provide an overview of management criteria and an understanding of the constraints and policies used in conducting analyses and making decisions concerning water use within the Kaskaskia Basin.

This report describes the following work of the Illinois State Water Survey, funded by the Illinois Clean Coal Institute:

1) Retrieval and summation of existing information regarding surface water and groundwater availability in the region. This report of existing information will also include information provided by the Illinois Department of Natural Resources-Office of Water Resources (IDNR-OWR) addressing the water supply storage and allocations from Carlyle Lake and Lake Shelbyville.
2) Development of surface and groundwater hydrologic models to simulate the hydrology of the Kaskaskia River watershed, water levels in the federal reservoirs, and selected local groundwater resources. Specific models developed include:
   - a Streamflow Accounting Model,
   - a Watershed Simulation Model and Reservoir Routing Models, and
   - a set of Groundwater Flow Models.

Major portions of this report deal with a summary of existing information. The models developed in this study will be applied to water use planning scenarios in the ongoing Phase II effort funded by the IDNR-OWR. Only limited results are available for inclusion in this report.

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PHASE I SUMMARY

APPENDICES TO THE REPORT

Executive Summary

This report presents a summary of 1) the technical information assembled to describe existing water availability and sources of supply within the 22-county Kaskaskia River region in southwestern and south-central Illinois, and 2) the development of computer models that will be used in future studies to estimate impacts to water availability resulting from future water development in the region. Through funding by the Illinois Clean Coal Institute (ICCI), this document was prepared for the Kaskaskia Basin Water Supply Planning Committee (KBWSPC) to aid the development of a plan for meeting the future growth of water supply demands within the basin to the year 2050. It contains background information to provide an overview of management criteria and an understanding of the constraints and policies used in conducting analyses and making decisions concerning water use. In a forthcoming project funded by the Illinois Department of Natural Resources, the models will be applied by the ISWS to a broad range of conditions, including a set of selected future water use scenarios to more fully characterize the water availability within the Kaskaskia River region to the year 2050. In addition, as the KBWSPC deliberates and prepares its water supply planning document, the information presented in this report will be reviewed and, in some cases, additional analysis may be performed and results revised. A more complete reporting of the model development, the results of the scenario simulations, and subsequent work concerning water availability will be published at the end of that forthcoming study.

The existing technical information compiled as the first task of this study includes a review of previous analyses and publications dealing with the Kaskaskia River region's water resources; collection of hydrologic data, primarily as needed for hydrologic modeling; and, in certain cases, additional analyses of that data, such as data mining of well records and yield analyses of surface water supply sources. This compiled information focuses on the four primary sources of water supply within the Kaskaskia River watershed: 1) the two large federal reservoirs (Carlyle Lake and Lake Shelbyville) and low flow releases from these reservoirs; 2) water supply reservoirs on tributary streams; 3) direct withdrawals from tributary streams; and 4) groundwater from within the Kaskaskia basin.

Three categories of models were developed for use in evaluating water supply availability in the Kaskaskia River region under existing conditions and future scenarios: 1) a streamflow accounting model, designed to examine how water resource modifications have changed the availability of flow in streams and to estimate how the flow will change in the future under selected water use scenarios; 2) a hydrologic simulation model of the Kaskaskia River watershed and reservoir routing models describing the inflow-outflow patterns in the two federal reservoirs; and 3) numerical and analytical groundwater models used to determine the yield and rate of replenishment of selected community systems in the region. In all modeling cases, the work performed to date includes the development of the model using model calibration and verification procedures, producing interim modeling results pertaining to water supply development.

Except along the river, the geology over much of the Kaskaskia River watershed is largely unfavorable for the development of groundwater systems that supply water for more than a few households. For many communities the historical development of groundwater supply systems has been problematic, in that communities often resort to using a large number of shallow wells or a long pipeline to a distant aquifer. Because shallow groundwater also does not provide a reliable source of baseflow for many streams in the region, most larger communities in the watershed have needed to develop reservoir storage to provide a reliable primary source of supply during drought periods.

Probabilistic-based yield analyses of the community reservoir supplies in the region indicate that most systems appear to have an adequate supply, i.e., with less than a 10 percent chance that shortages would be experienced during a drought of record condition. Six reservoir systems in the region are considered inadequate or at risk of water shortages, however. Most of these systems serve small communities that potentially could haul water or possibly interconnect with a larger system if faced with the threat of shortages.

A preliminary re-evaluation of the yield for the federal reservoirs was performed using the previously developed (2001) monthly water budget models of the lakes. Although this assessment suggests the potential for a slight increase in the 50-year drought yield of the reservoirs, it is recommended that a more detailed water budget analysis using daily data inputs and evaluation of data uncertainties be conducted in revising yield estimates. Furthermore, yield estimates for federal reservoirs were based on an assumption that water withdrawals or releases occur at a constant rate throughout the drought duration, rather than the more likely scenario that there would be periodic releases from the reservoirs for major downstream users. It is recommended that future analyses include variable water use scenarios that may occur during a major drought.

Roughly 60 percent of the water supply storage in the two federal reservoirs is allocated to coal-fired power plants located in the lower reaches of the river in the Kaskaskia Navigation Channel. A considerable amount of river flow in this reach is also needed to provide water for lockages at the Kaskaskia Lock and Dam. Previous analysis of water needs in the navigation channel should be revised, not only because of changing water supply needs, but also because that analysis did not provide an assessment of the operation of the channel during the most severe drought conditions such as occurred in 1953–1955. Similar to the yield analysis for federal reservoirs, the analysis should consider scenarios that simulate realistic, variable water releases from the reservoirs.

Water for moderate growth at existing public water supplies on the Kaskaskia River has also been considered in the allocation of water from the federal reservoirs, but any large, additional development for water supply in the Kaskaskia River region will need to address the limitations in the water supply yields of the federal reservoirs. The need in the Kaskaskia region for future sustainable economic development (such as for coal mining, coal-fired power plants, coal-based liquid fuel production facilities, and related growth in public water supplies) will require a comprehensive regional water supply planning process to identify future needs and economically viable water supply sources that can be developed without undue controversy. Such a comprehensive study and plan for the Kaskaskia River region will be needed to answer the necessary questions and allow for the proper development and siting of future coal-based energy development facilities.

Objectives

The purposes of this study are to 1) assemble technical information on existing water resources and sources of water supply to describe existing water availability within the 22-county Kaskaskia River region in southwestern and south-central Illinois, and 2) develop computer models and conduct further analyses that will aid water resources scientists in estimating the effects of existing and future water use activities and climatic stresses on water availability and sustainability of regional water supply resources within the region. The information generated in this study will provide input to the Kaskaskia Regional Water Supply Planning Committee, a group of stakeholders that have been convened to develop a regional water planning document that will provide guidance in meeting water demands for both population and economic growth, including coal development, to the year 2050.

This document was prepared for the Kaskaskia Regional Water Supply Planning Committee in aiding the development of a plan to meet the future growth of water supply demands within the basin. It contains background information to provide an overview of management criteria and an understanding of the constraints and policies used in conducting analyses and making decisions concerning water use.

Introduction and Background

The availability and sustainability of an adequate and dependable water supply is essential for a society's public, environmental, and economic health. Going back as far as 1988–1989, when the last major drought occurred across major portions of Illinois, the sustainability of our water supplies has become an increasingly important and debated issue. Since 1988, droughts have affected Illinois only regionally, but water supply sustainability has continued to be a growing concern, particularly with the potential for development of a number of large water supply systems across the state, especially in the energy sector (e.g., peaker-power plants, ethanol production, and coal gasification), and the creation of regional water supply systems.

Recognizing these concerns led to the initiation, under direction of Executive Order EO 2006-01 in 2006, of a pilot program for comprehensive regional water supply planning and management in Illinois. Two areas were initially selected for this program: an 11-county region in northeast Illinois and a 15-county region extending across east-central Illinois (Figure 1). Stakeholder committees were formed for each region and technical support to those committees was provided by the University of Illinois' Prairie Research Institute and the Illinois Department of Natural Resources-Office of Water Resources (IDNR-OWR). By all accounts, the two pilot planning studies were extremely

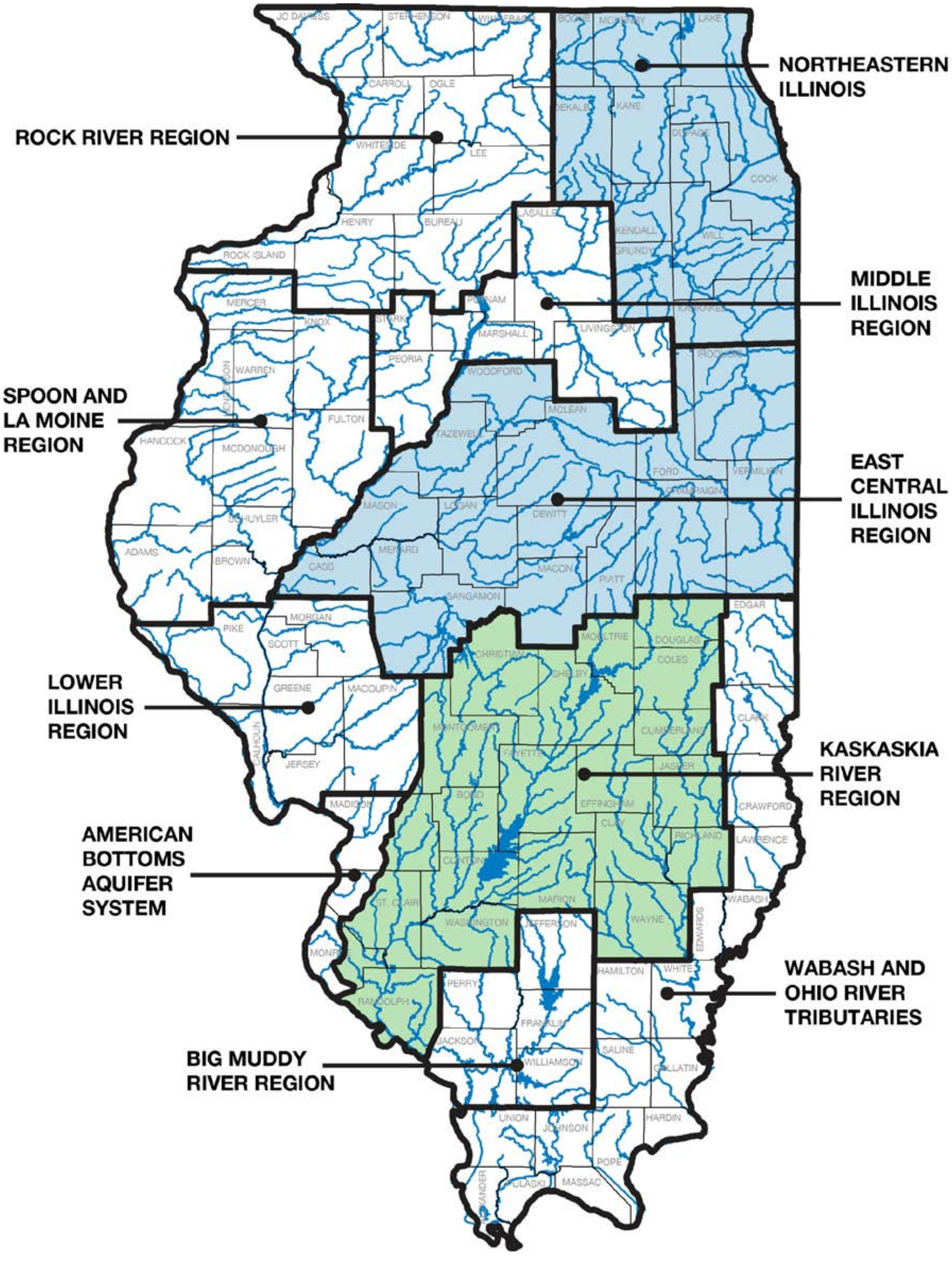

Figure 1. Recommended priority water supply planning regions in Illinois. The Kaskaskia River basin is the third planning region initiated by the IDNR Office of Water Resources.

successful efforts and have developed comprehensive water supply plans for implementation in coming years (RWSPC, 2009; CMAP, 2010).

It was further recognized that water supply planning in Illinois must expand beyond the two pilot areas initiated in 2006. Based in part on recommendations of high priority watersheds and aquifers in Illinois (Wehrmann and Knapp, 2006), IDNR-OWR initiated plans in 2009 to establish study efforts and a regional water supply planning committee for the Kaskaskia River region in southwestern Illinois. The Kaskaskia River basin water supply planning effort will be a cooperative effort between the IDNR-OWR, the ISWS, Southern Illinois University-Carbondale (water use projections) and the KBWSPC, the latter of which includes stakeholder representation from various major water use and public-interest sectors in the region. The role of the ISWS in the planning process will be to provide scientifically sound estimates of water availability and sustainability for the region and identify potential impacts of selected water uses.

The Kaskaskia River may be the most managed river in Illinois. Water storage and releases from two federal reservoirs control flooding, ensure navigation and water quality, and provide for water supply, fish and wildlife conservation, and recreation. Numerous water withdrawals occur along the river and from the reservoirs, providing for public water supply and industrial needs. The Kaskaskia lock and dam maintains the navigation pool providing for bulk transport of goods and recreation. Effluent discharges from municipal systems and industries, and cooling water returns from power plants occur along the main channel and its tributaries. The IDNR-OWR has either performed or contracted for numerous studies on the Kaskaskia basin to establish plans to meet water supply requirements in consideration of navigation and impacts to recreation and fisheries.

The four primary sources of water supply within the Kaskaskia River watershed are 1) the two large federal reservoirs (Carlyle Lake and Lake Shelbyville) and low flow releases from these reservoirs; 2) water supply reservoirs on tributary streams; 3) direct withdrawals from tributary streams; and 4) groundwater from within the Kaskaskia River valley. Of these, the two federal reservoirs represent by far the largest water sources within the watershed, with a collective yield during severe drought conditions of 42 million gallons per day (mgd). As recently as 2002, the water supply from the two federal reservoirs had been largely untapped. However, with recent allocations administered by IDNR-OWR for use with electricity generation, coal mining, and regional water supplies, the available water supply from the federal Carlyle Lake and Lake Shelbyville is now fully allocated. It can be argued that recent developments in the energy sector have been the driving force toward the full water supply allocation from the reservoirs, as roughly 80 percent of the total yield allocation is for three power plants, with the largest two being coal-fired plants located on the most downstream reaches of the Kaskaskia River.

Water for moderate growth at existing public water supplies on the Kaskaskia River has also been considered in the allocation of water from the federal reservoirs, but any large, additional development for water supply growth in the Kaskaskia River region would need to address the limitations in the water supply yields of the federal reservoirs. It should be noted that the yields of these reservoirs will also slowly diminish over time as a result of sediment deposition in the reservoirs. The needs in the Kaskaskia River region for future sustainable economic development (coal mining, coal-fired power plants, coal-based liquid fuel production facilities, and related growth in public water supplies) will require a comprehensive regional water supply planning process to identify future needs and economically viable water supply sources that can be developed without undue controversy. Such a comprehensive study and plan for the Kaskaskia River region will be needed to answer the necessary questions and allow for the proper development and siting of future coal-based energy development facilities.

This report describes the following work of the ISWS funded by the Illinois Clean Coal Institute:

a. Retrieval and summation of existing information regarding surface water and groundwater availability in the region. This report of existing information will also include information provided by IDNR-OWR addressing the water supply storage and allocations from Carlyle Lake and Lake Shelbyville.

b. Development of surface and groundwater hydrologic models to simulate the hydrology of the Kaskaskia River watershed, water levels in the federal reservoirs, and selected local groundwater resources. Specific models developed include:
   - a Streamflow Accounting Model,
   - a Watershed Simulation Model and Reservoir Routing Models, and
   - a set of Groundwater Flow Models.

The major portion of this report will deal with the summary of existing information. The models developed in this study will be applied to water use planning scenarios in an upcoming effort funded by the IDNR Office of Water Resources, and thus only limited results are available for inclusion in this report.

Data and Procedures

Compilation of Water Resources Information for the Kaskaskia River Region

Groundwater Resources. Information examined in the assessment of groundwater resources in the Kaskaskia River region includes 1) findings from reports and basic data maintained by the ISWS for each community water supply; 2) annual water withdrawal data submitted to the Illinois Water Inventory Program; 3) the ISWS aquifer test database; and 4) GIS coverages of geology, soil, and other data. The hydrogeology of the Kaskaskia Aquifer has been studied in detail at several small sites, primarily where geophysical and hydrology explorations have occurred to locate high-capacity wells. No comprehensive studies of the entire aquifer exist, especially one with a large number of expensive test borings, observations wells, and aquifer tests that would be necessary to provide sufficient data to better understand the whole system. A data-mining exercise of ISWS well records to further characterize groundwater conditions and identify any previously unknown aquifers is discussed in Appendix A.

Surface Water Resources. A good first step toward an understanding of the water resources of a region is to look at how the existing developed resources came to be, and the factors that drove the decisions in their development. In the Kaskaskia River region, where there are limited groundwater resources, particularly from deeper aquifers, the history of water supply development is to a certain extent also a history of drought and its impacts on surface and near-surface supplies. For background in this planning effort, reports and agency files describing the development of water supplies in the region were gathered and summarized. Also evaluated were regional planning studies from past decades and their relevance to current planning activities. Appendix B provides a more detailed description of the materials evaluated in this effort.

Additional reports and previous analyses on surface water supplies, including low flow studies, drought impacts, and reservoir yield estimates in the Kaskaskia River region were gathered and examined. Within this overall effort, the IDNR-OWR also compiled and summarized available information regarding water supply allocations from the federal reservoirs (Carlyle Lake and Lake Shelbyville), analyses in determining the amount of available allocation, allocation accounting procedures, and information from state authorities regarding water use and development.

Daily streamflow data, collected, processed, and published by the U.S. Geological Survey (USGS), remain the primary source of information for determining water availability from streams. Data processing and preparation for the Streamflow Accounting Model, discussed under model development, provided the main vehicle through which the USGS data are processed and evaluated to estimate streamflow availability during periods of drought. Reservoir yield analyses, performed by the ISWS using USGS data and climatic records, are the main sources of information for determining water availability during drought from the numerous water supply reservoirs in the region. The ISWS yield analyses for Lake Shelbyville and Carlyle Lake, used by IDNR as a factor in setting the allocation limit of the reservoirs, were also revisited in this study. The basic method used in reservoir yield analysis is developing a water budget of the reservoir during historical drought sequences, such as the 1930s or 1950s droughts. In this water budget approach, the collective effects of stream inflows, water withdrawals, evaporation, and precipitation on the reservoir storage are described through a daily or monthly accounting. The yield of the reservoir is the maximum rate of water withdrawal that can be incurred before the reservoir runs out of a pre-determined amount of its storage.

Hydrologic Modeling

Hydrologic models are conceptual, mathematical representations of the hydrologic processes that are believed to affect the distribution of water within the environment. Such models are simplifications of the physical environment for a number of reasons: the hydrologic processes are often complex and not fully understood, particularly with regards to the interactions between water on the surface and in the ground; the media (geologic materials) through which water flows underground and the surfaces on which water flows are often highly heterogeneous in nature; the physical characteristics of these media and surfaces are not easily measurable and thus must be estimated through model calibration; and there are usually relatively small amounts of hydrologic data available to calibrate or “train” the model and its parameters.

Even with these limitations, hydrologic models are highly useful tools for understanding and characterizing the availability of water under a variety of conditions. Models provide the capability to estimate the distribution of water under a combination of factors and conditions that may have not occurred in the past or that may have not been measured. Models allow us to understand the expected paths by which groundwater flows, which could not otherwise be characterized without a highly dense network of observation wells. Models allow us to juxtapose conditions to estimate, for example, the effects of the 1950s drought on today’s water supply reservoirs, many of which did not exist at the time of the drought. In the same manner, models also allow us to take scenarios of future water use and to project how water availability would be affected by such scenarios.

Three categories of models were developed for use in evaluating water supply availability in the Kaskaskia River region under existing conditions and future scenarios:

1. A Surface Water (Streamflow) Accounting Model, designed to examine how water resource modifications have changed the availability of flow in streams and to estimate how the flow will change in the future under selected water use scenarios.
2. A hydrologic simulation model of the Kaskaskia River watershed, designed to simulate the precipitation-runoff process in the watershed, using observed daily records of precipitation and temperature to produce daily streamflow records at selected locations within the watershed. Separate models of inflow-outflow patterns in the two federal reservoirs were also developed as part of the overall watershed simulation process.
3. A set of groundwater models. Two types of models, numerical and analytical, are used to determine the yield and rate of replenishment of selected community systems in the region. The selection of model type usually depends on the amount of data available and the degree of modeling detail warranted by a community’s particular conditions.

In all modeling cases, the work performed to date includes developing the model, using model calibration and verification procedures, and producing limited modeling results. In a forthcoming project funded by the IDNR-OWR, the models will be applied to a broader range of conditions, including a set of selected future water use scenarios to more fully characterize the water availability within the Kaskaskia River region to the year 2050. A more complete reporting of the model development, results of the scenario simulations, and subsequent conclusions concerning water availability will be published at the end of that forthcoming study.

Development of the Streamflow Accounting Model

The Illinois Streamflow Accounting Model (ILSAM) produces estimates of flow frequency for any stream location within a watershed. Flow frequency values are estimated to reflect the variability of flow conditions exhibited in long-term hydrologic records (over the past 60-plus years) juxtaposed with changes in those flow conditions caused by the current state of water resource projects and water use within the watershed (termed “flow modifiers”). ILSAM includes a utility that allows the model user to also introduce changes in these flow modifiers, such as increasing the amounts of a water withdrawal or discharges (such as from a wastewater treatment plant), which can be used to estimate associated changes in streamflow. In using this utility, the water availability of a particular stream or the watershed as a whole may be assessed for various future water use scenarios.

For the current ILSAM application, the number of streamflow frequency statistics estimated by the model, or “parameters,” was expanded from 154 to 181 to add more flow statistics during drought conditions, which is useful for evaluating reservoir yields. Flow parameters estimated by the model mostly fall into one of two categories: 1) flow duration estimates, which describe the relationship between a given flow rate at a stream location and the percentage of time that the flow rate is equaled or exceeded; and 2) low flow or drought flow estimates, which for a selected duration (such as a consecutive 7-day period) describe the relationship between the flow rate and the expected interval (in years) of such a low amount occurring. For example, the 7-day, 10-year low flow (Q7,10) describes the lowest flow amount, averaged over 7 consecutive days, that is expected to occur on average only once in a 10-year period. Flow parameters of both types are useful for various applications related to water quality standards, water supply, and for describing instream flow needs for recreation, navigation, and aquatic habitat.

Daily streamflow data from over 30 streamflow gaging stations in the Kaskaskia River watershed and surrounding areas with similar hydrology were analyzed to determine the flow frequency characteristics of streams in the region. All streamgaging records are from stations operated by the U.S. Geological Survey (USGS), with the oldest records dating back to the 1910s. Aside from the fact that gages are located at various sites on different streams, there are several other reasons why flow frequency characteristics computed for any particular gage may not be directly comparable to the frequency characteristics from other gaging records in the region. One of the most basic factors causing differences in flow frequency is the period of years of the gaging record. Just as precipitation amounts can vary substantially from year to year or from decade to decade, so also do streamflow amounts; in fact, the differences in streamflow tend to be magnified compared to the precipitation differences. As indicated by Singh and Ramamurthy (1990)**,** a 10 percent increase in the average precipitation can lead to a 40 percent increase in average streamflow amount for most locations in Illinois. To develop comparable streamflow amounts between various locations across a watershed, it is essential that the flow estimates be based on similar periods of record. For streams in the Kaskaskia River region, the analysis of flow records for ILSAM uses a consistent base period of record of 1948–2009, and the flow frequency estimates for gaging records that have a shorter period of record need to be adjusted to reflect the longer period. The adjustment process is described in Appendix D. Because of these adjustments, the ILSAM flow frequency estimates usually do not match the frequency computed directly from the gaging record. The adjusted values are clearly more pertinent for water supply planning purposes when one considers that the most severe droughts in the region occurred prior to 1970, whereas most streamgage records do not begin until after 1970.

A second adjustment to streamgaging records is performed whenever flows in a stream have clearly been altered by some human activity, for example, the construction of a reservoir, withdrawal or diversion of flows, or the release of treated wastewaters into a stream. Data collected and used to evaluate the effect of such modifications to the flow frequency in a stream include wastewater discharge data from the Illinois Environmental Protection Agency, water use data from the Illinois Water Inventory Program (IWIP), and reservoir dimension and operation information that affect the character of a reservoir's outflow, from the National Dam Inventory (U.S. Army Corps of Engineers) and other sources. Various analyses have been conducted and procedures developed by the ISWS over the past few decades to estimate the effects of various human alterations, as described in Appendix D. Other alterations to the natural hydrology, such as agricultural management practices and land use change likely have some effect on the hydrology of a stream; however, these effects tend to be indirect and are not clearly observed in the analysis of most streamgaging records. As a result, these types of hydrological modifications are not addressed in the analyses.

Development of Watershed Simulation and Reservoir Routing Models

A watershed model was developed in this study for the primary purpose of simulating water quantity under changing climate and hydrologic conditions. This purpose complements the ILSAM model which predicts streamflow conditions in a more static environment. The watershed model developed for simulation of the Kaskaskia River basin is an application of the Soil and Water Assessment Tool (SWAT), one of the most widely used watershed models that was developed to predict the water, sediment, and agricultural chemical processes in large, complex watersheds (Arnold et al., 1999). The model incorporates a suite of algorithms that are capable of simulating hydrologic and water quality processes such as surface runoff and baseflow, sediment transport, nutrient transport and cycling, and crop growth. For the purposes of water supply planning, only the water quantity segments of the model are activated and utilized.

To simulate the daily streamflow for selected locations within the watershed, SWAT requires daily weather data and information on the topography, soil properties, vegetation, and land management practices within the watershed. Most of these data are available from various government agencies (Nietsch, et al., 2001). Digital land use and soil maps are used by the model to identify the land uses and soil types in the subbasins of a watershed, and a digital elevation model (DEM) is used in subbasin delineation and computing geomorphic parameters for each subbasin in the watershed. The watershed area of the Kaskaskia River is predominantly agricultural with corn and soybeans accounting for 60 percent of the land use. Most soils in the upstream portion of the watershed, north of Shelbyville, have a moderate infiltration rate, whereas soils in the central and downstream portions of the watershed have slower infiltration rates and a higher runoff potential. Precipitation and temperature records from a total of 35 weather stations in or near the watershed were used in the model development. Average annual precipitation in the region ranges from a low of 40 inches along the northwestern boundary of the Kaskaskia River watershed to 45 inches along the southeastern boundary.

For model calibration purposes, the watershed was divided into four major subwatersheds. Corresponding daily streamflow data from four USGS gaging stations were used to calibrate and validate the model; three of the gaging stations were located on the main stem of the Kaskaskia River (at Shelbyville, Carlyle, and New Athens) and the fourth on Shoal Creek (near Breese), which is the largest tributary to the Kaskaskia River. The four larger subwatersheds were independently calibrated using a combination of automatic and manual model calibration techniques. For the two subwatersheds that receive inflow from an upstream source, data from upstream gages on the Kaskaskia River were used as inflow inputs into the models.

A total of 20 sensitive model parameters were selected for calibration of streamflows. These parameters govern the hydrologic processes, including rainfall-runoff relationships, accumulation of snow, and snowmelt runoff and groundwater flows. Since this model will primarily be used to analyze water supply conditions during drought and the impact of potential climate change on low flow hydrology and surface water availability, historic drought periods were taken into account while selecting the calibration and validation periods. Therefore, flow records from 1960 to 1969 and from 1950 to 1959 were used for calibration and validation, respectively. The use of the pre-dam time frame (1950–1969) was also essential in developing and testing a well-calibrated hydrologic model because the flows in the Kaskaskia River were not further complicated by effects from Lake Shelbyville and Carlyle Lake. A more complete discussion of the calibration and validation methods used in model preparation is provided in Appendix E.

Simulation of the watershed hydrology also requires an examination of conditions in the post-dam era since 1970. The SWAT model used in this study has a reservoir algorithm, but its routing scheme uses a simple water balance method in which the outflow volumes are computed using observed daily and monthly outflows, average annual release rates for uncontrolled reservoirs, or controlled outflow with target release. Since Shelbyville and Carlyle reservoirs have their own release schedules which cannot be simulated within SWAT, a separate reservoir routing model using Storage Indication or Puls Method has been developed. The storage indication method makes use of a continuity equation in its finite difference form. Data required for reservoir routing simulations were obtained from various sources, and 15 years of data from 1990 to 2004 were processed for use in the simulations. Reservoir inflows, outflows, and pool elevations were obtained from St. Louis district Corps of Engineers website:
(http://mvs-wc.mvs.usace.army.mil/archive/archindex.html).

To develop the reservoir routing model, storage-elevation, storage-outflow, and surface area-elevation relationships were obtained for Lakes Shelbyville and Carlyle. Weekly release schedules for both lakes were determined based on target release schedules and 15 years of reservoir outflows and pool elevation data from 1990 to 2004. These release schedules were determined using the reservoir routing model coupled with an optimization algorithm. The algorithm estimates the expected (most likely) release associated with the current lake pool elevation and week of the year. This algorithm produces a more realistic outflow pattern, with transitions similar to observed reservoir operations, as compared to a rigid adherence to target levels.

Development of Groundwater Flow Models

To a water supply planner, groundwater flow models can be used to quantify the response of an aquifer to changes in water demands and predict how future demands will impact a system. Hydrogeologists also use models to better conceptualize and quantify the flow in an aquifer. For the Kaskaskia watershed, three numerical models were constructed and modified in areas where geologic and hydrologic field data have been collected, including the Kaskaskia Aquifer near Shelbyville, the ridge-drift aquifer near Vandalia, and the Mahomet Aquifer. Although an insufficient amount of field data exists to provide any meaningful results for a model of the entire Kaskaskia Aquifer, for those three locations these models provide an improved understanding of the impacts from pumpage, the interactions with surface water, and where recharge is occurring. Analytical models have been developed by the ISWS using well test data to assess the potential yield and sustainability for 22 public groundwater supplies.

Numerical groundwater models simulate flow by dividing an aquifer into thousands of small representative cells that are each assigned permeability and storage coefficients and specified elevation or flux information for flow boundary conditions such as streams, wells, drains, and valley walls. The model then solves the groundwater flow equation for each cell and balances the mass of water throughout the model. Principal results of a model are water levels and fluxes, from which other information can be derived about flow directions, wellfield drawdowns, streamflow losses, and recharge rates. The most difficult and informative step in model development is the model calibration process in which calculated water levels and flow are compared to values measured in the field. A poor calibration suggests that the conceptual model of how the flow is represented needs to be modified, preferably with the help of additional field data.

Assessments on 22 other public groundwater supply systems in the Kaskaskia River region were completed principally through use of analytical models. Such models “idealize” aquifer conditions into relatively simple solutions without the use of more sophisticated digital flow models. Given the paucity of data on these small aquifers and the expense of (and low priority for) acquiring additional data on them, analytical model solutions are well-suited for estimating aquifer yields on these aquifers. This is typically done by calculating long-term well-field drawdowns using image-well theory (Walton, 1962) and adjusting modeled pumping rates to keep calculated drawdown less than the available drawdown. Available drawdown is typically the difference between the static, or non-pumping, groundwater level and the tops of well screens. Because many of these aquifers are very shallow and often unconfined (i.e., water table conditions), available drawdown may be limited to 50 percent of the saturated aquifer thickness (drawdown exponentially increases when 50 percent thickness is exceeded) or the top of the well screened, whichever depth is less.

Results and Discussion

Compilation of Groundwater Resources

Except along the river, the geology over much of the Kaskaskia River watershed is largely unfavorable for the development of groundwater systems that supply water for more than a few households. For many communities the historical development of groundwater supplies has been problematic, often resorting to using a large number of shallow wells or a long pipeline to a distant aquifer. Although rainfall is plentiful, the lack of suitable aquifer material and the widespread presence of heavy clay soil prevent the infiltration and storage of water in usable quantities. With the exception of the Mahomet Aquifer in the headwaters region, the principal sources of groundwater in the basin are the sand deposits that are associated with the modern Kaskaskia River valley, referred to in this report as the Kaskaskia Aquifer, where surface water is also plentiful (Figure 2). As discussed in regional surveys by Pryor (1956) and Selkregg et al. (1957), the probability of finding sand and gravel aquifers decreases away from the major streams. For many communities, the use of groundwater has several important advantages over surface water, such as lower treatment costs and greater sustainability during droughts.

Water Resources of the Bedrock Aquifers. The Kaskaskia River watershed overlies the Illinois Basin, a sequence of Paleozoic rocks thousands of feet thick. The lower portion of the sequence contains thick sandstones and limestone aquifers filled with heavy brines. The upper portion is dominated by Pennsylvanian age shales with thin layers of coal, limestone, and sandstone that generally do not yield more than 10 gallons per minute to a well (Illinois Technical Advisory Committee on Water Resources, 1967). Water quality in the shallow bedrock is variable and often too high in dissolved minerals for many uses. Near the Mississippi River the surficial bedrock map (Kolata, 2005) shows Mississippian-age sandstones and limestones rising out of the Illinois Basin. These units can contain fresh water and are currently being used by communities such as Percy, Ruma, and Steeleville in Randolph County and St. Jacob in Madison County. The bedrock aquifer (the Aux Vases sandstone) around Red Bud in Randolph County proved inadequate and the town switched from using eight bedrock wells in town to two sand and gravel wells in the Kaskaskia River bottoms. Pockets of fresh water also occur in the bedrock in Shelby County (Sanderson, 1967) where it had once been used by Tower Hill. Other communities in the region that have used the bedrock aquifers in the past but have given them up for alternate sources include Tuscola (Douglas Co.), Lerna (Coles Co.), Farina (Fayette Co.), Iuka (Marion Co.), and Smithton and Millstadt (St. Clair Co.).

Water Resources of the Glacial Aquifers. The Pleistocene glacial advances over the Kaskaskia River watershed changed the landscape by cutting down the shale bedrock uplands and filling in the valleys with mostly fine-grained materials. As the glaciers

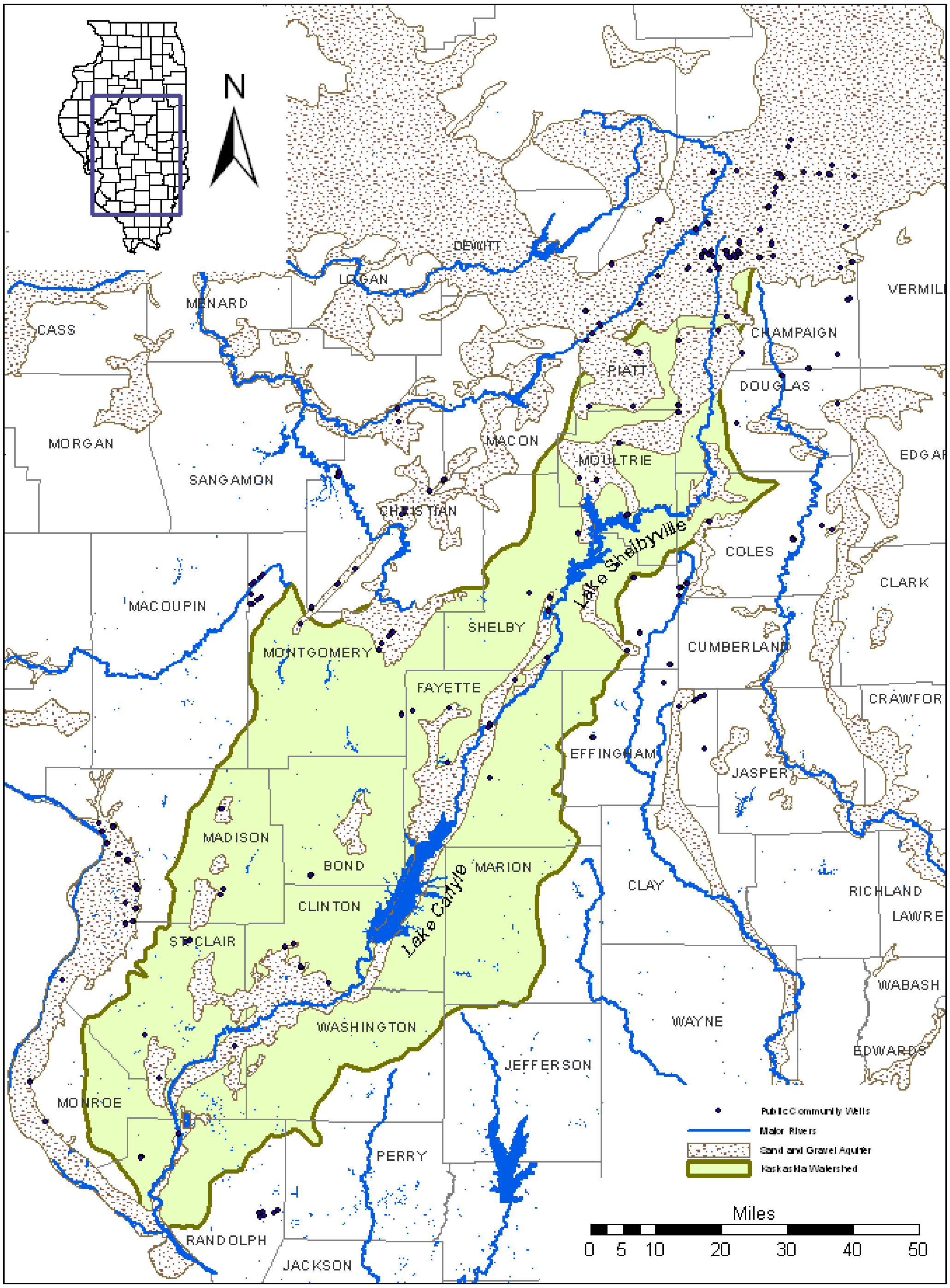

Figure 2. Extent of major sand and gravel aquifers and location of active public water supply wells in the study area

melted, dirt and rocks within the ice dropped out and formed a blanket of clay-rich till that covers most of the basin. Meltwater deposited sandy outwash in some of the stream valleys, such as the Kaskaskia. The final glacial advance came as far south as Shelbyville, where it formed a large end moraine. Streams cut through the Shelbyville Moraine, forming steep valleys and the ideal reservoir sites now occupied by Lake Shelbyville, Lake Decatur, and Clinton Lake. Meltwater from the last glaciation was directed down the Kaskaskia River valley where stream currents carried the clays and silts downstream and left behind the coarser sands and gravels (Cartwright and Kraatz, 1967). Sands deposited during the different glacial advances along with any pre-glacial and modern alluvium collectively form the Kaskaskia Aquifer. These sands are commonly divided up by clay and silt deposits both vertically and laterally. Most of the tributary valleys south of Shelbyville likely received little to no meltwater during the last glaciation resulting in these valleys becoming backwater areas that filled with fine-grained sediment rather than sandy aquifer materials.

South of Shelbyville the glacial deposits generally range from 25 to 100 feet thick and contain only scattered sands barely large enough to map outside of the Kaskaskia Valley. Sands occur along Silver Creek in Madison and St. Clair Counties but are currently only utilized by Alhambra. Running southwest through Macon, Christian, and Montgomery Counties is an unusually long and narrow (40 miles by ½-mile) sand known as the Taylorville strip aquifer (Burris et al., 1981). This aquifer supplies water to Assumption, Moweaqua, Stonington, Palmer, and Harvel, as well as Taylorville, which is supplemented by Lake Taylorville. Several communities, such as Farmersville, Waggoner, and Fillmore in Montgomery County have developed supplies in sands too small to map on a statewide scale. A description of the glacial Kaskaskia and Mahomet Aquifers appears in Appendix A.

Compilation of Surface Water Resources

Many water supply reservoirs in the region were constructed by communities in direct response to water supply shortages that were experienced during the most severe drought periods, specifically the droughts occurring in the 1890s, 1930s, and 1950s. Streamflow records were not collected during the earliest 1890s drought, and only limited records are available for the 1930s drought. Thus, much of the region's estimates of water availability are based on data and experiences from the 1950s drought, which is considered to be the worst of the historical droughts.

Yield estimates for community surface water supplies were most recently determined by the ISWS in 2010 (www.isws.illinois.edu/data/ilcws/drought.asp). Data uncertainties were evaluated by the ISWS in determining the yield for each community, such that each community's yield estimate was developed on a probabilistic basis. The designated 50 percent yield value is the best (most likely) estimate for the water supply system; however, there is also roughly a 50 percent probability that the estimate is either overestimated or underestimated compared to the "true" yield, which is an unknown value. With the designated 90 percent yield, there is only a 10 percent chance that the yield estimate is too low; thus the community can have 90 percent confidence that the yield amount could be provided during the selected drought. In the most recent analysis, the ISWS has turned to yield estimates that are based on the worst historical drought, rather than a yield estimate based on drought frequencies (e.g., 50-year drought), which are uncertain and difficult to accurately estimate. The 1953–1955 drought is the worst drought on record for most surface water supply systems in the Kaskaskia River region.

Table 1 lists the 50 percent and 90 percent yield estimates with the drought of record for community surface water systems in the region. Also listed is an average demand for each community based on the 2005–2010 period. If the 50 percent yield is less than the demand, the community is categorized as "inadequate," i.e., there is greater than a 50

Table 1. Yield Estimates for Community Surface-Water Supplies (all values in million gallons per day)

	50% Yield	*90% Yield*	*Demand*	
Altamont	0.22	0.12	0.26	Inadequate
Breese	0.71	0.69	0.69	At Risk
Centralia	7.56	7.56	4.0	
Coulterville	0.06	0.01	0.17	Inadequate
Effingham	6.7	5.7	2.1	
Fairfield	0.56	0.46	0.9	Inadequate
Farina	0.07	0.05	0.14	Inadequate
Greenville	4.2	3.0	1.3	
Highland	3.7	2.0	1.3	
Hillsboro	5.3	3.3	1.3	
Kinmundy	0.36	0.26	0.08	
Litchfield	4.3	2.5	1.3	
Mattoon	8.8	5.0	2.5	
Olney	2.9	2.1	1.4	
Pana	1.1	0.82	0.62	
Salem	6.0	6.0	1.3	
Taylorville	4.6	3.1	2.2	
Wayne City	0.30	0.26	0.33	Inadequate

Notes: Not listed are communities that have direct withdrawals from the Kaskaskia River as a primary or emergency supply, and thus are viewed to have an adequate fail-safe supply, including Carlyle, Evansville, Kaskaskia WD, Nashville, SLM Water District, Sparta, and Vandalia. Also not listed are the newly developed Gateway and Holland Water Companies that have allocations from the federal reservoirs. Effingham's yield estimate includes water from Holland Water Company. The yields for Centralia and Salem are established by separate agreements with the U.S. Corps of Engineers to obtain water from Carlyle Lake.

percent chance that the system would not have sufficient water to satisfy the demand during a record drought condition similar to the 1950s drought. If the demand is less than the 50 percent yield but exceeds the 90 percent yield, the system is considered to be "at risk," i.e., there is greater than a 10 percent chance that the system would not have sufficient water to satisfy the demand during a record drought condition. There are six systems in the region that are considered to be either inadequate or at-risk. Most of these systems are small, and it is possible that such communities could choose to haul water or interconnect with a nearby system in the case of a severe drought. Fairfield is undertaking the process to add a second off-channel storage reservoir to increase their supply, but until that time is considered inadequate.

The ISWS also conducted a preliminary re-evaluation of the yield analyses for Lake Shelbyville and Carlyle Lake; the prior analyses were conducted by the ISWS in 2001 for the IDNR-OWR. The prior yield estimates were based on a monthly water budget analysis of the federal reservoirs during selected major droughts using historical climate data and USGS streamflow records. For the current analysis, the drought frequencies were revised based on the additional years of record; the yield of Lake Shelbyville was adjusted to account for increased inflow amounts coming from upstream effluents, and the accounting procedure was changed so that the State of Illinois' storage was not debited during Decembers when water from the federal reservoirs was being dumped to reach the winter pool level. Those three changes caused a 4 mgd collective increase in the 50-year yield of the two reservoirs. Given that the total State of Illinois' water supply allocations were already slightly greater than the previously estimated 50-year yield, these revised yield estimates may not translate into the availability of additional allocation. In addition, it is recommended that the water budget analyses be revised to be computed using daily instead of monthly data; that change may be expected to lower yield estimates, perhaps by about 5 percent.

For some locations in the watershed, water resource developments over the past 50 years have altered streamflow amounts at additional locations. This is particularly true for portions of the Kaskaskia River, specifically: 1) upstream of Lake Shelbyville, as influenced by groundwater and effluent discharges from the Champaign-Urbana area that add flow to the river, and 2) the Kaskaskia Navigation Channel, which is influenced both by flow releases from Carlyle Lake and from increasing amounts of effluents from collar communities in the East St. Louis area. In these cases, even if identical climate conditions of the 1950s drought occurred again, flow in a stream may not be the same as that historically recorded at a streamgage. For water supply evaluation, the goal is to estimate the water availability that would occur given the climatic conditions of observed historical drought, but with adjustments to account for the current state of water resource development in the region. The process of adjusting flow records to describe current water availability from streams was examined in the development of the ILSAM model, and is presented in a later section of this report and in Appendix D.

Flow conditions in the Kaskaskia Navigation Channel were evaluated by Durgunoglu and Singh (1989) with regards to meeting water demands for lockages at the Kaskaskia Lock and Dam, community water supply withdrawals, and withdrawals by the Baldwin power plant. However, their analysis only investigated the period of record since Carlyle Lake was built, during which the worst droughts occurred in 1976 and 1988. Because conditions have changed since 1989, with fewer lockages but impending demands of a second power plant, this study might need to be revisited, as it seems that releases from Carlyle Lake would likely be needed during periods of severe drought to meet all downstream water demands. In addition, it is recommended that analysis be performed to estimate flow conditions and the potential need for water releases and management in the channel during conditions similar to the 1953–1955 drought of record.

Authorities and Water Allocations

The IDNR has broad authorities under the *Rivers, Lakes and Streams Act* to protect the *Public Waters of Illinois* from wrongful encroachment and to establish by regulations water levels to preserve fish and aquatic life. The *Public Waters* may generally be described as the commercially navigable lakes and streams of Illinois and the backwater areas of those streams. There are certain public rights in the *Public Waters* that are reserved for the citizens of Illinois. IDNR-OWR issues permits for construction projects that may impact the flood-carrying capacity of the rivers, lakes, and streams. Permits are also required for construction for dams and for any construction within a public body of water. OWR reviews proposed activities in *Public Waters* to ensure that the public's rights are not diminished by the activity.

Figure 3 shows locations of the designated *Public Waters* of Illinois. *Public Waters* on the Kaskaskia River begin at the mouth of the river and continue upstream to Fayette County at river mile 157, located about 9 miles south and 2 miles west of Herrick. The drainage area at this point is about 1708 square miles, and the river at this point has an estimated mean flow of 1415 cubic feet per second (cfs) and a 7-day, 10-year low flow of 28.2 cfs.

Under the *Kaskaskia River Watershed and Basin Act*, the IDNR may independently make agreements for the formulation of plans, acquisition of rights of way, and the construction, operation, and maintenance of any navigation, flood control, drainage, levee, water supply, and water storage projects. This Act provides for regulation, distribution, and use, including restriction of use or withdrawal of water from the Kaskaskia River below Carlyle Dam. OWR has established permit criteria in the review and response to permits that involve a water supply withdrawal on a *Public Water*. The OWR policy for existing public water supply systems on public waters is to not require a cessation or limitation of withdrawal upon the river reaching a specified low flow unless the system were to serve a major new user or geographical area.

Under the July 6, 1983 USA/Illinois Contracts, the State of Illinois has the right to utilize 13.9 and 14.2 percent of the total joint-use storage space in Lake Shelbyville and Carlyle Lake, respectively, for water supply. The remaining storage is federal storage for “rights reserved,” which includes the minimum 50 cfs water quality release, releases for navigation, and releases for flood control. Joint-use storage is the storage above the top of the dead pool storage (reserved for sedimentation) up to the normal summer pool level,

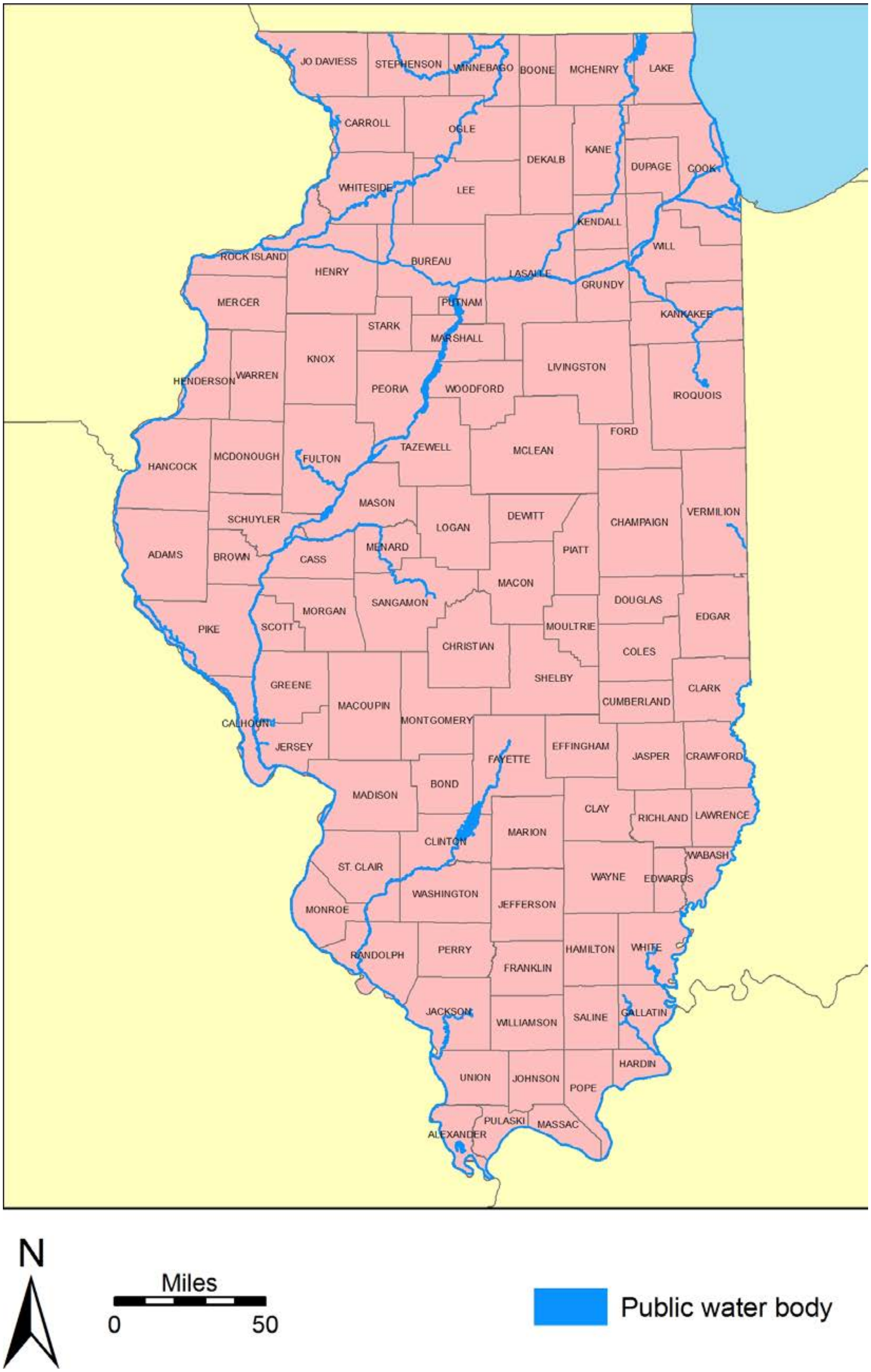

Figure 3. Locations of the designated Public Waters of Illinois

the elevation of 599.7 at Lake Shelbyville and 445.0 at Carlyle Lake. The State's water supply storage in Lake Shelbyville amounts to 24,714 acre-feet, and the storage in Carlyle Lake is 32,692 acre-feet. These storage amounts can change in the future if bathymetric surveys indicate that the total storage in the lakes' joint-use pools has changed, for example, as a result of capacity loss from sedimentation.

Allocations of Water Supply Storage in Lake Shelbyville and Carlyle Lake. The IDNR works with the Illinois Department of Commerce and Economic Opportunity in evaluating water supply allocations made from the State's storage at Shelbyville, Carlyle, and Rend Lakes. Table 2 lists the Kaskaskia Basin Water Supply Agreements, which include allocations for two regional public water supply systems, three electric generating facilities, and four lakeside public golf courses. Each of these allocations is presented in more detail in Appendix C. As of June 2011, there have been no withdrawals or releases of the State's storage to serve the needs of Timberlake, SCCS Ventures, Holland Energy, Holland Regional, Dynegy, or Prairie State. IDNR Water Allocation Agreements for withdrawals from the *Public Waters* of the Kaskaskia include protections for instream flows, protection of navigation and other storage releases, and protection of domestic water use in a water emergency. Agreement language also provides means for obtaining additional water supply storage capacity if it is determined that there is a future demand for additional domestic water use.

The July 6, 1983 contracts for water storage space in the Shelbyville and Carlyle reservoir projects prohibit downstream consumptive use of Kaskaskia River water in excess of natural inflows during a navigation release, unless such usage is replenished to the navigation system by pumping or other means or unless water is released for that purpose. OWR performed an analysis of the future water supply demands of other users on the lower Kaskaskia River that are not under contract for State-owned water supply storage, also considering the ability to maintain protection of navigation releases. There are five known public water supply (PWS) systems that withdraw water from the lower Kaskaskia River downstream of the Carlyle dam. The water supply needs for the river withdrawals are normally met by existing river flows and releases from water supply

Table 2. Kaskaskia Basin Water Supply Agreements

Purpose	Agreement Date	Quantity/Rate	Source
Eagle Creek (golf course)	1988 August 24	480 acre-feet	Shelbyville
Governor's Run (golf course)	1994 April	190 acre-feet	Carlyle
Holland Energy Power Plant	2000 June 1	8.0 mgd	Shelbyville
Timberlake (golf course)	2001 August 23	50 acre-feet	Shelbyville
Holland Regional Water System	2002 December 10	5.0 mgd	Shelbyville
Gateway Regional Water Company	2002 December 23	4.0 mgd	Carlyle
Prairie State Power Plant	2003 May 19	13.35 mgd	Carlyle & Shelbyville
Dynegy Baldwin Power Plant	2004 April 8	14.35 mgd	Carlyle
SCCS Ventures (golf course)	2007 May 30	50 acre-feet	Shelbyville

storage that will most likely only be requested during low flow conditions. Holland Energy, Holland Regional, Prairie State, and Dynegy may, under normal to slightly drier than normal conditions, withdraw from the river without the necessity for a water supply release. This situation minimizes the lake impacts during all but the driest conditions. Also, since withdrawals by Prairie State and Dynegy are located near the mouth of the Kaskaskia within the navigation channel, fewer releases and associated impacts may be realized than if the withdrawals were located farther upstream.

Results of the Streamflow Accounting Modeling

The ILSAM model provides estimates of streamflow frequency based on an analysis of historical streamflow and water use records from the past 60-plus years. It does not provide a simulation of flows resulting from climatic events nor attempt to synthesize a time series of flow values such as a daily or annual record. Thus, in generating a set of streamflow values representative of "current watershed conditions," as they existed roughly during the 2005–2010 time frame, it does not simulate specific historical conditions that occurred within that period. For its use in estimating streamflow values associated with future water use scenarios, ILSAM assumes that the basic climate conditions of the region will remain unchanged, i.e., that the range of conditions expressed in the 1948–2009 base period is applicable for planning purposes. Although there are societal concerns about future climate change impacts, at this time predictions from the suite of accepted global and regional climate models are highly variable and uncertain. This is particularly the case with regard to the potential changes in precipitation that would be expected to have the greatest effect on future streamflow conditions.

The potential effect of future water use on streamflow characteristics to 2050 will be analyzed in future work. However, because a previous ILSAM model was developed for the region 20 years ago, differences in the streamflow estimates between the two model versions can provide a 20-year window for identifying trends that might be expected to continue in the future.

Results indicate that watershed precipitation over the past 20 years was higher than the previous 60-year long-term average. The higher precipitation amount is also reflected in total (and thus average) streamflow amounts over the past 20 years. Inclusion of the most recent 20 years in the long-term streamflow estimates noticeably affects frequency estimates of high and medium flow conditions, but only slightly affects low flow frequency estimates. Such changes in flow conditions resulting from precipitation are not necessarily considered an increasing trend, but instead may be related to normal variability in climate.

In contrast, there appear to be two types of changes in low flow frequency in the watershed that are directly associated with human activities and are considered to be part of an overall trend or change from the past. First, effluent discharges from wastewater treatment plants are causing noticeable low flow increases in the Silver Creek watershed in St. Clair County and in the upper Kaskaskia River immediately downstream of

Champaign-Urbana. In both cases, the wastewater releases appear to be related to gradual population growth that may be expected to continue in the future. A second observed increase in low flow amount has occurred immediately downstream of the federal reservoirs. The increase in low flow releases from the reservoirs appears to be a response to maintain favorable water quality conditions downstream of the reservoirs, and affects the low flow frequency estimates for all downstream locations on the Kaskaskia River. A more complete description of changes in flow frequency estimates is provided in Appendix D.

Results of the Watershed Simulation Modeling

Daily flow simulations produced by the Kaskaskia River watershed model are currently available for 1950–1969 and 1990–2004. The 1950–1969 period was used to calibrate and verify the watershed model to conditions prior to when the federal reservoirs were constructed and filled. The second period, 1990–2004, was used to calibrate and verify the reservoir routing models, and is a set of years for which daily estimates of reservoir inflow were available from the U.S. Army Corps of Engineers' (St. Louis District) website. During the calibration and validation procedures, model performance statistics were calculated to evaluate the output of the model, including the Nash-Sutcliffe Efficiency statistic and the percent bias of the results. Model performance statistics generally show that monthly simulations were classified as “very good” for the four major subwatersheds on which calibration was based. Daily flow simulations for the four subwatersheds were classified as “good” using the same performance guidelines as for monthly simulations, except for the Shoal Creek watershed where daily flows were classified as “satisfactory.” Graphical comparisons between observed and simulated monthly flow volumes are presented for the Kaskaskia River at Shelbyville in Figure 4, showing the model's good performance in simulating seasonal variations in streamflows. Flow volumes for each month are expressed as the equivalents in inches of runoff from the portion of the Kaskaskia River watershed located upstream of Shelbyville.

Results of the reservoir routing model for Lake Shelbyville, using the optimized weekly release schedules, are shown in Figure 5 for 1990–2004. Also shown for comparison are the observed flow releases for the same time period, indicating that there is a good match between observed and simulated values. In order to illustrate the substantial attenuating and lagging effects the reservoir operation has on flow amounts on the river, plots of inflows into and outflows from Lake Shelbyville are presented for year 1996 in Figure 6. Similar results for Carlyle Lake are shown in Appendix E.

With the watershed and routing models completed, it is possible to simulate conditions such as the expected outflow from the reservoir during the most severe historical droughts, such as what occurred in the 1930s and 1950s. The reservoir routing model will also produce estimates of storage volume in the reservoir, and thus expected lake elevation during severe droughts. These simulations will be produced during the next year of study. Also, the watershed model will be used to estimate impacts related to possible climate change scenarios through the year 2050.

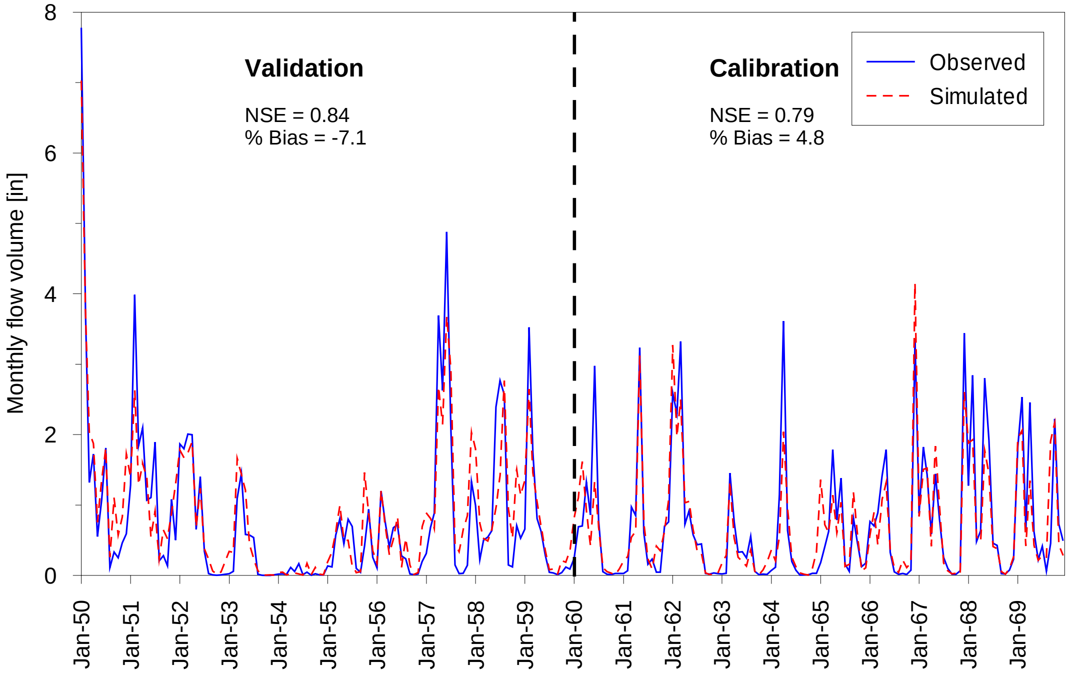

Figure 4. Monthly flows for USGS 05592000 Kaskaskia River at Shelbyville, IL

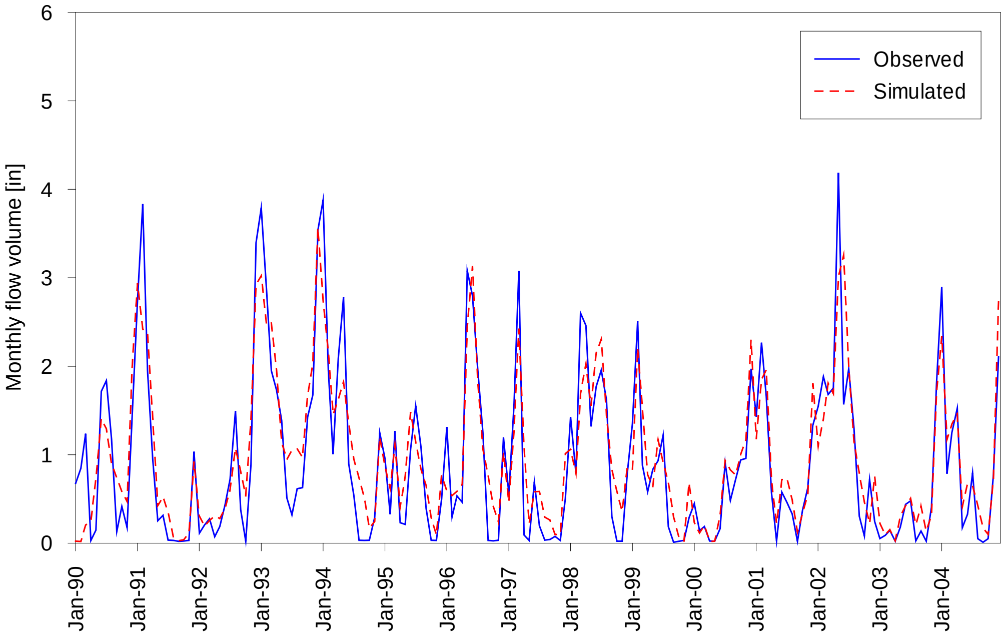

Figure 5. Monthly outflows for Lake Shelbyville

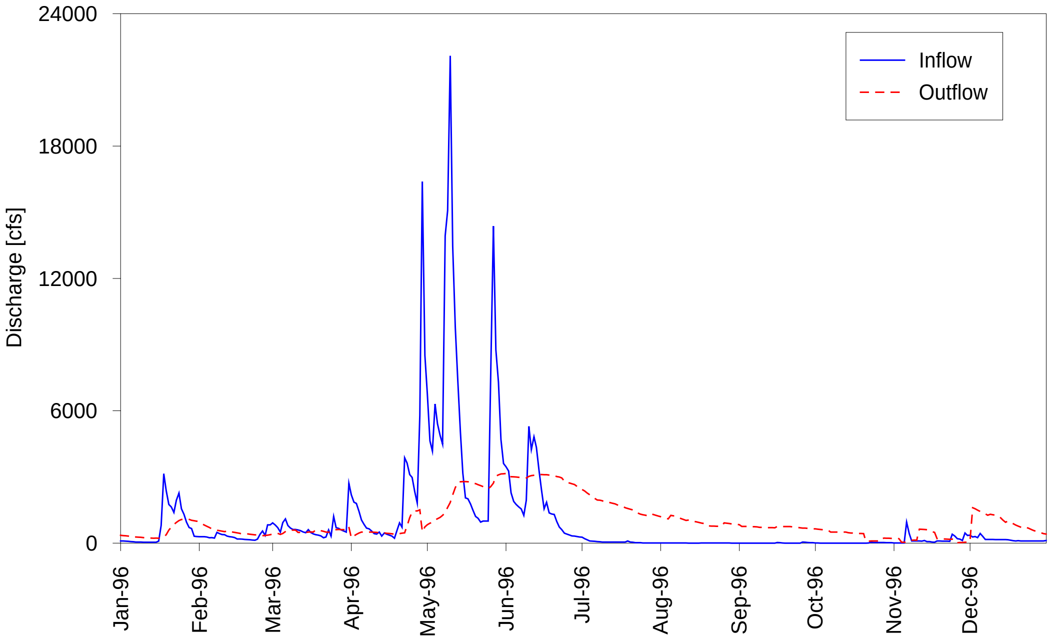

Figure 6. Daily inflows and outflows for Lake Shelbyville

Results of the Groundwater Flow Modeling

Mahomet Aquifer Model. The Mahomet Aquifer model is the subject of a separate water supply planning study and will not be discussed in detail herein; however, several important findings also have implications for the Kaskaskia Aquifer model. Proper matching of model-predicted water levels and baseflow discharges with long-term records from the Mahomet Aquifer requires increasing the amount of groundwater recharge as the pumping rates increase. Thus, the impacts of groundwater development are less than what standard predictions with static conditions would indicate. Water-level records also indicate that a large portion of any streamflow leakage to the aquifer occurs during high streamflow conditions when the vertical gradients are the greatest. Large influxes of surface water in the winter and spring mitigate the impacts from groundwater use except during long droughts. For the Kaskaskia Aquifer, a rise of 1 foot in the river level could cause as much as 20 million gallons of water to be stored in the aquifer per linear mile of river.

Shelbyville Model. The groundwater flow model of the Kaskaskia Aquifer near Shelbyville, originally constructed by Anliker and Roadcap (1997) using the U.S. Geological Survey's MODFLOW program, was modified and updated for the current project. The focus of this previous modeling effort was to determine the recharge areas for the north and south wellfields to help the city develop water supply management and monitoring plans to protect the quantity and quality of water in the Kaskaskia Aquifer. A diagram of the model and an analysis of the potential yield of the wellfield are included in Appendix F.

The model results show that the north wellfield is supplied by flow from the northeast in a portion of the Kaskaskia Aquifer that does not line up with the modern Kaskaskia River. Because the north wellfield is some distance from the Kaskaskia River and a half mile from Robinson Creek, any loss of baseflow discharge is small and diffuse across the area. However, significant flow loss may be occurring from a small unnamed stream that passes near the wellfield that receives the discharge from the upstream wastewater treatment plant. The south wellfield sits in the bottomlands and is surrounded by a large loop of the Kaskaskia River on three sides and the valley wall on the forth. Because there is a 6-foot drop in river elevation through the loop, the river water may be shortcutting across the loop via the groundwater. At the wellfield, located at the upstream end of the loop, the model calculates streamflow losses of 0.35 mgd under non-pumping conditions and 0.54 mgd when the wellfield is operating at 0.31 mgd. The remaining 0.12 mgd needed to balance the pumpage comes largely from recharge within the loop. The net water budget of the model with both wellfields running at a combined 0.82 mgd shows that the river gains a net of 2.3 mgd (3.6 cfs), which is on par with the gain of 4.1 cfs in the Q7-10 low flow estimate from the ILSAM model. Recharge across the whole model area totaled 3.12 mgd.

Vandalia Model. The 50-foot thick sand and gravel deposit that comprises the ridge-drift aquifer at Vandalia is unusual in that it lies above the Kaskaskia River within the western hillside of the valley. The water level within the sand and gravel deposit is more than 40 feet higher than the water level in the river, even though the valley floor is less than 0.5 miles away. A long and narrow hydraulic flow barrier roughly 40 feet high must exist along the lower hillside in order to maintain the large potential groundwater gradients. The origin of this flow barrier is unclear, but it is possible that a lateral moraine composed of fine-grained material formed as a narrow glacier moved down the valley ahead of the advance of the main sheet of ice. The aquifer runs parallel to the river for approximately 3 miles and varies in width from 0.5 to 1 mile. The aquifer does not receive any regional flow or intersect any perennial streams, so all of the recharge is from local precipitation. The aquifer discharges to several small creeks and to springs along the hillside of the main valley.

To assist in the analysis of two aquifer tests performed in test wells for the Kaskaskia Springs Water Company, Olson et al. (2009) constructed a numerical model of the aquifer using MODFLOW. The model incorporated the irregular boundaries of the aquifer, the discharge points at the stream and springs, recharge from precipitation, and the pumpage from the test wells. From a model simulation of the 8-day aquifer test, Olson et al. (2009) calculated a transmissivity of 32,600 gallons per day per foot (gpd/ft). Further simulations indicated that by pumping a new wellfield at 0.4 mgd, flow to the springs could drop by 14 to 34 percent under normal rainfall conditions and by 28 to 57 percent under dry conditions.

Because streamflow is important to many stakeholders in the water supply planning groups, more information was needed on how the springs respond to pumpage. For this project, we collected spring flow measurements at six sites to verify the model, because it was originally constructed with little surface water flow data. At the two streams closest to the proposed wellfield, the disagreements between the model and the field data were less than 10 percent, well within the uncertainty of the flow measurements. Further to the north and south, the disagreements ranged from 25 to 75 percent. At these sites, the model showed less flow, indicating that there may be more sand and gravel or recharge than is currently known.

Analytical Models. A summary of 22 analytical model assessments is provided in Appendix F. Eleven of these public supplies now purchase water from another supplier or have developed their own surface supply (Farina). Another (Red Bud) has abandoned use of the limestone bedrock beneath town and now pumps groundwater from wells tapping sand and gravel deposits located within the Kaskaskia River bottoms several miles away. Yet another (Gays) is no longer a public water supply; residents are connected to the Moultrie County Water District. Shifts in water supply sources are likely a result of marginally or deficient aquifer capacity, particularly during drought, or as affected by a growing demand.

A short description of the analytic models and how the estimated yield was calculated for each of the ten communities continuing to use their local aquifers as evaluated by Wehrmann et al. (1980) or Visocky et al. (1978) is provided in Appendix F. For those communities, the latest average daily usage was divided by the estimated aquifer yield to compute what is called a Use-to-Yield (UTY) ratio. UTY values exceeding 0.9 suggest locations where groundwater availability problems exist or could be impending; any value greater than 1 means that the aquifer is being pumped at rates exceeding its estimated yield (Wehrmann et al., 2003). Average daily pumpage was based on the most current data available in the Illinois Water Inventory Program (IWIP) database.

Conclusions and Recommendations

This report presents a summary of 1) the technical information assembled to describe existing water availability and sources of supply within the 22-county Kaskaskia River region in southwestern and south-central Illinois, and 2) the development of computer models that will be used in future studies to estimate impacts to water availability resulting from future water development in the region.

Compilation of existing technical information includes a review of previous analyses and publications dealing with the Kaskaskia River region’s water resources, a collection of hydrologic data, primarily as needed for hydrologic modeling, and, in certain cases, additional analyses on that data, such as data mining of well records and yield analyses of surface water supply sources. This compiled information focuses on the four primary sources of water supply within the Kaskaskia River watershed: 1) the two large federal reservoirs (Carlyle Lake and Lake Shelbyville) and low flow releases from these reservoirs; 2) water supply reservoirs on tributary streams; 3) direct withdrawals from tributary streams; and 4) groundwater from within the Kaskaskia River region.

Three categories of models were developed for use in evaluating water supply availability in the Kaskaskia River region under existing conditions and future scenarios: 1) a streamflow accounting model, designed to examine how water resource modifications have changed the availability of flow in streams and to estimate how the flow will change in the future under selected water use scenarios; 2) a hydrologic simulation model of the Kaskaskia River watershed and reservoir routing models describing the inflow-outflow patterns in the two federal reservoirs; and 3) numerical and analytical groundwater models used to determine the yield and rate of replenishment of selected community systems in the region. In all modeling cases, the work performed to date includes the development of the model using model calibration and verification procedures, producing interim modeling results pertaining to water supply development.

Except along the river, the geology over much of the Kaskaskia River watershed is largely unfavorable for the development of groundwater systems that supply water for more than a few households. For many communities the historical development of groundwater supply systems has been problematic, often resorting to using a large number of shallow wells or a long pipeline to a distant aquifer. Because shallow groundwater also does not provide a reliable source of baseflow for many of the streams in the region, most larger communities in the watershed have needed to develop reservoir storage to provide a reliable primary source of supply during drought periods.

Probabilistic-based yield analyses of the community reservoir supplies in the region indicate that most systems appear to have an adequate supply, i.e., with less than a 10 percent chance that shortages would be experienced during a drought of record condition. Six reservoir systems in the region are considered inadequate or at risk of water shortages, however. Most of these systems serve small communities that potentially could haul water or possibly interconnect with a larger system if faced with the threat of shortages.

A preliminary re-evaluation of the yield for the federal reservoirs was performed using the previously developed (2001) monthly water budget models of the lakes. Although this assessment suggests the potential for a slight increase in the 50-year drought yield of the reservoirs, it is recommended that a more detailed water budget analysis using daily data inputs and evaluation of data uncertainties be conducted in revising the yield estimates. Furthermore, yield estimates for the federal reservoirs were based on an assumption that water withdrawals or releases occur at a constant rate throughout the drought duration, rather than the more likely scenario that there would be periodic releases from the reservoirs for major downstream users. Future yield analyses should include variable water use scenarios that are more likely to occur during a major drought.

Roughly 60 percent of the water supply storage in the two federal reservoirs is allocated to coal-fired power plants located in the lower reaches of the river in the Kaskaskia Navigation Channel. A considerable amount of river flow in this reach is also needed to provide water for lockages at the Kaskaskia Lock and Dam. Previous analysis of water needs in the navigation channel by Durgunoglu and Singh (1989) needs to be revised, not only because of changing water supply needs, but also because that analysis did not provide an assessment of the operation of the channel during the most severe drought conditions such as occurred in 1953–1955. Similar to the yield analysis for the federal reservoirs, the analysis should consider scenarios that simulate realistic, variable water releases from the reservoirs.

Water for moderate growth at existing public water supplies on the Kaskaskia River has also been considered in the allocation of water from the federal reservoirs, but any large, additional water supply development in the Kaskaskia River region will need to address the limitations in the water supply yields of the federal reservoirs. The needs in the Kaskaskia River region for future sustainable economic development (such as for coal mining, coal-fired power plants, liquid fuel production facilities, and public water supplies) will require a comprehensive regional water supply planning process to identify future needs and economically viable water supply sources. Such a comprehensive study and plan for the Kaskaskia River region will be needed to answer the necessary questions and allow for the proper development and siting of future energy development facilities.

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Appendix A

Description of Regional Aquifers

Aquifer Information

General groundwater conditions for the Kaskaskia River basin study area are shown in Figures A1–A7. The occurrence of groundwater correlates with the thickness of the glacial drift overlying the bedrock (Figure A1). The region was covered by multiple glaciations with the most recent, known as the Wisconsinan, only advancing as far south as Shelbyville. The extent of the Wisconsinan is marked by the Shelbyville Moraine, a large topographic feature that stretches across east-central Illinois. North of the moraine the glacial deposits are thick and contain widespread sand layers, and south of the moraine the glacial deposits are thin with only isolated sands. In the Mahomet Valley at the extreme north end of the Kaskaskia watershed the glacial deposits can be over 300 feet thick and contain 150 feet of sand.

Maps of the expected yields of wells completed in sand and gravel aquifers and bedrock aquifers are presented in Figures A2 and A3. As shown, the highest well yields (as much as 100 gallons per minute) within the Kaskaskia basin study area lie within the sand and gravels along Kaskaskia River valley (Illinois Technical Advisory Committee on Water Resources, 1967). Outside of the river valley, well yields drop dramatically, and large areas appear where sand and gravel aquifers are virtually absent and other water sources (e.g., surface water) are usually developed. The bedrock well yields within the Kaskaskia basin study area are generally very poor with capacities of less than 10 gallons per minute. While not capable of being shown on this map, the quality of the water produced from bedrock wells within the study area is also very poor and tends to be highly mineralized. Well yields can be further defined by conducting controlled aquifer tests in high capacity wells. The relationship of drawdown in a well versus time during a test can be used to determine the permeability and storativity of an aquifer. Compared to the Mahomet Aquifer, few tests have been conducted in the Kaskaskia Aquifer, but they do provide valuable information (Figure A4).

Because the geology of the watershed is not mapped in great detail, a data-mining exercise was performed on the ISWS private well database to see if any previously unknown sand bodies exist that are capable of supporting a community well. Of the 34,060 records for domestic, commercial, and irrigation wells with locational information in the 19 counties touching the watershed, 16,284 of the records had information on whether a well was bored (37 percent) or drilled (63 percent). Records for 19,065 wells could be classified as being completed in the bedrock (30 percent) or in glacial deposits (70 percent). A total of 14,732 well records overlapped both groups and are plotted on Figures A5–A7. The 3196 wells completed in bedrock are principally in the southwest counties of St. Clair, Monroe, Randolph, Clinton, and Washington where there is fresh water in the sandstones. The 5038 large-diameter dug and bored wells are widely distributed throughout the region except over the Mahomet Aquifer and the freshwater sandstones. These wells are constructed where there are no significant sands in the glacial deposits and typically only yield enough water for a household supply. The distribution of drilled glacial wells is highly dependent on the presence of saturated glacial sands more than a few feet thick. Of the 6498 drilled glacial wells, 5873 (90 percent) are north of the termination of the Shelbyville Moraine or are in the American Bottoms. A majority of the remaining drilled wells in the Kaskaskia River watershed are in the Kaskaskia Aquifer, and only a handful of well clusters exist, which may indicate significant unmapped sands. However, a review of the individual well records from these did not reveal any sand bodies that could support a high-capacity well.

The Kaskaskia Aquifer

Information on the hydraulic character of the Kaskaskia Aquifer is available for stretches of the aquifer from Illinois State Geological Survey (ISGS) and Illinois State Water Survey (ISWS) reports, ISWS well data and aquifer test results, files for communities tapping into the aquifer, and engineering borings at the dam sites. Due to the multiple depositional and erosional cycles in the valley, the extent and thickness of the aquifer sands are extremely variable. Past attempts to develop a groundwater supply in the aquifer, such as an attempt by the Village of Ramsey (Sanderson, 1996), have often required geophysical surveys and multiple test holes to find a suitable location for a high-capacity well. In general, well records indicate that the aquifer sands become thinner, less extensive, and less productive moving downstream from Shelbyville. Well installation records and aquifer tests show wells capable of pumping more than 150 gallons per minute (gpm) are possible at selected locations along the river, such as at Cowden, Aviston, and near Red Bud.

The upper reach of the aquifer at Shelbyville was mapped by Cartwright and Kraatz (1967) as a meandering sand body roughly 1 mile wide with a maximum thickness of 20 to 40 feet along its axis. The Shelbyville north wellfield occupies the thickest and widest point in the 9-mile stretch that was mapped (Figure A8). Downstream in north-central Fayette County, Sanderson (1996) conducted tests at a site with two sand units 30 feet thick separated by 20 feet of clay. Previous testing conducted in this stretch of the river suggested that the upper sand unit could not provide more than a million gallons per day (mgd) to a wellfield. Three aquifer tests of the lower aquifer indicated that a 1 to 1.5 mgd supply could be developed but at two widely spaced wellfields. At Vandalia, Larson and Sargent (1999) conducted geophysical surveys that suggest sufficiently thick sand deposits to develop a 1.5 mgd water supply occur along the west bank of the river south of town. North of Vandalia, Larson and Sargent (1999) investigated a ridge-drift aquifer, similar to the Taylorville strip aquifer, which occurs along the west bluff of the river above the valley floor. The authors believed this aquifer could be pumped at 1.5 mgd for short periods, but question the long-term viability based on overdraft problems encountered at Taylorville. Aquifer test and model analysis by Olson et al. (2009) suggest that a supply of 0.4 mgd could be developed from the ridge-drift aquifer.

South of Lake Carlyle many small systems have been developed in shallow or thin sands near the river. Due to inadequate supply, contamination, or other economic reasons, many systems have converted to purchasing surface water from larger water utilities.

Germantown obtains two-thirds of its water from four 25-foot-deep wells that pump only 20 to 30 gpm. Potentially more sustainable supplies have been developed at towns where the aquifer sand is thicker and at greater depth where there is more available drawdown. These supplies include sands of depths at 42–72 feet for Aviston, 31–52 feet for Bartelso, and 24–70 feet for St. Libory. The most productive supply in the aquifer below Lake Carlyle was developed adjacent to the river near Red Bud where the aquifer is 67 feet thick and at the surface. Two wells were installed with pumps capable of producing 525 gpm, although much of this water is likely induced directly out of the river.

As with any shallow aquifer, the potential for contamination cannot be overlooked. In 1996 Okawville switched to a surface water source because of suspected contamination from oilfield brines. Between 1971 and 1990 the iron and hardness concentrations in Okawville well #4 increased from 5.5 to 24 milligrams per liter (mg/L) and 338 to 1088 mg/L, respectively. The aquifer at Shelbyville south wellfield is at the surface and contains nitrate at concentrations above the standard that is suspected to have come from agricultural activity. The north wellfield has 10 to 15 feet of clayey material at the surface that appears to better protect the aquifer from contamination. The shallow wellfield at Germantown has experienced low levels of contamination with industrial organic compounds, although it remains free of coliform.

From a water supply planning perspective, the impact of groundwater use in the watershed should be minimal to the flow in the Kaskaskia River, especially if the minimum releases of 10 cubic feet per second (6.5 mgd) from Lake Shelbyville and 50 cubic feet per second (32.8 mgd) from Lake Carlyle already provide a substantial rate of flow in the river. The largest groundwater supplies have pumping capacities of less than 3 mgd, but because of regional groundwater flow, the amount of surface water that one of these systems could induce would be significantly less. In addition, a large portion of the pumped groundwater will later be discharged to the stream as wastewater. It may be possible to deplete the low flows by constructing a large riparian wellfield with a capacity of 5 to 10 mgd in a location where the aquifer is in good connection with the stream, such as at Shelbyville or Red Bud.

The Mahomet Aquifer

The extreme north end of the watershed is underlain by the Mahomet Aquifer, which supplies Champaign-Urbana with more than 25 million gallons of water per day. The aquifer is formed in a large buried valley sand deposit 100 to 150 feet thick that can commonly supply more than 2000 gpm to individual wells. The aquifer extends from western Indiana to the Illinois River and has a total use of approximately 200 mgd (Wilson et al., 1998; Wehrmann et al., 2011). The small fraction of the Mahomet Aquifer underlying the Kaskaskia River basin is covered with over 100 feet of impermeable clay, which prevents any significant amount of recharge within the basin from reaching the aquifer. Water originating from elsewhere in the Mahomet Aquifer is sent down the Kaskaskia River from the southwest wastewater treatment plant in Champaign. During dry periods, an industrial user operates four high-capacity wells that discharge Mahomet Aquifer groundwater directly into the stream for use downstream at Tuscola.

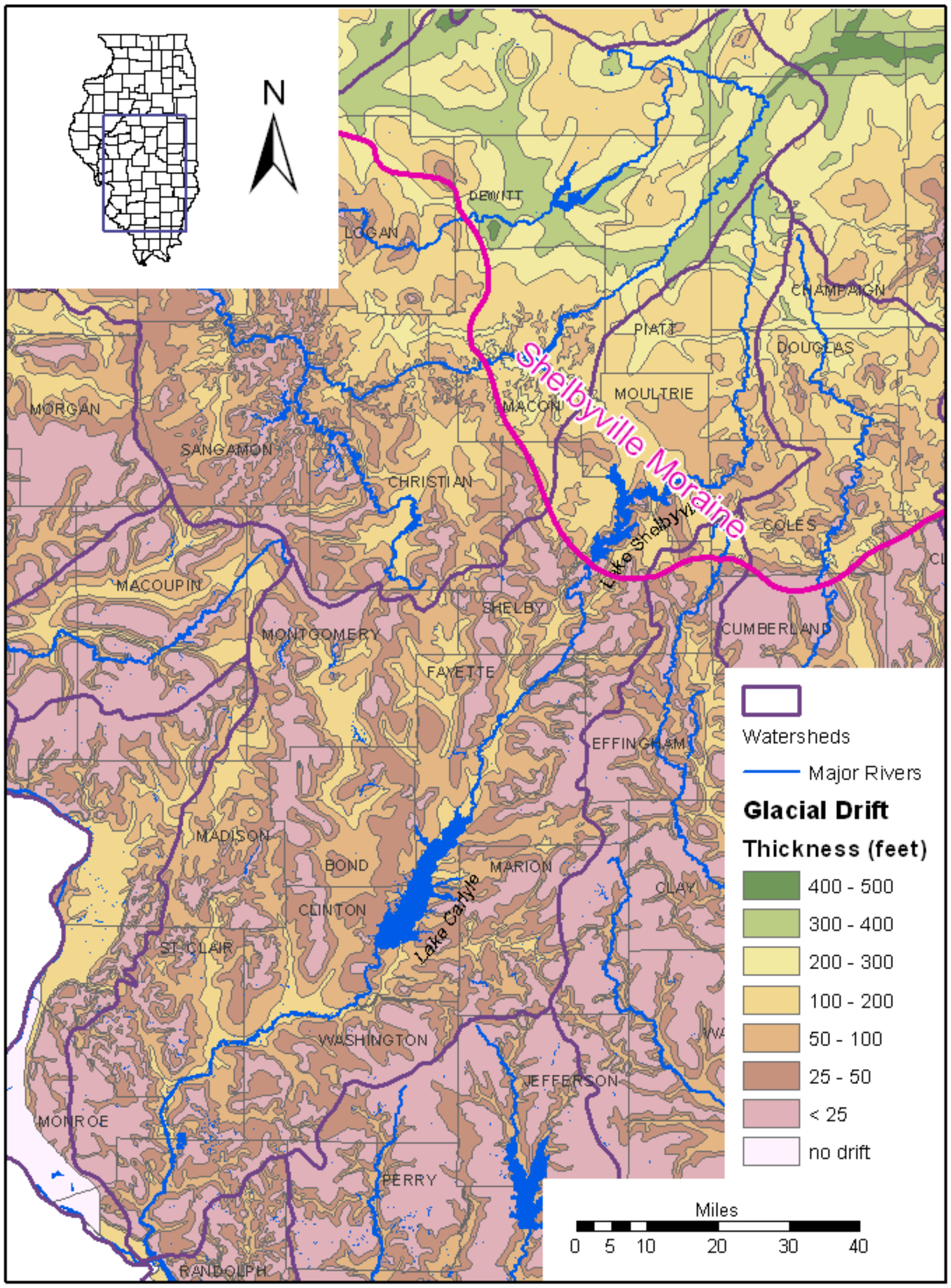

Figure A-1. Thickness of the glacial drift in central and southern Illinois (from ISGS data)

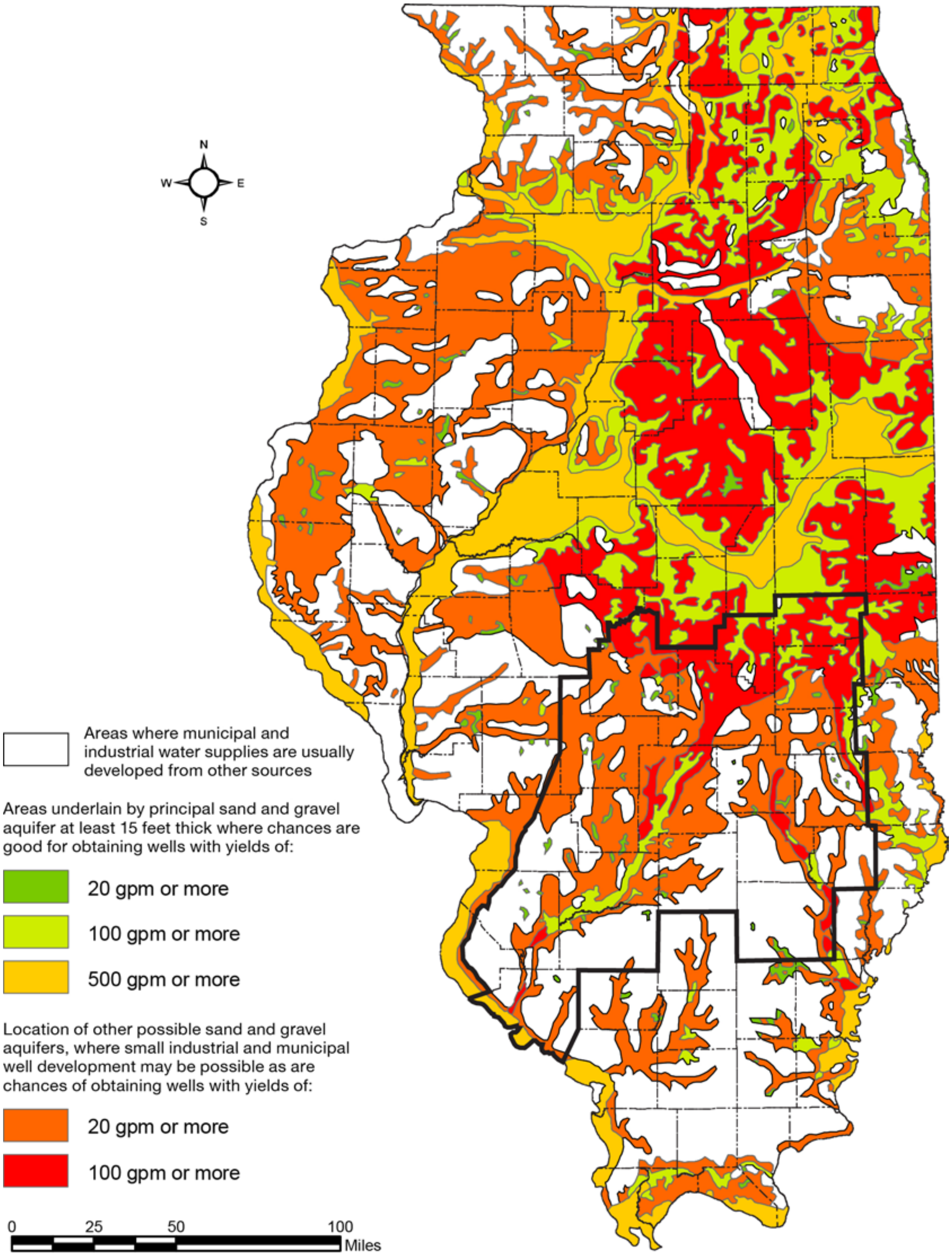

Figure A-2. Expected yields of wells completed in sand and gravel aquifers in Illinois, after Illinois Technical Advisory Committee on Water Resources (1967)

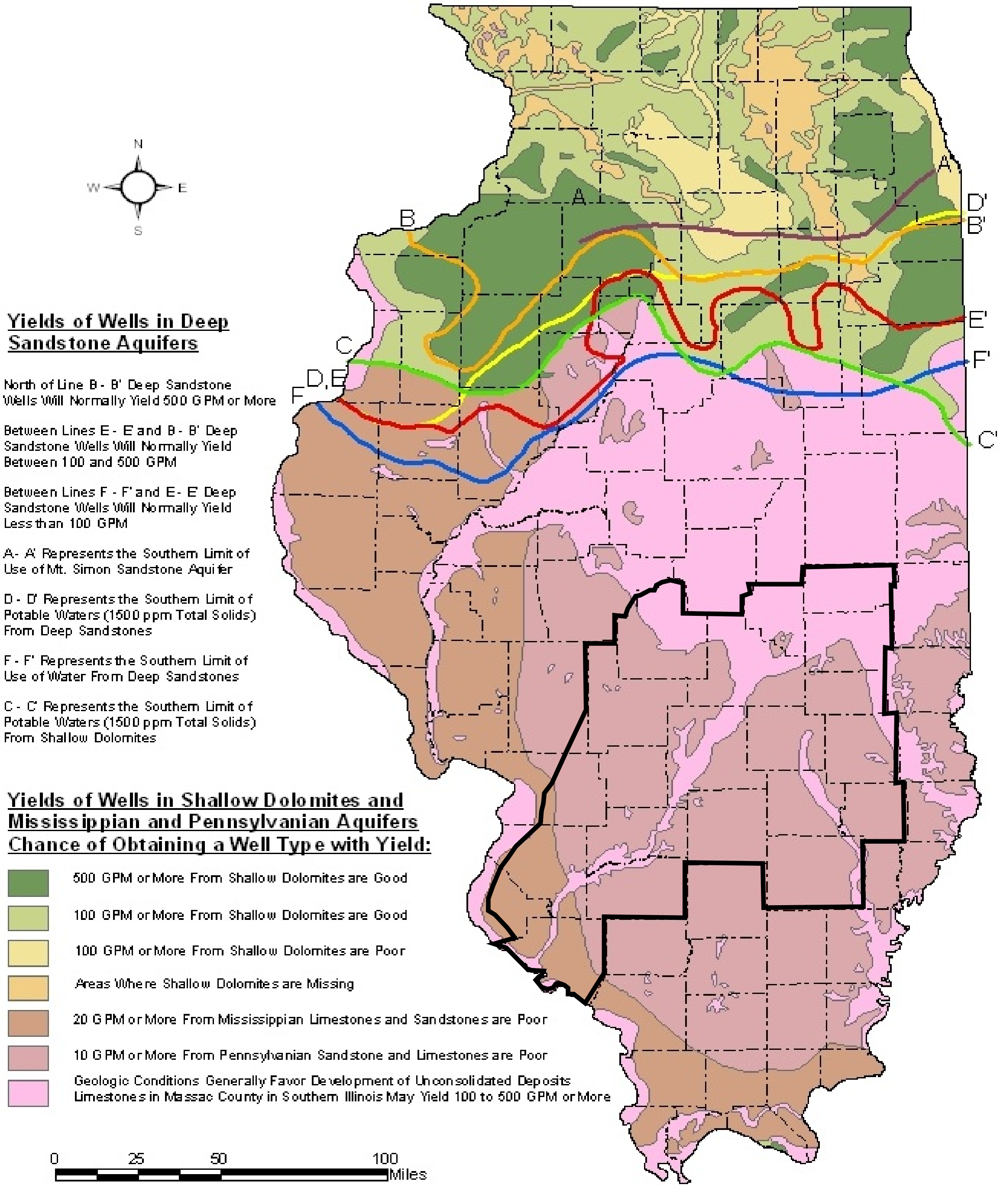

Figure A-3. Expected yields of wells completed in bedrock aquifers in Illinois, after Illinois Technical Advisory Committee on Water Resources (1967)

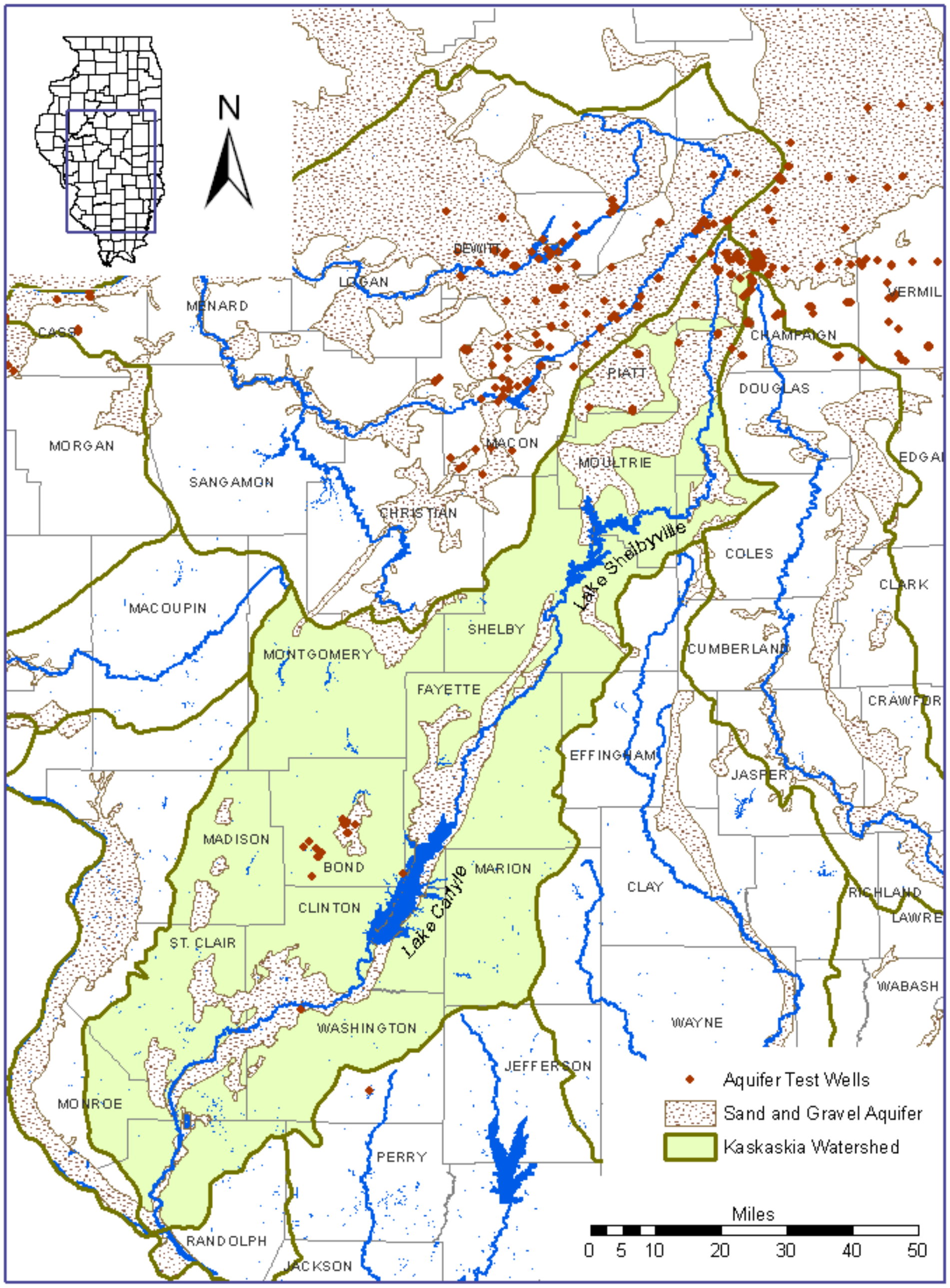

Figure A-4. Locations of aquifer tests on file at the ISWS

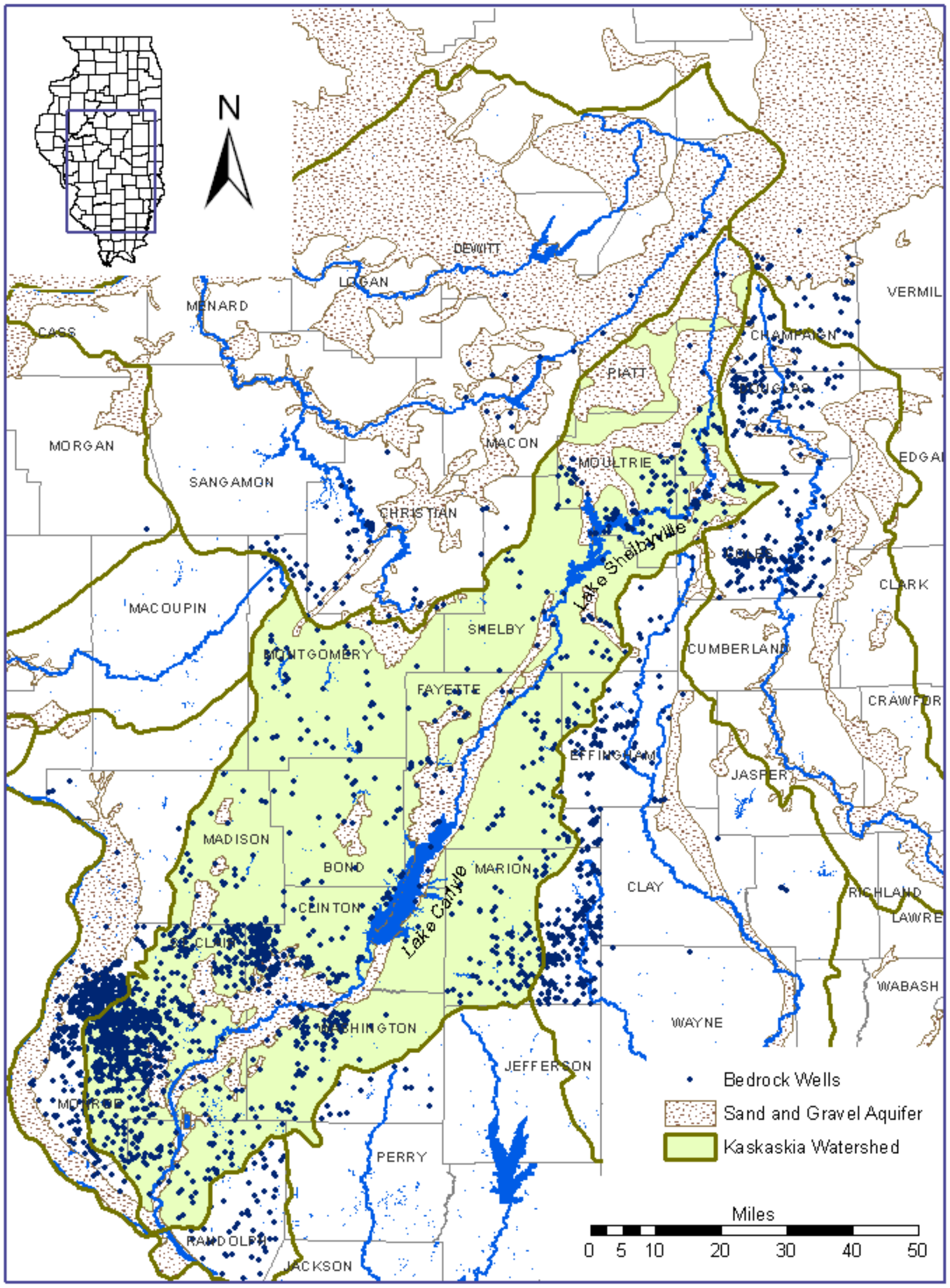

Figure A-5. Location of wells in the ISWS database completed into bedrock

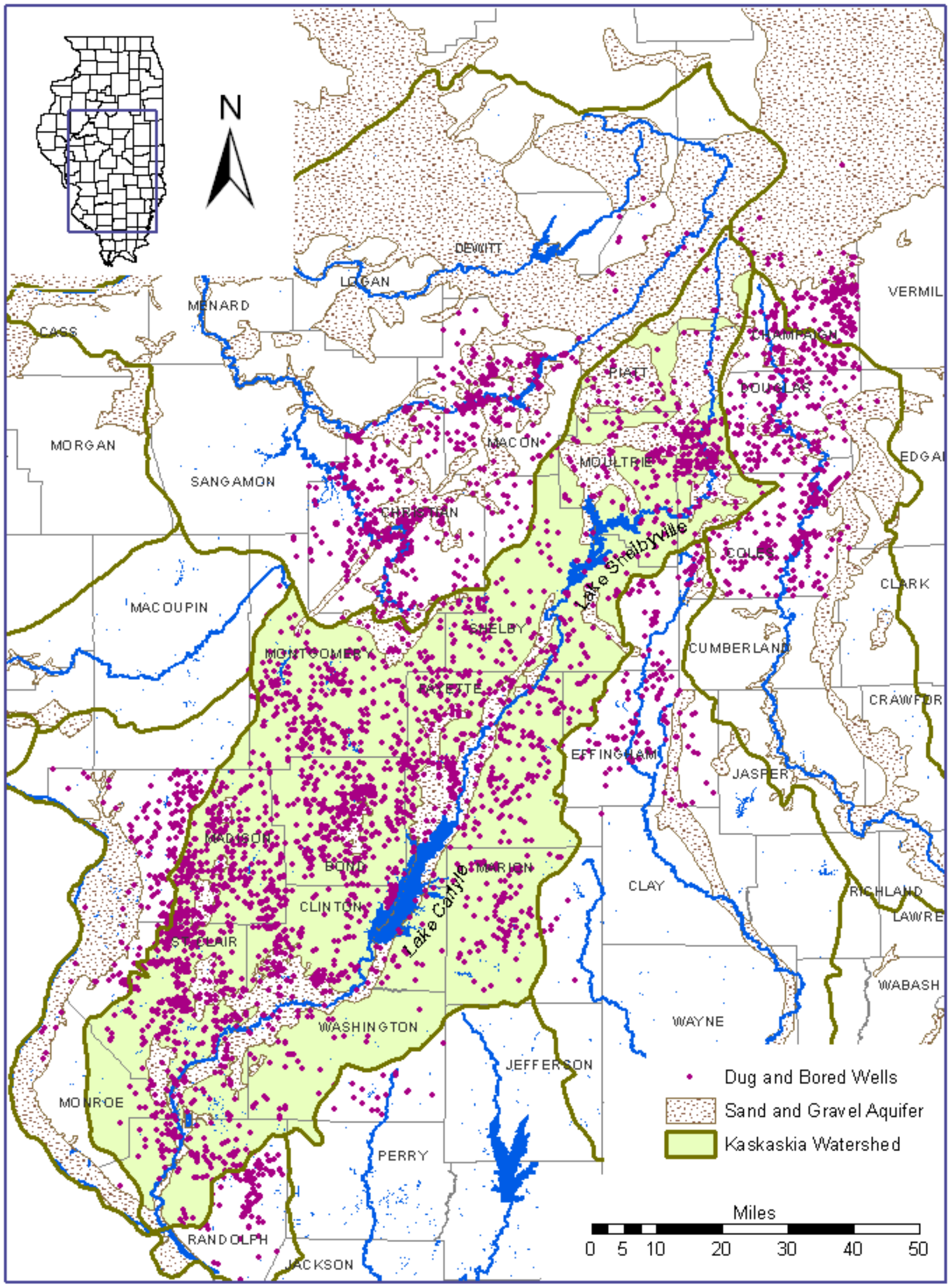

Figure A-6. Location of dug and bored wells in the ISWS database completed in the glacial deposits

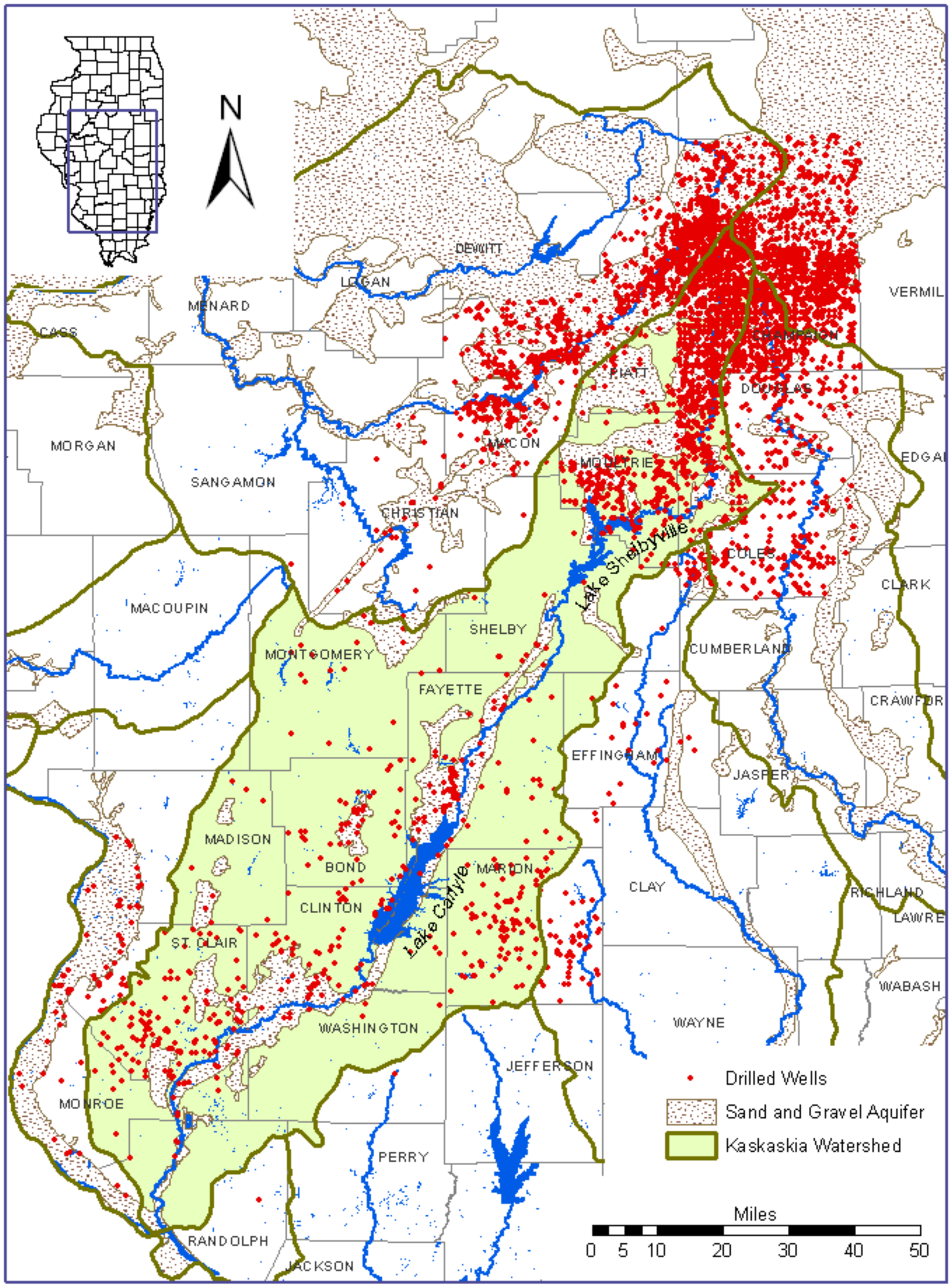

Figure A-7. Location of drilled wells in the ISWS database completed in the glacial deposits

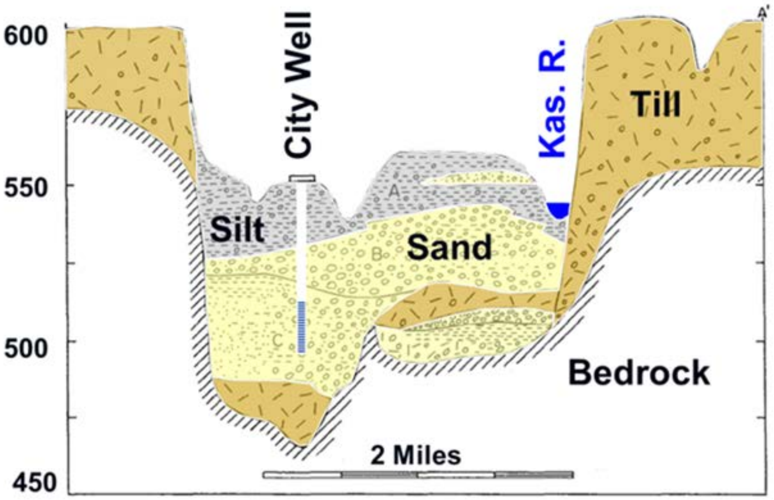

Figure A-8. Geologic cross-section through the north Shelbyville wellfield (Cartwright & Kraatz, 1967)

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Appendix B

Surface Water Resources in the Kaskaskia River Region

A Brief History of Water Development in the Kaskaskia River Region

> "The stream (Kaskaskia River) is subject to great variations in volume, as it drains a region in which the substrata are of compact clay, which promotes a rapid run-off and furnishes but little water in seasons of drought." – Leverett (1896)

In the late 1800s when community water supplies in the Kaskaskia River region were first being developed, most systems obtained their water from shallow wells dug into either glacial drift or stream valleys. Of 28 community supply systems in the region, only 7 used streams as a source of supply, and all but one of these systems (Carlyle) supplemented that supply with groundwater during times of low streamflow (Leverett, 1896). In 1894–1895, Illinois suffered its worst drought to date, and the effect on both surface supplies and groundwater wells was severe. "In many localities where such wells before yielded a sufficient supply a large number became entirely dry because the available ground water was exhausted" (Leverett, 1896).

Period of Community Reservoir Construction

In the decades following the 1894–1895 drought, many communities in the region began building surface water reservoirs to store water for times of droughts. Litchfield, one of the larger communities in the region at the time, with a population of 5800, was the first to build a water supply reservoir. In 1912, the largest community in the region, Belleville, interconnected with the East St. Louis system and began the first inter-basin transfer of water in the region. By 1925, 12 water supply reservoirs had been built, and a total of 18 communities in the region depended entirely on surface water supplies. By the 1940s, following another severe drought in 1929–1931, a total of 20 communities had constructed their own water supply reservoirs (Gerber, 1937; Habermeyer, 1925, 1938, 1940). A chronology of reservoir construction is provided in Table B-1.

The 1953–1955 drought was the worst on record, and most communities discovered that their existing reservoirs and other sources of supply were insufficient. Of the 58 reservoir supply systems in Illinois, 40 were considered to have shortages during the 1953–1955 drought (Hudson and Roberts, 1955). In the Kaskaskia River region this included the reservoir supplies for Altamont, Ashley, Centralia, Coulterville, Hillsboro, Mattoon, Nashville, Olney, Pana, Sparta, and St. Elmo. In most cases, the inadequacy of the supply was attributed to a combination of insufficient reservoir size and large increases in community water use that had occurred in previous decades. The declining capacity of reservoirs from sedimentation, often cited as a potential concern for water supply adequacy, was not considered a major factor for most systems (Hudson and Roberts, 1955).

Table B-1. Construction of Water Supply Reservoirs in the Kaskaskia River Region

Year	*Reservoir/Community*
1896	Litchfield
1903	St. Elmo
1908	Mattoon (Paradise Lake)
1911	Centralia
1912	Highland, Pana, Salem
1917	Coulterville, Sparta
1918	Hillsboro
1924	Olney (Vernor Lake)
1925	Litchfield
1934	Effingham
1935	Altamont, Nashville
1937	Oakland
1939	Coulterville
1940	Ashley
1943	Centralia (Raccoon Lake)
1945	Kinmundy, Pana
1947	Charleston
1954	Olney (Borah Lake)
1957	Effingham (Lake Sara)
1958	Mattoon
1961	Sorento, Taylorville
1962	Highland (Silver Lake)
1964	St. Elmo (Lake Nellie), Coffeen Lake (power generation)
1965	Litchfield (Lou Yaeger), Vandalia
1968	Baldwin Lake (power generation)
1969	Greenville (Governor Bond)
1972	Altamont, Olney (East Fork)
1975	Newton Lake (power generation)
1978	Hillsboro (Glenn Shoals)
1998	Kinmundy

Following the 1953–1955 drought, there was a new wave of building larger reservoirs for communities in the region, including lakes for Effingham, Mattoon, Vandalia, Litchfield (Lou Yaeger), Highland (Silver Lake), Greenville (Governor Bond), and Taylorville. The last of the water supply reservoirs in this period, Lake Glenn Shoals (Hillsboro), was completed in 1978. During the 1950s drought, the flow in the Kaskaskia River at Vandalia had fallen to below 3 million gallons per day (mgd), prompting that community to build a reservoir. However, in general, communities that directly withdrew from streams seemed to be the least likely of all surface water supplies to experience shortages (Hudson and Roberts, 1955), in most cases because streams were depended on as a supply when the minimum streamflows were much greater than the withdrawals. Because most groundwater supplies in the region have limited yields, the community water supplies that rely on surface water tend to be the larger communities in the region. Except for the portion of the Kaskaskia River region north of (and including) Shelbyville, every community with a population greater than 1500 depends on surface water for its water supply.

In addition to the community water supply reservoirs, there have been three large reservoirs built in the region to provide cooling for power plants: Coffeen Lake, Baldwin Lake, and Newton Lake. In contrast to Coffeen and Newton Lakes, which impound streams, Baldwin Lake gets most of its water by pumping from the Kaskaskia River.

Recent Water Supply Trends – Greater Interconnection of Supplies

For the most part, the water supply reservoirs built in the years following the 1950s drought have continued to provide an adequate supply for the region's communities, having been built to meet expected water use growth during a future drought of similar severity. But, as noted by Hecht and Knapp (2008), there has been a reduction in the number of smaller communities that continue to provide their own water (for example, Patoka, St. Elmo, and Sorento); in most cases these communities have interconnected with larger community supplies or with a rural water district. For many smaller communities with surface water supplies, the decision to stop supplying their own water is related to the higher costs and treatment plant upgrades needed to meet stricter USEPA surface water treatment regulations, mandated in the 1996 amendments to the Safe Water Drinking Act. It does not appear that this is necessarily a trend to switch from surface water to groundwater, however, but instead to use larger, more reliable supply sources that provide greater cost effectiveness. Water demand for many of the larger systems in the region has increased, not just because of population growth, but because they now serve many smaller surrounding communities.

Carlyle Lake, Lake Shelbyville, and the Kaskaskia Navigation Project

A history of the events leading to the construction of the two federal reservoirs, Lake Shelbyville and Carlyle Lake, has been described in Dwyer and Espereth (1977), Hall (2006), and other publications. Initial considerations for the two reservoirs date back to the 1930s, and plans developed by the U.S. Army Corps of Engineers were revived in the late 1940s and 1950s. As retold by Dwyer and Espereth (1977), it was the combined multipurpose benefits of the reservoir projects, including for flood control, water supply, navigation, recreation, and conservation, and the anticipated economic benefits and opportunities associated with each that led to the broad local support for the reservoirs. Although the Navigation Project would be authorized several years later, commercial and industrial navigation interests, particularly the desire for low-cost coal transportation, were important elements in the overall support for the reservoirs.

Most of the pertinent water supply information regarding Lake Shelbyville and Carlyle Lake and allocations of the State of Illinois water supply storage are included in Appendix C. Additional information regarding yield studies for the lakes are given later in this Appendix.

The Kaskaskia River Navigation Project was authorized by Congress in 1962 to provide a navigable waterway from the Mississippi River to Fayetteville, 50 miles upstream on the Kaskaskia River. The project included not only channelizing the river over this reach, but also constructing and operating a lock and dam directly above the confluence with the Mississippi River. The dam maintains a minimum water level at approximately 368 feet elevation, providing a 9-foot deep pool along the length of the navigation channel. The lock allows boats to be raised and lowered between the Mississippi River and the navigation channel. The lock is 600 feet long, 84 feet wide, and can be operated up to a maximum lift of 29 feet (difference in elevation between the navigation pool and the Mississippi River). Under normal water level conditions in the Mississippi River, the elevation difference between the Mississippi River and the Kaskaskia channel is often in the range of 5 to 15 feet. During these conditions, the amount of water needed to fill the lock ranges from 2 to 5 million gallons. At times of near maximum lift, such as might be needed when drought creates low water levels in the Mississippi, as much as 10 million gallons might be needed for a single lockage. For much of the summer of 1988, for example, the Mississippi River elevations ranged from 345 to 347 feet, thus requiring an average lift of 23 feet for several months during the drought. With the amount of commercial barge traffic that was originally envisioned for the Kaskaskia channel, it was anticipated that water releases from Carlyle Lake and Lake Shelbyville would be needed to supplement the natural flows downstream of the lake in satisfying the water demands for lockages. But because commercial barge traffic has not reached its potential and lockages have been fewer in number, water releases from Carlyle Lake have not been needed to maintain flows in the navigation channel; although, as described in more detail in Appendix C, section 16, conditions during the drought of 1987–1988 required restrictions in both water use and lockages to avoid the need for navigation releases.

The lock and dam was opened at the end of 1973, and the full channelization and operation of the navigation pool was completed in 1978. For roughly 15 years, the commercial traffic on the channel increased, reaching a peak annual tonnage in 1989 of 4.4 million tons. The reported peak number of lockages per year, 3720, occurred in 1991. Since that time, the commercial traffic has dropped off considerably, reaching a minimum annual tonnage (409,000) in 2000 and a minimum number of lockages (1037) in 2008 (U.S. Army Corps of Engineers, 2011). Although the primary purpose of constructing the Kaskaskia Navigation Channel was for navigation of commercial barges, with emphasis on coal transportation, the overwhelming use of the waterway to date has been for recreational boating.

The Illinois Department of Natural Resources (IDNR) operates wildlife management areas immediately upstream of Carlyle Lake and Lake Shelbyville primarily for waterfowl conservation and hunting purposes. Operation of the Carlyle Wildlife Management Area involves large withdrawals and returns of water from the lake. During the fall, two 30,000-gallon stationary pumps located at an intake at River Mile 113.8 and one portable 24,000-gallon pump are used to withdraw water from Carlyle Lake and flood the 3,500-acre wetland area until the depth of water is approximately 18 inches. Thus, the total volume of withdrawal is estimated to be 5,250 acre-feet. The date during which pumping commences depends upon both the start date of duck hunting season and the storage in the impoundments within the Wildlife Management Area. After duck hunting season concludes (usually in late January), approximately 12 inches of the water (3500 acre-feet) are released back into Carlyle Lake and the remainder is retained to provide a feeding ground for migratory waterfowl as they return north. Then, on the first week of April, the rest of the water is drained from the impoundment into Carlyle Lake. More water is pumped into these wetlands during dry years than wet years. These large water diversions to date have not been considered in analyzing the water budget or yield analyses of the reservoirs, and although they may not noticeably alter the water supply accounting, they should be analyzed for potential effects.

Water Supply Planning and Evaluation Studies

Water Supply from Lake Shelbyville and Carlyle Lake

The Illinois Technical Advisory Committee on Water Resources (ITACWR, 1967), in a report prepared for Governor Kerner, first examined the potential role of the federal reservoirs for meeting future water supply needs in the Kaskaskia River region. In that study, there was an implied expectation that several water districts would form to withdraw and treat water from the federal reservoirs (and the river downstream of the reservoirs) and distribute that water to many communities in the region.

In the decade following the construction of Carlyle Lake and Lake Shelbyville, the Illinois State Water Survey (ISWS) conducted several planning studies on the Kaskaskia River region, with some being partially funded by the Illinois Division of Water Resources, Department of Transportation (now in the Department of Natural Resources). Singh et al. (1972) conducted an optimization analysis to indicate how water reserves in Carlyle and Shelbyville could be used for future water supply needs at minimal cost. Similar to the ITACWR approach, the analysis by Singh et al. (1972) assumes that most of the communities would be interconnected and water provided from the federal reservoirs and a select few other reservoirs. One of the study options considered constructing an additional seven medium-sized reservoirs in the watershed. A second option was based primarily on using Carlyle Lake, but considered using Lake Lou Yaeger as an additional regional resource for part of the watershed. The study did not consider Lake Shelbyville as a desirable regional resource because of transmission costs, and did not look at releases from that lake except in terms of supplying potential deficits in Carlyle Lake. Singh et al. (1972) concluded that the State's water supply storage in Carlyle Lake should be adequate to meet most of the watershed's community water supply needs in the region to 2020. The study looked only at community supplies and did not consider water supply allocations for other uses. This study and the previous ITACWR report also did not address the fact that many larger communities in the watershed had recently constructed their own supply reservoirs.

Subsequent ISWS studies examined the optimal joint operation of the two lakes (Singh, et al., 1975; Singh, 1977). Similar to other documents of that era, Singh (1977) considered that the main purpose of the joint-use pool was to meet the water needs of the Kaskaskia Navigation Project. Even with the high rate of river traffic projected at that time, Singh estimated that the joint-use storage in Carlyle Lake alone would be sufficient for meeting the navigation flow requirements. Singh's analysis included looking at changes in major policy and operating levels of the federal reservoirs to maximize water supply "when state and federal storages are not considered separate and distinct and the total storage is regulated in the best interest of all purposes." Singh (1977) goes on to conclude that a total of 65 mgd of water supply withdrawal could be made available from the system during a 50-year drought if up to 20 percent of the unused federal reserve were used for water supply. Impacts to agriculture (by flooding) and recreation were considered in the optimization analysis; however, low-water impacts to recreation were not considered to occur until water elevations in the Carlyle and Shelbyville reservoirs fell below 438 and 589 feet, respectively. The study did not consider impacts to fish and wildlife conservation. Economic optimization analyses such as Singh et al. (1972) and Singh (1977) were very popular research tools of that time period, but often did not result in water resource policy changes, in part because: 1) they typically did not consider non-economic factors in decision making, 2) they often ignored or undervalued social benefits for which it was difficult to determine monetary worth, and 3) they were practical only when decision making was centralized and did not require multiple stakeholder groups to "buy in" to the decision.

Kaskaskia Navigation Channel

Durgunoglu and Singh (1989) investigated low flow records on the lower Kaskaskia River to identify the frequency and degree to which the flow in the river might not be expected to satisfy water demands for lockages at the Kaskaskia Lock and Dam, community water supply withdrawals, and withdrawals by the Baldwin power plant. This study was conducted during the late 1980s when the amount of lockages and commercial barge traffic was noticeably higher than at present. Their analysis also only investigated the period of record since Carlyle Lake was built, during which the worst droughts occurred in 1976 and 1988. Thus, the study did not try to extrapolate beyond the period of record to estimate potential conditions that may have occurred during some of the more severe historical droughts prior to 1970. Their analysis indicates that during the 1976 and 1988 droughts the river's flow would have been capable of satisfying water supply withdrawals (including the Baldwin plant) and meeting high evaporation losses from the navigation pool, but deficits would occur when also trying to meet the lockage needs during these summers. Deficits would cause a drop in the navigation pool unless additional water was released from Carlyle Lake. Their analysis indicated that even if the withdrawals for the power plant were discontinued, lockage would need to be restricted to avoid water deficits during these drought years. Because conditions have changed since 1989, with fewer lockages but the impending demands of a second power plant, this study might need to be revisited, as it seems that releases from Carlyle Lake would likely be needed during periods of severe drought to meet all downstream water demands. Two of the alternatives presented by Durgunoglu and Singh are the possibilities of 1) operating the navigation channel at a slightly higher elevation (368.8 feet), providing extra storage of water for times of deficit, and 2) pumping Mississippi River water into the navigation pool during times of need.

Estimation of Water Supply Yields

In most years, Illinois is considered to be a water-rich state. Severe droughts of the type that threaten water supplies are rare enough that generations can sometimes pass before a community experiences a hint of water shortages. Since the 1950s, only a few moderately severe droughts, such as what occurred in 1988–1989, have produced conditions that were considered to be a significant threat to some of Illinois' community water supplies; even then the impact was regional and felt only at a few select systems.

Two of the worst droughts on record in the Kaskaskia River region occurred in the 1930s and 1950s. Streamgaging records, needed to evaluate the hydrologic impact of drought, are available from a number of gaging stations in the region during the 1950s drought, considered to be the drought of record. In the 1930s, gages were primarily located only on large rivers; within the Kaskaskia watershed, for example, there was only one gage operating at that time (the Kaskaskia River at Vandalia). Because there is a limited number of severe historical droughts, calculation of water supply yields must rely heavily on those few severe droughts for which data are available; thus, substantial weight is given to hydrologic records from the 1950s, such that the more recent hydrologic records may often be disregarded in water supply yield analyses. (The extension of gaging records to estimate drought flows is addressed in Appendix D).

Systems using Direct Stream Withdrawals

A direct withdrawal system is one in which water is withdrawn from streams without the need to store water in a reservoir for use in low flow periods (typically these systems may have storage, but only for a few days of use). Four systems in the Kaskaskia River region are considered to have direct withdrawals: Carlyle, Evansville, Kaskaskia Water District, and SLM Water Commission. All of these systems are considered to have an adequate source of supply because the minimum flows in the lower Kaskaskia River far exceed the systems' withdrawal rates. Other communities, such as Nashville, Sparta, and Vandalia, which have direct-withdrawal components within their system, also rely on reservoir storage. Direct withdrawal systems are used only when the historical minimum flow in the stream or river exceeds the water demands of the system, usually by a substantial amount. The 1-day, 50-year low flow in the region's streams, used to describe the minimum flow rate, are calculated by the ILSAM model (Knapp, 1990), the update of which is described in Appendix D. Breese, Charleston, Effingham, Fairfield, Flora, Mascoutah, Vandalia, and Wayne City are all systems that had direct withdrawal systems at various times over the past century, but for which their streams were shown to provide insufficient flow during a severe drought.

Community Water Supply Reservoir Systems

Water Budget Method. A reservoir's yield is the maximum demand at which water could be withdrawn from an impounding reservoir over a selected hydrologic period without the reservoir's storage falling below a critical volume. This amount is computed using a mass-balance (water budget) equation that typically calculates the storage in the reservoir using a monthly time-step:

$$S_t = S_{t-1} + Q_t + SA_{t-1} * (E_t - P_t) - D_t$$

The volume of water, S_t, that remains in the reservoir at the end of month is the balance of the storage at the end of the previous month, S_{t-1}, the inflow that occurs during that month, Q_t, the net evaporation from the reservoir during that month, $E_t - P_t$, based upon the surface area of the reservoir at the end of the previous month, SA_{t-1}, and the withdrawals, D_t, from the reservoir. The inflow and net evaporation vary from month to month. Meanwhile, the demand is usually assumed to be constant throughout the entire time period for which the yield is computed. The critical duration of the drought is the period during which the maximum amount of storage is accessed, i.e., the difference in time between when a reservoir's storage first begins to decline below its full storage and when the reservoir reaches its minimum storage. The most common critical duration for Illinois water supply reservoirs is 18 months; however, the critical duration depends upon the size of the reservoir, inflow characteristics, and water demand, and for some reservoirs can be as long as 54 months.

Inputs into the water budget equation of streamflow, precipitation, and evaporation can be from sequential hydrologic observations, such as the analysis for a specific historical drought. However, input into the equation can also be developed from processed statistical information, such as is commonly used in determining yields associated with an estimated 50-year drought frequency. In this manner, an estimate of total inflow, precipitation, and evaporation over the course of a 50-year drought frequency is estimated using the hydrologic and climatic records, and is then used as a collective input in the equation to estimate total change in storage for a given demand rate. This type of drought frequency analysis is often termed a non-sequential analysis because the processed hydrologic information does not bear the sequential patterns of any specific drought period, and the water budget is computed for the collective drought period instead of on a month-by-month basis.

Yield Calculations. Previous yield analyses from the ISWS have always been based on the non-sequential method for drought frequencies. McConkey-Broeren and Singh (1989) used this method in determining the yield for community surface water supply systems in Illinois, and determined that eight systems in the Kaskaskia River region might experience drought-related shortages during a 50-year drought. These systems were Coulterville, Fairfield, Farina, Flora, Kinmundy, Sorento, Waterloo, and Wayne City. Three of these systems, Flora, Sorento, and Waterloo, now purchase water from other systems. In 1998, Kinmundy constructed a new, larger reservoir immediately downstream of their old reservoir, and is no longer considered an inadequate system.

Yield estimates for community surface water supplies were most recently estimated by the ISWS in 2010 (www.isws.illinois.edu/data/ilcws/drought). The ISWS evaluated uncertainties in the data used as input into the water budget method, such that each community's yield estimate was developed on a probabilistic basis. The designated 50 percent yield value is the best (most likely) estimate for the water supply system; however, there is also roughly a 50 percent probability that the estimate is either overestimated or underestimated compared to the "true" yield, which is an unknown value. With the designated 90 percent yield, there is only a 10 percent chance that the yield estimate is too low; thus the community can have 90 percent confidence that the yield amount could be provided during the selected drought. In the most recent analysis, the ISWS has turned to yield estimates that are based on the worst historical drought, rather than a yield estimate based on drought frequencies, such as the 50-year drought, which are uncertain and difficult to accurately estimate. The 1953–1955 drought is the worst drought on record for most surface water supply systems in the Kaskaskia River region.

Table B-2 lists the 50 percent and 90 percent yield estimates with the drought of record for community surface water systems in the region. Also listed is an average demand for each community based on the 2005–2010 period. If the 50 percent yield is less than the demand, the community is categorized as "inadequate," i.e., there is greater than a 50 percent chance that the system would not have sufficient water to satisfy the demand rate during a record drought condition similar to the 1950s drought. If the demand is less than the 50 percent yield but exceeds the 90 percent yield, the system is considered to be "at risk," i.e., there is greater than a 10 percent chance that the system would not have sufficient water to satisfy the demand rate during a record drought condition. There are six systems in the region that are considered to be either inadequate or at-risk: Altamont, Breese, Coulterville, Fairfield, Farina, and Wayne City. Many of these community systems were also considered inadequate in the previous 1989 study, and for some, their supply sources have not been noticeably upgraded in the past 20 years. Most of these systems are small, and it is possible that such communities could choose to haul water or interconnect with a nearby system in the case of a severe drought. Fairfield is undertaking the process to add a second off-channel storage reservoir to increase their supply, but until that time is considered inadequate.

Carlyle Lake and Lake Shelbyville Yield Evaluation

The ISWS also conducted a preliminary re-evaluation of the yield analyses for Lake Shelbyville and Carlyle Lake that was previously computed in 2001 for the IDNR Office of Water Resources. The previous yield estimates were based on a monthly water budget analysis of the federal reservoirs during selected major droughts using historical climate data and USGS streamflow records. For the re-evaluation, drought frequencies were revised based on the additional years of record; the yield of Lake Shelbyville was adjusted to account for increased inflow amounts coming from upstream effluents; and the accounting procedure was changed so that the state storage was not debited during Decembers when water from the federal reservoirs was being dumped to reach the winter pool level. Those three changes caused a 4 mgd collective increase in the 50-year yield of the two reservoirs. Given that the total State's water supply allocations are already slightly greater than the previous estimate 50-year yield, these revised yield estimates may not translate into the availability of additional allocation. In addition, it is recommended that the water budget analyses be revised in the upcoming project to be computed using daily instead of monthly data, a change that may be expected to lower yield estimates, perhaps by about 5 percent.

Table B-2. Yield Estimates for Community Surface-Water Supplies (all values in million gallons per day)

	50% Yield	*90% Yield*	*Demand*	
Altamont	0.22	0.12	0.26	Inadequate
Breese	0.71	0.69	0.69	At Risk
Centralia	7.56	7.56	4.0	
Coulterville	0.06	0.01	0.17	Inadequate
Effingham	6.7	5.7	2.1	
Fairfield	0.56	0.46	0.9	Inadequate
Farina	0.07	0.05	0.14	Inadequate
Greenville	4.2	3.0	1.3	
Highland	3.7	2.0	1.3	
Hillsboro	5.3	3.3	1.3	
Kinmundy	0.36	0.26	0.08	
Litchfield	4.3	2.5	1.3	
Mattoon	8.8	5.0	2.5	
Olney	2.9	2.1	1.4	
Pana	1.1	0.82	0.62	
Salem	6.0	6.0	1.3	
Taylorville	4.6	3.1	2.2	
Wayne City	0.30	0.26	0.33	Inadequate

Notes: Not listed are three reservoir systems that also have direct withdrawals from the Kaskaskia River as a primary or emergency supply, and thus are viewed to have an adequate fail-safe supply: Nashville, Sparta, and Vandalia. Also not listed are the newly developed Gateway and Holland Water Companies that have allocations from federal reservoirs; Effingham's yield estimate includes water from Holland Water Company. The yields for Centralia and Salem are established by separate agreements with the U.S. Corps of Engineers to obtain water from Carlyle Lake.

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Appendix C

Authorities, Water Allocations and Analyses

C.1 Introduction

The Kaskaskia River may be the most managed river in Illinois. Water storage and releases from two federal reservoirs control flooding, ensure navigation and water quality, and provide for water supply, fish and wildlife conservation, and recreation. Numerous water withdrawals occur along the river and from the reservoirs, providing for public water supply and industrial needs. The Kaskaskia lock and dam maintains the navigation pool providing for bulk transport of goods and recreation. Effluent discharges from municipal systems and industries and cooling water returns from power plants occur along the main channel and its tributaries.

In a managed river system such as the Kaskaskia, a course of action for one purpose generally has effects on other purposes. While a manageable system affords certain opportunities of benefit, those management decisions must consider the impacts of those decisions on all the resources and values of interest to the public. Thus, it becomes necessary to analyze numerous variables to determine what may be the best or optimal decision to meet the multiple purposes of flood control, navigation, water supply, and recreation. The Illinois Department of Natural Resources, Office of Water Resources

(IDNR-OWR), has either performed or contracted for numerous studies on the Kaskaskia basin to establish plans to meet water supply requirements in consideration of navigation and impacts to recreation and fisheries.

The IDNR has broad authorities under the Rivers, Lakes and Streams Act to protect the public waters of the State of Illinois from wrongful encroachment and to establish by regulations water levels to preserve fish and aquatic life. Under the Kaskaskia River Watershed and Basin Act, the IDNR may independently make agreements for the formulation of plans, acquisition of rights of way, and the construction, operation, and maintenance of any navigation, flood control, drainage, levee, water supply, and water storage projects. This Act provides for regulation, distribution, and use, including restriction of use or withdrawal of water from the Kaskaskia River below Carlyle Dam.

This document was prepared for the Kaskaskia Basin Water Supply Planning Committee in aiding the development of a plan for meeting the future growth of water demands within the basin. It contains background information to provide an overview of management criteria and an understanding of the constraints and policies used in conducting analyses and making decisions concerning water use. The focus is on aspects integral to the Kaskaskia regional water supply planning study, including low flow and drought conditions and the use of available water storage within Lake Shelbyville and Carlyle Lake.

Basic Water Supply Terminology

- Volume charges usually use units of 1,000 gallons or 100 cubic feet (748 gallons).
- Water supply is often expressed in terms of million gallons per day (mgd).
- River flow is generally expressed in cubic feet per second (cfs).
- Volumes of reservoirs are often expressed in acre-feet. One acre-foot is the volume of water required to cover one acre of land to a depth of 1 foot (43,560 cubic feet).

Statistical Estimates of Stream Quantity

The ISWS has developed the Illinois Streamflow Assessment Model (ILSAM) and related website where statistical estimates on streamflow are available for the Kaskaskia River basin. This site provides an excellent tool for planners and resource managers. The following are definitions for typical streamflow statistics used in water supply planning. Go to http://www.isws.illinois.edu/data/ilsam/ for information and access to ILSAM.

- Annual Flow-Duration Values relate the streamflow amount to the percentage probability that the daily flow will be exceeded over a long-term base period without regard to the sequence of flow events. The 90 percent flow (Q90), for example, is the daily streamflow rate that is exceeded on exactly 90 percent of the days. The 75 percent flow (Q75) is necessarily a higher flow rate because it is exceeded less frequently.

- $\underline{Q_{7,\,10}}$ - A 7-day low flow for a stream is the average flow measured during the 7 consecutive days of lowest flow during any given year. The 7-day, 10-year low flow (Q7,10) is a statistical estimate of the lowest average flow that would be experienced during a consecutive 7-day period with an average recurrence interval of 10 years. Because it is estimated to recur on average only once in 10 years, it is usually an indicator of low flow conditions during drought. The Illinois Environmental Protection Agency (IEPA) often uses estimates of the Q7,10 as the base flow condition in Illinois streams at which certain water quality standards apply, such as defining permit limits for effluent standards and mixing zones. The Q7,10 is also used as a reference flow for several drought water resource management issues.

- Drought flows are similar to low flows, except that the duration of the period is longer and is defined in months instead of days, and the average low flows are developed from average monthly streamflow values. Drought flows are not computed as an annual series, because a drought period typically encompasses multiple years. ILSAM provides flow values for drought durations of 6, 9, 12, 18, 30, and 54 months at recurrence intervals of 10, 25, and 50 years.

Unit Conversions
1 cubic foot = 7.48 gallons
1 cfs = 7.48 gallons per second ~ 449 gallons per minute ~ 0.646 million gallons per day
1 million gallons per day (mgd) = 1.547 cfs
1 acre = 43,560 square feet
1 acre foot = 43,560 cubic feet ~ 325,851 gallons

Abbreviations
OWR – *IDNR Office of Water Resources*
ISWS – *Illinois State Water Survey*
USACE – *United States Army Corps of Engineers* (The Kaskaskia Basin is in the St. Louis District of the USACE)

C.2 State Water Quantity Authorities

Cited below are the main authorities governing the regulation and use of water withdrawals within the Kaskaskia River basin. This section provides an overview to gain a general understanding of the limitations and basis for permitted water withdrawals. For more information on water law in Illinois, readers can go to the Illinois State Water Survey website at http://www.isws.illinois.edu/wsp/law.asp, which provides links to the statutory authorities, court cases, and interpretations.

Statutory Authorities

Under the ***Rivers, Lakes and Streams Act*** (615 ILCS 5/), the IDNR has broad authorities to protect the public waters of the State from wrongful encroachment and to establish by regulations water levels to preserve the fish and aquatic life. Under this statutory authority, permits are also required for dams, for any construction within a public body of water; and for construction within floodways.

Section 7 of the Rivers, Lakes and Streams Act includes the following: *"It shall be the duty of the Department of Natural Resources to have a general supervision of every body of water within the State of Illinois, wherein the State or the people of the State have any rights or interests, whether the same be lakes or rivers, and at all times to exercise a vigilant care to see that none of said bodies of water are encroached upon, or wrongfully seized or used by any private interest in any way, except as may be provided by law and then only after permission shall be given by said department, and from time to time for that purpose, to make accurate surveys of the shores of said lakes and rivers, and to jealously guard the same in order that the true and natural conditions thereof may not be wrongfully and improperly changed to the detriment and injury of the State of Illinois. …The Department of Natural Resources shall have power and authority to inquire into encroachments upon, wrongful invasion and private use of every stream, river, lake or other body of water in which the State of Illinois has any right or interests. The department shall have power to make and enforce such orders as will secure every stream, river, lake or other body of water, in which the State of Illinois has any right or interest against encroachment, wrongful seizure or private use."*

Section 18 of the Rivers, Lakes and Streams Act includes the following: "*…The Department of Natural Resources may grant, subject to the foregoing provisions of this Section, a permit to any person, firm or corporation, not a riparian owner, to use the water from any of the public bodies of water within the State of Illinois for industrial manufacturing or public utility purposes, and to construct the necessary intakes, structures, tunnels, and conduits in, under, or on the beds of such bodies of water to obtain the use of such water or to return the same, provided, however, that such use shall not interfere with navigation. Such permit shall be for a definite period of years not exceeding 40 years and may be renewed subject to the same time limitation…."*

Section 27 of the Rivers, Lakes and Streams Act states the following: *"At all times this act shall be construed in a liberal manner for the purpose of preserving to the State of Illinois and the people of the State, fully and unimpaired, the rights which the State of*

Illinois and the people of the State of Illinois may have in any of the public waters of the State of Illinois, and to give them in connection therewith, the fullest possible enjoyment thereof, and to prevent to the fullest extent, the slightest improper encroachment or invasion upon the rights of the State of Illinois, or any of its citizens with reference thereto."

The IDNR is also responsible under Illinois Statutes for conserving and preserving the State's natural resources. Under the provisions of the ***Fish and Wildlife Coordination Act***, the IDNR is given permit review responsibilities relative to Corps of Engineers permit applications. The IDNR also administers the ***Interagency Wetland Policy Act of 1989***, which is applicable to state agency actions and the ***Illinois Endangered Species Protection Act***, which is applicable to state agencies and local governments. Consultation with the IDNR under these Acts may be necessary in addition to other permit requirements.

Under the ***Kaskaskia River Watershed and Basin Act*** (615 ILCS 75/), the IDNR may independently make agreements for the formulation of plans, acquisition of rights of way, and the construction, operation, and maintenance of any navigation, flood control, drainage, levee, water supply, and water storage projects. This Act provides for regulation, distribution and use, including restriction of use or withdrawal of water from the Kaskaskia River below Carlyle Dam.

Under the ***Water Use Act of 1983*** (525 ILCS 45/), Soil and Water Conservation Districts are authorized to conduct impact evaluations on potentially large groundwater withdrawals (i.e., in excess of 100,000 gallons/day) and make public the effects of such withdrawals on other users of the water. The Act states that the "rule of reasonable use" shall apply to groundwater withdrawals in Illinois.

Effective January 1, 2010, the Water Use Act of 1983 required water use reporting under the ISWS Water Inventory Program for high-capacity wells or intakes (in excess of 100,000 gallons/day), or public water supply systems, with exemptions to agricultural irrigation for the first five years and irrigation within the boundaries of a water authority or other local government entity that estimates the withdrawal.

Under the ***Water Authorities Act*** (70 ILCS 3715/), the Board of Trustees has the power to inspect wells and withdrawal facilities, require registration and permits, require the plugging of abandoned wells, reasonably regulate the use of water during a shortage, supplement the existing water supply, and levy and collect a tax. (***Note***: There are no water authorities within the Kaskaskia River Watershed.)

Incorporation as a water authority *requires that not less than 500 legal voters to petition the circuit court of the county*... defining the boundaries, stating its name, and requesting the question of whether the proposed territory should be organized as a water authority be submitted to the legal voters of the proposed territory; requires public hearing and election for or against organization of a water authority. There are currently 17 water authorities in Illinois.

IDNR Office of Water Resources - Administrative Rules

(“Division” refers to the IDNR Office of Water Resources, Division of Resource Management)

Part 3700 - Construction in Floodways of Rivers, Lakes, and Streams

The Division issues permits for construction projects that may impact the flood-carrying capacity of the rivers, lakes, and streams. These rules affect all streams and lakes except those in northeastern Illinois regulated under Part 3708. *All construction activities in the floodways of streams in urban areas where the stream drainage area is one square mile or more or in rural areas where the stream drainage area is ten square miles or more must be permitted by the Division prior to construction.* The floodway is the channel and the adjacent portion of the floodplain that is needed to safely convey and store flood waters. Floodways have been delineated for many of these streams and are delineated on the Federal Emergency Management Agency's (FEMA) Flood Insurance Rate Maps. Those maps are available for viewing at the local building and/or zoning offices and FEMA's Map Service Center website. If a floodway has not been previously delineated, the Division generally requires permits for work anywhere in the floodplain. The Division issues permits to demonstrate compliance with its regulatory programs. The Division issues permits for work in and along the rivers, lakes, and streams of the state, including Lake Michigan, for activities in and along the public waters, and for the construction and maintenance of dams. Generally, the Division issues an individual formal permit to the applicant to demonstrate compliance with the rules. In some cases, the Division has issued statewide, regional, and general permits to reduce paperwork for the applicant.

Part 3704 - Regulation of Public Waters

The Division issues permits for activities in the public waters of the state. The public waters may generally be described as the commercially navigable lakes and streams of the state and the backwater areas of those streams. A list of public waters is included in Appendix A of the rules. There are certain public rights in the public waters that are reserved for the citizens of the state. The Division reviews proposed activities in public waters to ensure that the public's rights are not diminished by the activity. Activities that require review are not limited to construction. A permit is issued to demonstrate that the activity does not diminish the public's rights. A construction project in public waters will require review under the Part 3700 and Part 3702 rules, as well as the Part 3704 rules.

Part 3702 - Construction, Operation and Maintenance of Dams

The Division issues permits for the construction, operation, and maintenance of new dams and the modification, operation, and maintenance of existing dams. Dams are classified by the Division based on hazard potential. There are three hazard classifications. All dams in the two higher classifications are required to have a permit under these rules. Dams in the lower hazard classification require a permit for construction or modification if they meet certain size criteria. Permits are also required for removing dams and transferring ownership of dams.

When is a Permit Required?

Construction in the floodways of the rivers, lakes, and streams of the state requires a permit from the OWR Division of Water Resource Management. The Division's jurisdiction includes all streams in urban areas where the stream drainage area is 1 square mile or more and all streams in rural areas where the drainage area is 10 square miles or more. Construction includes such activities as the placement, construction, or reconstruction of any building or structure, filling, excavating, modifying channels, storing materials, constructing levees, bridges, culverts, roads, and other similar activities.

The floodway is the channel and the adjacent portion of the floodplain that is needed to safely convey and store flood waters. The floodway can often be found on the local Flood Insurance Rate Map for that community or county. If no delineated floodway is shown, the Division generally requires permits for work anywhere in the floodplain. Permits are also required to construct, modify, remove, and operate all dams (except certain low hazard potential dams) independent of drainage area.

Some common minor construction activities have been identified that have been determined to be permissible if the project meets certain limitations. For those activities, a *statewide permit* has been issued. All individual projects that are within the listed limitations for the permit are automatically authorized. If the applicant determines that his proposed work is within the limitations, his project is approved under the statewide permit and he does not need to contact the Division for further approval.

What Other Approvals are Needed?

The standard State of Illinois joint application form includes copies for the USACE and the IEPA. Consultation with the Illinois Historic Preservation Agency and the IDNR Office of Realty and Environmental Planning is also required. In addition to State of Illinois floodway permit requirements, nearly every community in Illinois has adopted local floodplain management regulations. These regulations are applicable to the entire floodplain. Therefore, you should also contact your local governing body to determine if they have additional permit requirements.

C.3 Public Waters on the Kaskaskia River

Kaskaskia River *Public Waters* begins in Fayette County, East Line of the SW quarter of Section 31, Township 8 North, Range 2 East of the 3rd Principal Meridian. This location is about 9 miles south and 2 miles west of Herrick. The drainage area at this point is 1708 square miles; the River Mile is 157.1 (miles above the mouth of the Kaskaskia River).

The following values are from the Illinois Stream Flow Assessment Model (ILSAM) at River Mile 157.1 at Peppermill Ditch. Go to http://www.isws.illinois.edu/data/ilsam/ for more information. These flow statistics were computed using a base period of 1948–1989.

Q mean flow = 1415 cfs
Q75 (75 percent flow-duration value) = 152 cfs
Q90 (90 percent flow-duration value) = 48.8 cfs
$Q_{7,\,10}$ = 28.2 cfs
$Q_{91,\,50}$ (91-day, 50-year low flow) = 26 cfs

C.4 IDNR/OWR Permit criteria for Water Supply Withdrawals on Public Waters

The following is current permit criteria for OWR staff to follow in the review and response to permits which involve a water supply withdrawal on a Public Water:

- Existing Public Water Supply (PWS) Systems -All permits for expansion, replacement, or modification of current withdrawal structures, or for an additional withdrawal structure to an existing PWS system already utilizing the public water as its primary source, will require at a minimum, special condition 1 (see below), which specifies the Department's regulations, rules, and authorities as applicable to the public water where the withdrawal will be made. This condition shall specify the ability to (later) modify or alter the permit as necessary to satisfy the purposes set forth in those rules, authorities ..."Existing" PWS systems will include all normal growth and expansion of the existing systems as reasonably could have been expected or envisioned for that system. It does not, however, include a major new geographical area that could be served by a separate water supply district in itself, a large industrial user in need of raw water, or an attachment of an existing water supply system being served by some other water supply source to the existing public water supply source. If the existing PWS system requests a permit under any of the situations described in the previous sentence, then the permit will be treated as defined for Existing Systems Requesting Expansion.

- Other Existing Systems -All permits for replacement or modification of existing withdrawal structures utilizing the public water as its primary source, will require at a minimum, special condition 1, which specifies the Department's regulations, rules and authorities as applicable to the public water where the withdrawal will be made. This condition shall specify the ability to (later) modify or alter the permit as necessary to satisfy the purposes set forth in those rules, authorities ..."Existing" industrial systems does not include expansion and is limited to the needs of the current operating system. If the existing industrial system requests a permit which includes expansion, then the permit will be treated as defined for Existing Systems Requesting Expansion.

- Existing Systems Requesting Expansion -All permits for expansion of water withdrawal structures or for additional structures shall require, at a minimum, Special Conditions 1 and 2 (see below). Special Condition 2 shall be modified to apply only to the expanded withdrawal portion.

- New Withdrawals from Public Waters -All permits for new water withdrawal structures will require, at a minimum, Special Conditions 1 and 2.

- Withdrawals for Non-Riparian Usages -The concepts described above shall also be used for withdrawals to non-riparian sites and shall also include Special Condition 3 (see below) limiting the time of the withdrawal.

Special Conditions for Water Withdrawal Permits in Public Waters

1. This Permit may additionally be modified or altered as necessary to satisfy the purposes set forth in Section 3704.10 of the Department's Regulation of Public Waters (17 Ill. Admin. Code 3704) (or to fulfill the responsibilities assigned to the Department under the Kaskaskia River Watershed and Basin Act (615 ILCS 75)).

2. Permittee may only withdraw water pursuant to this Permit when the average of 7 consecutive days of flow in the river, as determined from the data collected at the U.S. Geological Survey stream gage at ________, Illinois (No.____), is above __ cubic feet per second. (Typically the Q7,10 if the gage is downstream of the withdrawal location. Larger flows may be required for other reasons such as sensitive natural resource areas.)

---or---Permittee may only withdraw water pursuant to this Permit when the average of 7 consecutive days of flow in the river at the point of the Permittee's withdrawal structure is above __ cubic feet per second. The flow in the river at the structure shall be calculated by determining the flow, from the data collected at the U.S. Geological Survey stream gage at _________, Illinois (No.____), and subtracting from it the Permittee's water withdrawal and thereafter adding to it the Permittee's water return, if any.

3. This Permit authorizes the use of water from the River under 615 ILCS 5/18 by a non-riparian landowner ("Permittee") for industrial manufacturing or public utility purposes, subject to the conditions contained herein. This Permit shall expire __ years from the date of issuance. The permittee may request renewal of this Permit in accordance with 615 ILCS 5/18. (The maximum period allowed is 40 years.)

Note: The above non-riparian permit expiration period shall not apply to the cities and villages due to authorities as cited under the Illinois Municipal Code, Division 125, "Construction of Wells and Waterworks by Cities and Villages" (65 ILCS 5/11-125 -2).

C.5 IDNR/OWR Permits issued for Water Intake Structures

(*Within the Public Waters of the Kaskaskia River*)

Permittee	Issue Date	Permit No.	Special Conditions
Village of Evansville	02/17/1942	5168	
Texas Company	02/17/1959	8951	
Village of Keysport	03/30/1964	10285	
City of Sparta	01/31/1967	11241	a, b
Texaco, Incorporated	04/12/1967	11291	c, d
Illinois Power (Dynegy)	04/18/1967	11294	
SLM Water Commission	08/06/1970	12460	e
City of Centralia	10/02/1972	13182	f
Kaskaskia Water District	06/20/1974	13762	f
Kaskaskia Water District	10/18/1977	15276	f
City of Sparta	05/18/1988	19524	g
City of Carlyle	10/11/2001	DS2001186	h
Prairie State Generating Co.	09/17/2002	DS2002134	h, i, j, k
City of Vandalia	10/08/2002	DS2002174	h
City of Sparta	04/28/2003	DS2003057	h, l
Illinois DNR	06/18/2003	DS2003095	h
Gateway Water Company	02/22/2006	DS2006018	h, m

C.6 Special Conditions Cited under Permits Issued for Water Intake Structures

a) The Permittee will provide acceptable metering installation to measure withdrawn water. The Permittee will maintain adequate records to determine the pumpage. All records regarding water withdrawal will be available at all times for inspection by representatives of the Department of Public Works and Buildings.

b) The Permittee agrees to pay for water used in excess of the withdrawal rate prevailing when the Kaskaskia River Navigation Project becomes effective.

c) The Texaco Company will meter the volume of water withdrawn and furnish monthly a record of the withdrawal to the Department of Public Works and Buildings.

d) The provisions of Contract DA-23-065-CIVENG – 65 between Texaco, Inc. and the United States are also included as the provisions of this permit.

e) **Note:** This permit is a valid document for construction. It is specifically noted that there are several items of concern regarding water withdrawal which must be satisfied before water which has been passed through the upstream reservoirs is taken from the Kaskaskia River by the applicant. The applicant has been advised of the necessity for developing documentation of agreement by letter dated June 26, 1970. The documents are now being developed.

f) The rights granted by the issuance of this permit are limited to the construction of the intake structure described herein, and do not include the right or authority to withdraw or otherwise use any waters which may be released from the Carlyle Reservoir to maintain flow in the Kaskaskia River. The withdrawal or use of said released waters is strictly prohibited without first having entered into a contract by and between the State of Illinois and the Permittee covering said withdrawal or use.

g) This permit does not authorize or sanction the withdrawal of water. However, withdrawals will be limited or prohibited during periods of low flow if necessary to prevent adverse effects on navigation or other public uses.

h) This permit may additionally be modified or altered as necessary to satisfy the purposes set forth in Section 3704.10 of the Department's Regulation of Public Waters (17 Ill. Admin. Code 3704) or to fulfill the responsibilities assigned to the Department under the Kaskaskia River Watershed and Basin Act (615 ILCS 75).

i) Permittee may only withdraw water pursuant to this Permit when the average of 7 consecutive days of flow in the Kaskaskia River at the point of the Permittee's withdrawal structure is above 92 cubic feet per second. The flow in the river at the structure shall be calculated by determining the flow, from the data collected at the U.S. Geological Survey stream gage at New Athens, Illinois (No. 05595000), and subtracting from it the Permittee's water withdrawal.

j) This Permit authorizes the use of water from the Kaskaskia River under 615 ILCS 5/18 by a non-riparian landowner ("Permittee") for industrial manufacturing or public utility purposes, subject to the conditions contained herein. This permit shall expire 40 years from the date of issuance. The Permittee may request renewal of this Permit in accordance with 615 ILCS 5/18.

k) As directed by the Department, Permittee may be required to limit withdrawals during periods of navigation releases, water supply storage releases on behalf of contracted users, or during a water emergency as declared by the Director of the Illinois Department of Natural Resources. If any portion of the State's water supply storage in Carlyle Lake is necessarily released to satisfy navigation purposes or contracted releases for downstream users, then the Permittee shall be responsible for payment of their portion of the federal operation and maintenance charges incurred as a result of the amount of state water supply storage necessarily released due to their withdrawal. Operation and Maintenances expenses are identified under Contract No. DACW43-83-C-0008 between the United States of America and the State of Illinois for water storage space in the Carlyle Lake Project.

l) Permittee may withdraw up to 1.0 mgd without restriction. However, the Permittee may only withdraw water in amounts greater than 1.0 mgd pursuant to this Permit when the average of 7 consecutive days of flow in the Kaskaskia River at the point of the Permittee's withdrawal structure is above 89.0 cubic ft. per second. The flow in the river at the structure shall be calculated by determining the flow, from the data collected at the U.S. Geological Survey stream gage at New Athens, Illinois (No. 05599500), and subtracting from it the Permittee's water withdrawal and thereafter adding to it the Permittee's water return, if any.

m) Disturbance of lakeshore vegetation shall be kept to a minimum during construction to prevent erosion and sedimentation. All disturbed areas shall be seeded or otherwise stabilized upon completion of construction.

C.7 Lake Shelbyville General Information on Water Supply Storage

Construction of Lake Shelbyville began in 1963 and the dam was completed in 1969. The water level in the lake first reached the top of the Joint-Use Pool (elev. 599.7) on July 6, 1971. The lake is fed by two main river branches, the Kaskaskia and the West Okaw. At their confluence, the Kaskaskia River and the West Okaw River have drainage areas of 673 and 292 square miles, respectively. The total drainage area of the lake is 1054 square miles. The dam is located at river mile 222, as measured upstream of the Kaskaskia River's confluence with the Mississippi River. The height of the earthen dam is 110 feet above the stream bed.

Normal summer pool elevation is considered as the top of the Joint-Use pool, at elevation 599.7, though operational rule levels require varying control elevations for flood control and environmental protection. The surface area of the lake at elevation 599.7 is 11,100 acres. The surface area of the lake at top of flood control elevation 626.5 is 25,300 acres. The dam spillway is concrete and controlled by 3 Tainter type gates. Flow releases generally outlet through two sluices with inlet elevations located about 50 feet below normal summer pool. At normal pool elevation of 599.7, Lake Shelbyville has an approximate length of 20 miles, width of 1 mile, and 172 miles of shoreline. It has an average depth of 16 feet and a maximum depth of 67 feet. Lake Shelbyville is the third largest lake in Illinois.

The July 6, 1983 Contract No. DACW43-83-C-0009 between the United States of America and the State of Illinois provides the State's water storage rights in Lake Shelbyville for the purpose of providing municipal and industrial water supply. The contract provides for storage space of raw water only, and there are no representations with regard to assurances on availability or quality of water. Under the Contract, the State

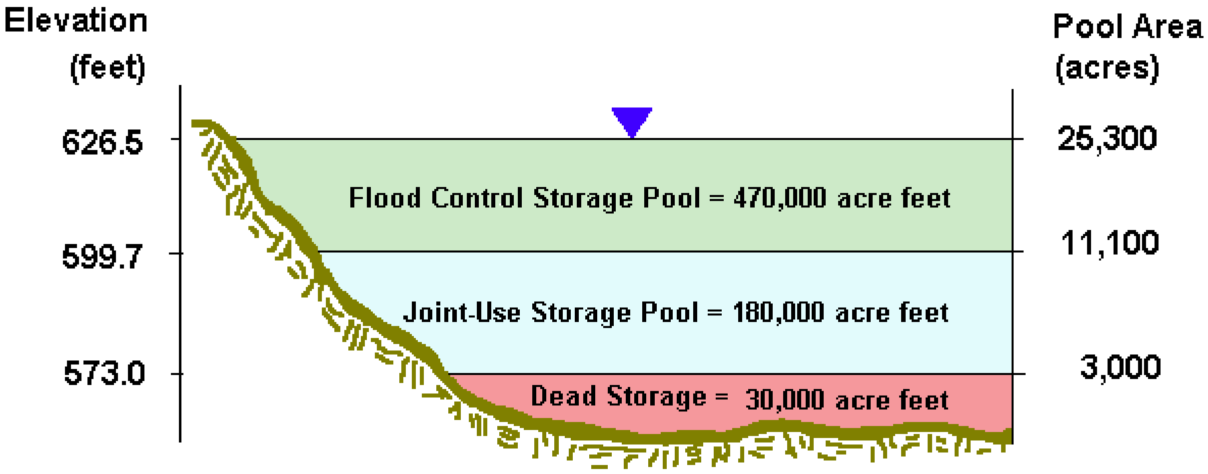

Figure C-1. Illustration of the joint-use pool in Lake Shelbyville. The designated State storage for water supply (24,714 acre-feet) is 13.9 percent of the joint-use pool.

has the right to utilize a share equal to 13.89 percent of the total joint-use storage space, which is the storage contained between elevations 573.0 (Top of Dead Storage Pool) and 599.7 (May and June USACE recommended "rule" level). The remaining 86.11 percent of the storage between these elevations is federal storage for "Rights Reserved" as shown in Article 1(C), which includes the minimum 10 cfs release, releases for navigation, and releases for flood control purposes.

C.8 Carlyle Lake General Information on Water Supply Storage

Construction of Carlyle Lake began in 1958 and completed in June 1967. Carlyle Lake first reached normal pool level in December of 1967. The project cost $41 million dollars. The total drainage area of the lake is 2690 square miles. The dam is located at river mile 107, as measured upstream of the Kaskaskia River's confluence with the Mississippi River. The height of the earthen dam is 67 feet above the stream bed.

Normal summer pool elevation is considered as the top of the Joint-Use pool, at elevation 445, though operational rule levels require varying control elevations for flood control and environmental protection. The surface area of the lake at elevation 445 is 26,000 acres. The surface area of the lake at top of flood control elevation 462.5 is 57,500 acres. The dam spillway is concrete and controlled by 4 Tainter type gates. Flow releases generally outlet through one sluice with inlet elevation located about 28 feet below normal summer pool. At normal pool elevation of 445.0, Carlyle Lake has an approximate length of 15 miles, maximum width of 3.5 miles, and 83 miles of shoreline. It has an average depth of 11 feet. Carlyle Lake is the largest lake in Illinois.

The July 6, 1983 Contract No. DACW43-83-C-0008 between the United States of America and the State of Illinois provides the State's water storage rights in Carlyle Lake

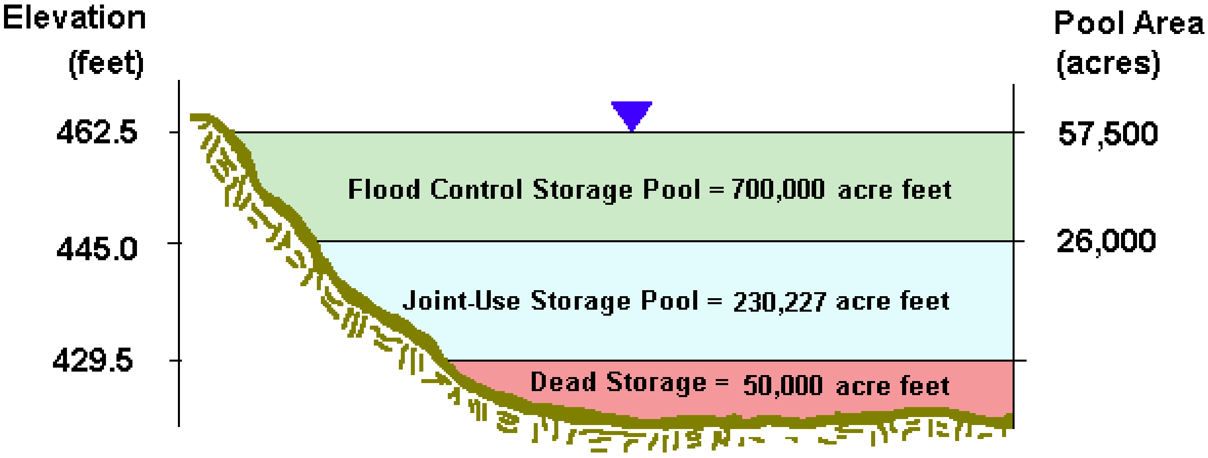

Figure C-1. Illustration of the joint-use pool in Carlyle Lake. The designated State storage for water supply (32,692 acre-feet) is 14.2 percent of the joint-use pool.

for the purpose of providing municipal and industrial water supply. The contract provides for storage space of raw water only, and there are no representations with regard to assurances on availability or quality of water. Under the Contract, the State has the right to utilize a share equal to 14.2 percent of the total joint-use storage space, which is the storage contained between elevations 429.5 (Top of Dead Storage Pool) and 445.0 (Top of Joint-Use storage Pool)**,** estimated to contain 32,692 acre-feet. The remaining 85.8 percent of the storage between these elevations is federal storage for "Rights Reserved" as shown in Article 1(C), which includes the minimum 50 cfs release, releases for navigation, and releases for flood control purposes.

C.9 Accounting Principles for Withdrawals/Releases from State Water Supply Storage

The federal contracts, accounting procedures, and rule curves to manage releases and best meet all the purposes for flood control, navigation, water quality and supply, recreation, and wildlife can be very complex. Several basic principles are involved in the accounting procedures which may be helpful in understanding their effect in developing a reliable yield amount.

When the pool level is above the top of the joint-use pool, the State and federal storage allocations are full and no measurement for storage credit or debit is made. When the pool level falls within the elevations of the joint-use pool, the operation of the reservoirs will require a detailed accounting of water quality releases, navigation releases, water supply withdrawals, reservoir inflow, and precipitation and evaporation from the reservoir surface. The water level and existing storage volume accounts will be recorded at the beginning and at the end of each month. The State's water supply account will be debited for water supply withdrawals from the lakes and for water supply releases from the reservoirs as requested by the State. The State's water supply account will also be debited for their proportionate share of low water releases. "Proportionate share" means the percentage of joint-use pool storage designated for the State's water supply, i.e., 13.9 percent for Shelbyville and 14.2 percent for Carlyle. For withdrawals directly from the lake, the State will be required to submit monthly pumping records to the USACE. The USACE will release and debit the amount the State requests for water supply releases from the reservoirs.

The State's water supply account within each reservoir will be credited with the proportionate share of net inflow into the reservoirs, which includes precipitation on the reservoir surface less evaporation. Credits from inflow are used against the debits in figuring the end of the month storage. Credits for inflow can only be used up to the maximum allocated storage. If either the State or federal storage account is full, all the excess water will be credited to the non-full account. Salem, Keyesport, and Texaco, Inc. were withdrawing water from the Kaskaskia River prior to construction of the Carlyle reservoir and were thus affected by operations of the reservoir. These withdrawals were granted prior vested rights to withdrawal from Carlyle Lake up to the amounts as stated in the USA/Illinois contract. These withdrawals are debited against the federal storage account. Releases from joint-use pool for flood control purposes (normal winter drawdown) are also taken entirely from federal storage.

Navigation releases from the reservoirs will be made when the local inflow downstream of Carlyle is insufficient to accommodate lockages, evaporation and maintain an adequate channel depth. All navigation releases will be debited against the federal storage account.

C.10 Yield Assessments of Water Supply Storage in Lake Shelbyville and Carlyle Lake (2001)

In establishing an acceptable level of risk for water supply allocations, it is important to note that the yield analysis is with respect to the State's available storage and not the total lake storage. At Lake Shelbyville, the State's storage is only 13.9 percent of the total storage within the joint-use pool that is estimated to contain roughly 180,000 acre-feet. If you include dead pool storage, the total volume is 210,000 acre-feet. Similarly, at Carlyle Lake, the State's storage is only 14.2 percent of the total storage within the joint-use pool that is estimated to contain roughly 230,277 acre-feet. If you include dead pool storage, the total volume is 280,227 acre-feet. To date, there have been no navigation releases from either reservoir. Federal storage releases from the joint-use pool have been for the purposes of conforming to target pool elevations or for maintaining the minimum downstream releases. These operations have resulted in always maintaining the vast majority of the joint-use pool in lake storage.

As detailed in the previous section, the State's water supply provided under contract with the USACE is in terms of volume of reservoir storage rather than in terms of a rate of withdrawal, such as million gallons per day. In contrast, yield computations and allocations for water supply are generally made in terms of rate of withdrawal. In needing to establish the upper limit for the rate of water supply withdrawal the State would allow for allocations, the OWR examined several factors and took into account various issues in evaluating the risk and implications of depleting the state available storage. These included the type and locations of withdrawals (direct lake withdrawals or storage releases for withdrawals from the river); the nature of the demands (industrial, irrigation, public water supply); the length of time projected to meet the demand (immediate or long-term projected demand for the regional public water supply systems); and the impacts of those demands (both lake and river impacts).

Water supply systems consider various components in analyzing water supply reliability, including economics, public health, and safety. In terms of evaluating what is an adequate raw water supply, the cost, ease, and ability to interconnect to another system or utilize an alternate source can be the main factor in a decision. Smaller community systems are more often able to look at alternative sources than larger systems since lesser volumes and infrastructure changes allow consideration of this option. Many systems are evaluated by a firm yield analysis figure as to the dependability of meeting a water supply demand without restriction. Periods typically used are the 20-year, 50-year, and

100-year. The drought of record is also used as a measure for dependability if sufficient hydrologic records exist.

The 50-year recurrence interval was chosen as a reasonable period to evaluate yield for allocation, in consideration of the nature of the demands and the protections provided in the agreements. The 50-year drought event has a 2 percent chance of occurrence in any given year. The 50-year drought event can also be stated as having an 18 percent probability of occurrence within a 10-year time period. While the yield analysis was established as the base for allocation, the actual probability of a deficit occurring has to consider the operational needs and projected demands as described in the next section. Further, the yields were determined based on the projected available storage 40 years beyond when the contracts were entered into, assuming a loss in water supply storage by the end of the contract period. The probability of a deficit occurring is expected to increase over the 40-year contract period as the water supply storage amount (adjusted by the USACE) decreases because of sedimentation. As a result, the current (2012) probability of a deficit occurring is slightly less than that associated with a 50-year event.

Though droughts often extend and overlap calendar years, their impacts to lake levels will most often only extend to the end of a calendar year. This is because the lakes are always drawn down to winter pool levels in December for flood control, which are levels as low or lower than what would be experienced in the initial year of a significant drought. In April the following year, levels are allowed to rise. In an extended drought or a drought beginning in the spring, target pool levels may not be met and the reservoirs could start the summer season at lower than normal pools. This occurred in 1988 and the normal pool was never reached at both Lake Shelbyville and Carlyle Lake throughout the remainder of the year. In this scenario, the greatest lake level impacts from water supply would be experienced. This would also be the time when the State's water supply storage account will become limited. With monthly accounting of water withdrawals and remaining storage, we will know how much water we will have left on a monthly basis during a drought. This will allow time for conservation efforts and other measures to avoid a restriction of usage.

A yield estimate was calculated utilizing the technique as outlined in ISWS Bulletin 67, "Hydrologic Design of Impounding Reservoirs in Illinois" by Terstriep, Demissie, Noel, and Knapp. However, the yield analysis is somewhat complicated by the storage apportionments, accounting procedures, and the operational rules that govern water releases from the reservoir. It was therefore necessary to create a water budget model, utilizing historical streamflow data as inputs, that could simulate the various reservoir operating rules and the accounting procedures to be used in determining the remaining water supply storage as releases from the reservoir are made. The ISWS created a monthly water budget model of the lake to estimate the net yield which could be met from the State's water supply storage. Historical streamflow data and drought flow frequency estimates were used as inputs. Average evaporation data for Lake Shelbyville was provided by the USACE and utilized in the analysis along with adjusting for target pool elevations and maintaining minimum releases in strict accordance with the USACE release schedule.

In conducting various model runs of historical droughts, it was observed that the return of the lake to its joint-pool target level in late spring is a critical factor in determining whether a drought will impact the State's water allocation. If the joint pool is not reached in spring, it is possible that the State's water storage may continue to be below its full allocation for 9 to 22 consecutive months, depending on the severity of the drought. Analysis of the 1953–1955 drought showed it to be the worst of record at Shelbyville, with storage deficits lasting nearly 24 months. Other drought periods of significance within the last 95 years occurred in 1914–1915, 1930–1931, 1940-1941, 1976–1977, and 1988–1989.

The following yield estimates are based strictly on the volume of water supply storage estimated to exist at the time of the latest sedimentation surveys for Lake Shelbyville (1984) and Carlyle Lake (1999), being 24,714 acre-ft at Lake Shelbyville and 32,692 acre-ft at Carlyle Lake. These water supply storage volumes are based on 13.9 percent and 14.2 percent of the total joint-use storage volumes at Lake Shelbyville and Carlyle Lake, respectively.

Event	Shelbyville	Carlyle
10-year	40 mgd	100 mgd
20-year	31 mgd	62 mgd
25-year	28 mgd	53 mgd
40-year	23 mgd	37 mgd
50-year	**21 mgd**	**31 mgd**
100-year	15 mgd	21 mgd

The ISWS also provided projections on an estimate of the **50-year** yield for about 40 years from now (2001 analysis), with the expectation that sedimentation would reduce the total storage within the joint use pool and thus the State's water supply portion. The significance of 40 years was due to the term of the agreements being 40 years, thus needing to consider the estimated available yield at that time in providing for our allocations. Sedimentation surveys were last made at Lake Shelbyville in 1984 and at Carlyle Lake in 1999. The 1999 survey identified that sedimentation had reduced the joint-use storage pool in Carlyle Lake; although, to date the USACE has not indicated that the State's storage volume would be reduced in either reservoir.

50-year yield estimate in 2041 for Lake Shelbyville = 18 mgd
50-year yield estimate in 2041 for Carlyle Lake = 29 mgd

The yield estimates above do not account for the respective percentages of minimum releases. In accordance with the USACE Design Memorandum on Low Flow Regulation (July 15, 1964, pages 14 and 15), the State's water supply accounts will be debited proportionately, as follows:

Lake Shelbyville	13.9% of 10 cfs ≈ 1.4 cfs ≈ **1 mgd**
Carlyle Lake	14.2% of 50 cfs ≈ 7.1 cfs ≈ **4.5 mgd**

Thus, including these debits for minimum releases and loss of storage space by sedimentation through the 40-year contract period, the following was determined to be a reasonable assessment of the amount of water supply which the State could make available for water supply use:

Lake Shelbyville ≈ 17 mgd

Carlyle Lake ≈ 24.5 mgd

C.11 Allocation of Water Supply Storage from Lake Shelbyville and Carlyle Lake

The USACE has been managing Lake Shelbyville and Carlyle Lake for recreation and flood control since completion of the dams in 1969 and 1967, respectively, and for navigation since completion of the Kaskaskia River Navigation Project in the late 1970s. The statutory authority given to the IDNR to independently enter into agreements for water supply from Lake Shelbyville and Carlyle Lake is granted in the Kaskaskia River Watershed and Basin Act (615 ILCS 75). The IDNR works with the Illinois Department of Commerce and Economic Opportunity, the Governor's Office, and with legislators in evaluating state water supply needs and in consideration of water supply allocations made from state storage at Lake Shelbyville, Carlyle Lake, and Rend Lake.

State water supply storage in Lake Shelbyville and Carlyle Lake became available upon dam completions, but it was not until 1988 with irrigation of the Eagle Creek Golf Course that a water supply withdrawal from State storage began. Though the IDNR received various inquiries for water supply use since storage became available, it was not until the late 1990s when proposals developed to the stage where the IDNR began considerations and analyses in the preparation of agreements for use of the water supply storage. Except for irrigation of Eagle Creek and Governor's Run golf courses, and recently by Gateway, the State's water supply storage has not been in use. Below is a listing of Water Supply Agreements for storage from Lake Shelbyville and Carlyle Lake, showing Agreement execution date, the amount of storage available for use, and the source. Through these agreements, the State has allocated the available water supply storage, providing a dependable source of water supply for two regional public water supply systems, three electric generating facilities, and four lakeside public golf courses.

Purpose	Agreement Date	Quantity	Source
Eagle Creek (golf course)	1988 August 24	480 acre-feet	Shelbyville
Governor's Run (golf course)	1994 April	190 acre-feet	Carlyle
Holland Energy Power Plant	2000 June 1	8.0 mgd	Shelbyville
Timberlake (golf course)	2001 August 23	50 acre-feet	Shelbyville
Holland Regional Water System	2002 December 10	5.0 mgd	Shelbyville
Gateway Regional Water Company	2002 December 23	4.0 mgd	Carlyle
Prairie State Power Plant	2003 May 19	13.35 mgd	Carlyle & Shelbyville
Dynegy Baldwin Power Plant	2004 April 8	14.35 mgd	Carlyle
SCCS Ventures (golf course)	2007 May 30	50 acre-feet	Shelbyville

Lakeside Golf Course Irrigation Allocations – Water supply agreements for golf course irrigation do not require metering. Thus, the allocations have been made based on a volume of storage rather than a withdrawal rate. Under concessionaire agreements, Eagle Creek and Governor's Run golf courses were the first uses of Lake Shelbyville and Carlyle Lake water supply. The volumes allocated for Eagle Creek and Governor's Run were established on the basis of maximum pump capacity and seasonal usage. For example, the annual water use of 480 acre-feet for Eagle Creek was based on a maximum pumping rate of 1 cubic foot per second (cfs) and eight months of continuous pumping. Timberlake and SCCS Ventures are covered under "small user" agreements established by the OWR to support lake-side development and ancillary facilities. Timberlake and SCCS Ventures entered into these agreements as a backup source of water to fill their subimpoundments during dry conditions. These agreements require maintaining an hourly log of withdrawals and pump size. Timberlake and SCCS Ventures have yet to make a withdrawal from Lake Shelbyville.

Holland Energy, LLC was the first large water supply agreement entered into by the IDNR, establishing policy decisions for conservation and protection language for all future agreements. Holland Energy is a merchant power plant utilizing natural gas to produce 650 MW of electricity. Located near Beecher City in Shelby County, it is owned by Wabash Valley Power/Hoosier Energy and was brought online in 2002. Holland Energy's withdrawal structure is located about 23 miles downstream of the Lake Shelbyville dam and about 3 miles upstream of the Cowden gage. It has 3 pumps, each capable of pumping 2500 gallons per minute. Holland Energy has rights up to a maximum 8 mgd release of water storage from Lake Shelbyville. No average annual withdrawal release was specified under Agreement, though Holland Energy informed the OWR that based on operational requirements, their weighted average annual usage would be about 5.3 mgd. As of June 2011, Holland Energy has not made a request for a release from Lake Shelbyville storage.

Holland Regional Water System, Inc. is a consortium of five entities (the City of Effingham, the City of Shelbyville, E J Water Corporation, Lincoln Prairie Water Company, and Lake Sara Service Cooperative) aimed at developing a supplemental water supply for the area. Holland Regional has rights up to a maximum 7.5 mgd release, but not more than a volume equivalent to an annual average release of 5.0 mgd, of water storage from Lake Shelbyville. In a cooperative effort with Holland Energy, Holland Regional utilizes Holland Energy's intake structure and raw water intake line to transmit water to a 10 million gallon reservoir located on 20 acres of ground near the Holland Energy Plant. In 2006, a 13-mile raw water line was completed from the reservoir to connect with a raw water line to the Effingham 6 mgd Water Treatment Plant. This would provide the City of Effingham with a backup water supply. In 2010, EJ Water constructed a 3.0 mgd water plant as a primary source of water to EJ's west side of the system and Lincoln Prairie Water. Current annual usage is approximately 365 million gallons per year. As of June 2011, there has been no release of Lake Shelbyville storage to serve the needs of the Holland Regional Water System.

Gateway Regional Water Company completed construction of their 3.0 mgd water treatment plant in late 2007. Water withdrawals from Carlyle Lake began in April 2008. Gateway has rights to withdraw up to 6.3 mgd of water from Carlyle Lake, but not more than an annual average withdrawal of 4.0 mgd. Gateway currently serves portions of Clay, Clinton, Fayette, Marion, and Wayne Counties. In 2010, the total annual withdrawal from Carlyle Lake was approximately 436 million gallons (an average rate of about 1.2 mgd).

Dynegy Midwest Generation has rights up to a maximum 58.0 mgd release, but not more than a volume equivalent to an annual average of release of 14.35 mgd, of water from Carlyle Lake for use in supplying water to Dynegy's Baldwin Energy Complex capable of producing 1800 MW of electricity. Power production at Baldwin (Illinois Power Company) began in 1970.

Prairie State Generating Company, LLC is nearing construction completion of its first 800 MW unit with plans to have its second 800 MW unit operational in 2012. Prairie State has rights up to a maximum 18.0 mgd release, but not more than a volume equivalent to an annual average of release of 13.35 mgd, of water from Carlyle Lake during the first ten years of their Agreement. Prairie State had requested a greater volume of water for release than what was determined to be available. Thus, an analysis was made as to the short-term (10-year versus 40-year) availability of water. This analysis took into consideration the timeline and projected plans for the regional water systems. The IDNR will evaluate the availability of water one year prior to the lapse of the first ten years of the Agreement, and designate the maximum annual average usage by Prairie State during the next ten years. Prairie State has rights to no less than an annual average release of 9.5 mgd during the term of the Agreement.

C.12 IDNR Water Allocation Agreements - Protection of Minimum Flows

Holland Energy - In the event that Holland Energy withdraws water directly from the Kaskaskia River, Holland Energy agrees to undertake the following environmental protection, monitoring, and mitigation measures:

(f) Monitor flow conditions on the Kaskaskia River above, at, and below Holland Energy's intake and discharge structures to determine whether low flow conditions exist and to determine compliance with water quality standards set forth as a condition in Holland Energy's NPDES permit. (Special Condition 2 of the NPDES permit states that there will be no discharge from the facility during extreme low flow conditions, defined as being those times when the river drops below 10 cfs immediately upstream of the outfall.)

***Holland Regional* -** If Holland Regional wishes to withdraw water from the Kaskaskia River when its flow is 29 cfs or less, as measured by USGS Gage Number 05592100 at Cowden, Illinois, (hereinafter "minimum flow circumstance"), Holland Regional must request a Lake Shelbyville water supply release, per the procedures set forth in Section 3, for an amount equal to or greater than the amount of water Holland Regional actually withdraws from the Kaskaskia River during the minimum flow circumstance.

> (NOTE: *29 cfs is the Q90 percent flow which was applied due to an "A" stream segment rating for biotic integrity which had recently been given. At the time the Holland Energy contract was being prepared, the biotic integrity rating was "C". Holland Regional utilizes Holland Energy's water withdrawal structure.)*

Prairie State - If Prairie State wishes to withdraw water from the Kaskaskia River when its flow is 69.3 cfs or less, (hereinafter "minimum flow circumstance"), as measured by USGS Gage Number 05594100 at Venedy Station, Prairie State must request a water supply release, per the procedures set forth in Section 3, for an amount equal to or greater than the amount of water Prairie State actually withdraws from the Kaskaskia River during the minimum flow circumstance. If a gage is installed at State Highway 13 Bridge or other suitable gage as mutually agreed to in writing, the existing 7-day, 10-year flow value will be determined at that gage location in establishing the minimum flow circumstance. (Note: U.S. Geological Survey stream gage No. 05595000, New Athens, Illinois installed in 2009; $Q_{7,\,10}$ = 92 cfs.)

***Dynegy* -** If Dynegy wishes to withdraw water from the Kaskaskia River when its flow is 69.3 cfs or less, (hereinafter "minimum flow circumstance"), as measured by USGS Gage Number 05594100 at Venedy Station, Dynegy must request a water supply release, per the procedures set forth in Section 3, for an amount equal to or greater than the amount of water Dynegy actually withdraws from the Kaskaskia River during the minimum flow circumstance. If a gage is installed at State Highway 13 Bridge or other suitable gage as mutually agreed to in writing, the existing 7-day, 10-year flow value will be determined at that gage location in establishing the minimum flow circumstance. (Note: U.S. Geological Survey stream gage No. 05595000, New Athens, Illinois installed in 2009; $Q_{7,\,10}$ = 92 cfs)

C.13 IDNR Water Allocation Agreements - Protection of Navigation and other Storage Releases

Holland Energy - no language

Holland Regional - The parties acknowledge that the U.S. Army Corps of Engineers may make releases for navigation purposes from the navigation storage. The parties further acknowledge that the State of Illinois may request releases on behalf of other water supply contracted users or for other State authorized purposes. During periods of such releases, Holland Regional agrees to restrict their withdrawals or request water releases on their behalf, to the extent necessary which ensures the protection of the quantity of flow released for such purpose(s). If Holland Regional makes any withdrawal of water that is released for navigation purposes, for other contracted users, or for other State authorized purposes and which requires an additional release to be made from State storage, then the State of Illinois shall charge Holland Regional for all Water Supply

Costs associated with the additional release pursuant to Paragraph 9(d) herein. The State of Illinois agrees to notify Holland Regional in advance of and upon cessation of the protected release(s) and agrees to provide Holland Regional with the quantity of flow being released requiring protection.

Prairie State – The parties acknowledge that the USACE may make releases for navigation purposes from the navigation storage. The parties further acknowledge that the State of Illinois may request releases on behalf of other water supply contracted users or for other State authorized purposes. During periods of such releases, Prairie State agrees to restrict their withdrawals or request water releases on their behalf, to the extent necessary which ensures the protection of the quantity of flow released for such purpose(s). If Prairie State makes any withdrawal of water that is released for navigation purposes, for other contracted users, or for other State authorized purposes and which requires an additional release to be made from State storage, then the State of Illinois shall charge Prairie State for all Water Supply Costs associated with the additional release pursuant to Paragraph 9(d) herein. The State of Illinois agrees to notify Prairie State in advance of and upon cessation of the protected release(s) and agrees to provide Prairie State with the quantity of flow being released requiring protection.

Dynegy - The parties acknowledge that the USACE may make releases for navigation purposes from the navigation storage. The parties further acknowledge that the State of Illinois may request releases on behalf of other water supply contracted users or for other State authorized purposes. During periods of such releases, Dynegy agrees to restrict their withdrawals or request water releases on their behalf, to the extent necessary which ensures the protection of the quantity of flow released for such purpose(s). If Dynegy makes any withdrawal of water that is released for navigation purposes, for other contracted users, or for other State authorized purposes and which requires an additional release to be made from State storage, then the State of Illinois shall charge Dynegy for all Water Supply Costs associated with the additional release pursuant to Paragraph 9(d) herein. The State of Illinois agrees to notify Dynegy in advance of and upon cessation of the protected release(s) and agrees to provide Dynegy with the quantity of flow being released requiring protection.

C.14 IDNR Water Allocation Agreements - Protection of Domestic Water Use in a Water Emergency

The following Agreement language is included in ***all Agreements beginning with and subsequent to the Holland Energy Agreement***, effective June 1, 2000. Thus, this language is also included in the Timberlake Golf Course, Holland Regional, Gateway, Prairie State, and Dynegy Agreements.

(b) The parties acknowledge that the State of Illinois may enter into agreements with other parties to allocate, secure or otherwise beneficially use water from Lake Shelbyville for Domestic Water Use, as defined herein, and Non-Domestic Water Use, as defined herein, and that the State of Illinois is otherwise authorized and entitled to protect the health and safety of its citizens. Therefore, in the event of a declared water emergency, as declared by the Director of the Illinois Department of Natural Resources or other responsible state official, which results in an insufficient supply of water in Lake Shelbyville to satisfy the water allocated and used for both Domestic Water Use, as defined herein, and Non-Domestic Water Use, as defined herein, and which deficiency of Lake Shelbyville water would pose a direct threat to the public health or safety of communities relying upon water from Lake Shelbyville (such an event is referred to as a "Water Emergency"), then the State of Illinois reserves its rights to prohibit or restrict, on an equal or pro-rata basis respectively, by volume of water used for Non-Domestic Water Use, the use of all Lake Shelbyville water for all Non-Domestic Water Use until the Domestic Water Uses for which Lake Shelbyville water has been allocated are otherwise satisfied. A "Water Emergency" shall also be deemed to exist, and the State of Illinois may proceed to exercise its rights to prohibit or restrict water use, if the Director of the Illinois Department of Natural Resources makes a reasoned determination in accordance with applicable law that such withdrawal of water from Lake Shelbyville for Non-Domestic Use will result in imminent, substantial and irreparable damage to natural resources. If the Director of the Illinois Department of Natural Resources makes a Water Emergency determination, (*Holland Energy…)* may seek to alleviate the water shortage, seek approval of the Director to mitigate any damages to natural resources and continue water use, or seek reconsideration of the determination. Any prohibition or pro-rata reduction allocation, as more fully set forth in the following paragraph, would apply on an equal percentage basis to the volume of all water used for Non-Domestic Use by each party receiving Lake Shelbyville water. The parties further recognize that the generation of electricity also provides for essential health and safety needs, and, additionally, it would be inequitable to restrict *(Holland Energy's…)* water rights while allowing others to take water for Non-Domestic Water Use.

If any party entitled to use water from Lake Shelbyville has both Domestic Water Uses and Non-Domestic Water Uses (collectively "Total Water Use"), whether supplied in whole or in part by Lake Shelbyville water, then the pro-rata reduction allocation of Lake Shelbyville water applicable to such party's Non-Domestic Water Use during a Water Emergency shall be determined based on the percentage of such party's Total Water Use that constitutes Non-Domestic Water Use. Thus, for example, if a party's Total Water Use is singularly supplied by 10 mgd of Lake Shelbyville water and such party uses 50 percent of that water (*i.e.*, 5 mgd) for Domestic Water Use, then the remaining 50 percent of that water (*i.e.*, 5 mgd) used for Non-Domestic Water Use will be subject to the Lake Shelbyville water pro-rata reduction. Likewise, if a party supplements its existing water usage with Lake Shelbyville water, then the percentage of that party's total Non-Domestic Water Use will be used to determine that party's pro-rata Lake Shelbyville water allocation reduction. For example, if such a party utilizes 30 mgd from a source other than Lake Shelbyville and supplements that amount with 10 mgd from Lake Shelbyville, for a total of 40 mgd, and 50 percent of that Total Water Use (*i.e.*, 20 mgd) is for Non-Domestic Water Use, then 50 percent of that party's Lake Shelbyville water (*i.e.*, 5 mgd) would be subject to a water allocation reduction during a Water Emergency.

(c) The State of Illinois agrees that all water allocation, water supply, or water use agreements, or modifications thereto, for water from Lake Shelbyville entered into between the State of Illinois and any party (including, without limitation, a State agency) subsequent to the date of this Agreement will contain the same or stricter limitations on the use of, and such party's rights to, water during a Water Emergency as are herein imposed upon (*Holland Energy…)* In the event that any such agreement does not contain the same or stricter limitations on such third party's rights to water during a Water Emergency as are herein imposed upon (*Holland Energy…),* then the limitations imposed upon (*Holland Energy…)* herein shall be waived by the State of Illinois and shall not be binding upon (*Holland Energy....)*

(d) The term "Domestic Water Use" as used in this Agreement means use of water for household drinking, cooking, sanitary, health and similar purposes, as well as for medical facilities and fire protection; however, the parties agree that "Domestic Water Use" does not include use of water for any commercial or industrial uses, lawn sprinkling, commercial or non-commercial car washes, or recreation purposes (whether in a residential or other setting). The term "Non-Domestic Water Use" as used in this Agreement means any use other than Domestic Water Use. The term "Domestic Water Users" as used in this Agreement means those persons or entities using water solely for Domestic Water Use. The term "Non-Domestic Water Users" as used in this Agreement means those persons or entities using water for any use other than Domestic Water Use.

C.15 IDNR Water Allocation Agreements - Future Domestic Water Use Capacity Increases

The following Agreement language is included in ***Agreements beginning with and subsequent to the Holland Energy Agreement***, effective June 1, 2000. Thus, this language is also included in the Timberlake Golf Course, Holland Regional, Gateway, Prairie State, and Dynegy agreements.

(a) The State of Illinois has determined that there may be a future need for additional Domestic Water Use supply capacity at Lake Shelbyville and that such additional Domestic Water Use capacity should be funded on a proportionate basis by the current and future Non-Domestic Water Users of Lake Shelbyville water. Therefore, (*Holland Energy…)* agrees that if (i) existing capacity for all water supply from Lake Shelbyville allocated and reasonably expected to be used for municipal and industrial water supply under the Lake Shelbyville Contract is fully allocated, and (ii) the State of Illinois determines after reasonable study that additional capacity for Domestic Water Use is required to supply Domestic Water Use reasonably anticipated to exist during the term of this Agreement, (*Holland Energy…)* will pay a proportionate share of the State of Illinois' costs ("Capacity Increase Costs") to increase reservoir capacity sufficient to supply up to, but not more than, an additional 8 mgd for such increased Domestic Water Use supply. (*Holland Energy's…)* proportionate share of the State of Illinois' Capacity Increase Costs will be based on the amount of Non-Domestic Water Use water allocated to Holland Energy ... under this Agreement relative to the total amount of water withdrawn or released from Lake Shelbyville or the Kaskaskia River that is used by any party for Non-Domestic Water Use, whether that Non-Domestic Water Use results from water allocated directly to Non-Domestic Water Users (such as industrial or commercial users) or to a public or private water supplier who then supplies water to Non-Domestic Water Users. (*Holland Energy…)* will not be obligated to pay any amount associated with Capacity Increase Costs for capacity increases above 8 mgd. Additionally, (*Holland Energy…)* has no obligation to make any payments relating to capacity increase projects for Non-Domestic Water Use supply.

(b) Holland Energy ...'s payment schedule for Capacity Increase Costs will be the same as for payments for "Major Replacement Cost" and "Major Rehabilitation and Dam Safety Assurance Programs Costs" under this Agreement; *i.e.*, (*Holland Energy…)* may, at its option, pay Capacity Increase Costs in a single lump sum or in annual installments in accordance with an amortization schedule not to exceed 25 years. (*Holland Energy's…)* obligations under this sub-paragraph, including payment of any outstanding balance on annual installment payments, shall terminate upon termination of this Agreement.

(c) The State of Illinois agrees that all water allocation, water supply, or water use agreements, or modifications thereto, for water from Lake Shelbyville entered into between the State of Illinois and any party (including, without limitation, any State agency) subsequent to the date of this Agreement, without regard to whether said party is a Non-Domestic Water User, a Domestic Water User, or a public or private water supplier, will contain the same or stricter provisions concerning payment obligations and cost sharing allocation among Non-Domestic Water Users with respect to Capacity Increase Costs as are imposed upon (*Holland Energy…)* under this Agreement. In the event that any such agreement does not contain the same or stricter provisions concerning payment obligations and cost sharing allocation among Non-Domestic Water Users with respect to Capacity Increase Costs as are herein imposed upon (*Holland Energy…)*, then the payment obligations and cost sharing allocation imposed upon (*Holland Energy…)* herein shall be waived by the State of Illinois and (*Holland Energy…)* shall have no further obligation to pay for any costs related to Capacity Increase Costs, including payments of any outstanding balance on annual installment payments. The State of Illinois further agrees that all Non-Domestic Water Users will be treated equitably with respect to allocation of Capacity Increase Costs, whether they obtain water directly from Lake Shelbyville or the Kaskaskia River, or indirectly from a Public Water Supplier or other party obtaining water directly from Lake Shelbyville or the Kaskaskia River.

C.16 USA/State Contract Language for Protection of Navigation Releases

An analysis was conducted in January 2003 to consider the water supply demands of other users on the lower Kaskaskia River not under contract for State-owned water supply storage and while maintaining the protection of navigation releases. Contract language contained in the July 6, 1983 contracts for water storage space in the

Shelbyville Reservoir Project (Contract DACW43-83-C-0009) and in the Carlyle Lake Project (Contract DACW43-83-C-0008) reads as follows:

Article 1C. (3) 3rd sentence:

> "At the time of such navigation release, downstream consumptive use of Kaskaskia River water in excess of natural inflows is prohibited to the State and others unless such usage is replenished to the navigation system by pumping or other means or unless water is released for that purpose."

Article 4B. (2):

> "Water withdrawals may be charged to the State's water supply storage space whenever navigation releases from the Shelbyville Reservoir are diverted, restricted, or otherwise appropriated by non-Federal interests, or whenever navigation releases from the Carlyle Reservoir are diverted, restricted, or otherwise appropriated by non-Federal interests. With the use of recorded release data from Carlyle Lake, outflows from actual lockages and estimates of evaporation and transpiration downstream from Carlyle Lake, the Regulation Office can estimate any diversions, restrictions, or appropriations (hereinafter called usages) that have been made by non-federal interests. The State shall be responsible for regular examination and control of non-Federal usage downstream from Carlyle Lake and may replenish any such usage to the navigation reach by pumping or other means. If any non-Federal usage is made and is not replenished to the navigation reach, thereby requiring an additional navigation release from Carlyle Lake, the amount of such usage shall be determined by the Regulation Office and shall be debited to the State storage in Carlyle and/or Shelbyville Reservoir, the selection of such storage location to be mutually made by the State and the Government."

OWR conferred with the USACE on the above language to mean that whenever there is a navigation release, the amount of that release minus the estimate of evaporation and transpiration losses associated with that volume of release in transport down the river channel must be protected to ensure its use for navigation within the navigation channel and for lockages.

An assessment of the natural inflows downstream of the Shelbyville dam to Carlyle Lake and downstream of the Carlyle dam to the Lock and Dam was made to determine allowable usages by the State. This assessment also considered the State usage of this (excess) inflow allowable no matter where the usage would take place. In other words State usage of the summation of the natural inflow could take place anywhere along the channel segments as long the volumes associated with the respective navigation releases are made available into Carlyle lake (Shelbyville releases) or within the navigation channel (Carlyle releases). This assessment considered the identifiable existing users on the lower Kaskaskia during a drought which were not under agreement for a water supply storage release.

Analysis of Public Water Supply (PWS) systems on the Lower Kaskaskia River

There are five known PWS systems which withdraw water as a primary source from the lower Kaskaskia River downstream of the Carlyle dam. SWS Contract Report 442 (Singh et al., 1988) indicates that the city of Sparta utilizes the Kaskaskia River for approximately 50 percent of their supply with the remaining source being two reservoirs located on Maxwell Creek. This report also indicated that the SLM Water Commission has side channel storage, but no capacity was indicated. This analysis will not consider any benefits of side-channel storage and will assume a direct and immediate reliance on the Kaskaskia River as their water supply source.

OWR policy for existing PWS systems on public waters is to not require a cessation or limitation of withdrawal upon the river reaching a specified low flow unless the system were to serve a major new user or geographical area. Though a specific restricted use value will not be specified, provisions for permit modifications (including withdrawal restrictions) may be instituted, as may be determined necessary to satisfy the IDNR's responsibilities under the Kaskaskia River Watershed and Basin Act. None of the existing PWS systems on the lower Kaskaskia River entered into an Agreement with the State to secure water supply storage from Carlyle Lake.

During a dry period what would be the current average and expected peak PWS withdrawals? What is our best estimate of these withdrawals 40 years from now?

The **current** average annual usage of the five PWS systems (as reported to the ISWS for 1998-1999) is about 5.1 mgd. In an extensive dry period during summer into early fall, usage can be much greater than average due to extensive lawn and garden watering, car and home washing, swimming pool use, golf course irrigation, etc. Peak usage for such dry seasonal periods can be two times the average usage. Thus, such seasonal periods could result in the five PWS systems withdrawing 10.2 mgd from the lower Kaskaskia.

One consideration of expected withdrawals **40 years from now** would be to establish a usage based on a reasonable population growth rate of the areas served by these PWS systems. County population projections provided by the Department of Commerce and Community Affairs from the year 2000 to year 2020 are plus 0.42 percent per year for Clinton County, plus 0.65% per year for St. Clair County, and minus 0.37 percent per year for Randolph County. If the highest **growth rate of 0.65 percent per year** (St. Clair County) is applied to all five systems to the year 2040, the average annual usage can be estimated at 6.4 mgd and the peak usage at 12.8 mgd. These estimates assume that the average per capita use will remain the same.

When we compare the projected growth rate to historical growth, we know that this may not be the best method for projecting usage for public water supply systems. For example, historical growth of the Carlyle system showed an increase of about 4.13 percent per year during the period from 1986 to 1998. This increase may be due more in servicing new areas and users which were not on a public water supply system, rather than just new users associated with population growth. Average annual usages of the

SLM and the Kaskaskia Water District systems increased at a rate of about 3.28 percent per year and 3.47 percent per year, respectively, from 1986 to 2000. While it is reasonable to expect a large service growth rate on new systems, growth rates should flatten out in time, as the PWS systems expand to the limits of their projected geographic areas.

However, if we were to conservatively assume a 3.5 percent per year average growth rate (rough historical estimate) to continue for all five systems, the average annual projected usage would increase from 5.1 mgd to 12.25 mgd by the year 2040. If we assume a peak usage as twice the annual average, the peak usage of the five PWS systems would be 24.5 mgd in 2040. This is equivalent to about <u>38 cfs</u>.

ILSAM provides detailed data on low flows and drought flows at all the gaging stations. Analyzing the difference (increase) in flow values established at Carlyle to the values established at New Athens and the Lock and Dam will provide for estimates of excess flows available for usage. The additional contributory drainage area from Carlyle to New Athens is 2435 square miles (5126 sq mi minus 2691 sq mi). Excess flow attributable down to the Lock and Dam is representative of a total of 3047 square miles of drainage area (5738 sq mi minus 2691 sq mi). The New Athens gage is closest upstream of the Baldwin withdrawal. Baldwin's withdrawals have had an effect on the flow data on the Lock and Dam. Upon contracting with Dynegy for Baldwin water supply, water withdrawals will be restricted to maintain the present Q7,10 flow. Thus, the excess flow available to the Lock and Dam may be considered conservative.

Listed below are several selected low flow values taken from ILSAM:

Flow Type	Carlyle	New Athens	Lock&Dam	Carlyle → Lock&Dam (difference or excess)
Q99	39 cfs	92 cfs	86 cfs	47 cfs
$Q_{7, 10}$	40 cfs	89 cfs	116 cfs	76 cfs
$Q_{7\text{-day, 50-year}}$	32 cfs	72 cfs	97 cfs	65 cfs
$Q_{31\text{-day, 10-year}}$	44 cfs	101 cfs	127 cfs	83 cfs
$Q_{31\text{-day, 50-year}}$	36 cfs	81 cfs	103 cfs	67 cfs
$Q_{91\text{-day, 10-year}}$	57 cfs	141 cfs	182 cfs	125 cfs
$Q_{91\text{-day, 50-year}}$	42 cfs	94 cfs	122 cfs	80 cfs

The least excess contributory flow for the events cited is 47 cfs and represents the excess flow which would be expected at the lock and dam 99 percent of the time. This excess flow is actually less than what would be available at New Athens 99 percent of the time (being 53 cfs). Again, this is due to the Baldwin withdrawal. The report did not provide data on more severe drought events, such as the 100-year. The excess flow availability would obviously be less for such extreme drought events.

The estimated peak demand (based on historical growth) of the PWS systems in 2040 is 38 cfs and could be met by the present 99 percent excess flow at the Lock and Dam (47 cfs). If Dynegy contracts for water supply the excess Q 99 percent flows should even be greater. The other flow events listed all indicate higher excess flows. The Q 7-day, 50–year flow at the Lock and Dam provides for about 65 cfs of excess contributory flow.

In summary, with the State being able to utilize up to the natural contributory flow downstream of Carlyle without charge during a navigation release, it can most likely meet the future (to year 2040) expected demands of the five PWS systems up to at least the 50-year drought event.

What happened during the 1987-88 drought?

The drought of 1987–1988 did create low flow event concerns which led to correspondence between the State and the St. Louis USACE, and the Illinois Power Company (IP). The concerns related to low flows being such that they could impair navigation interests and/or not support the commercial and particularly recreational lockages expected to occur over the summer. A field meeting on May 26, 1987 resulted in addressing many lock operation issues and collection of information on recreational and commercial lockages. In reading the notes and correspondence there appeared to be a concern about the potential for a navigation release and there was a significant effort to avoid such. The USACE contacted the OWR on June 19, 1987 and requested that the Baldwin IP Plant cease pumping for 24 hours on the weekend of June 20–21, 1987. Similarly, in May of 1988, OWR requested Illinois Power to cease withdrawals during Memorial Day weekend. Illinois Power complied with the requests as carried out by the OWR. A resulting outcome of these concerns and effort was the development of notification procedures between the OWR and Illinois Power, should it become necessary to curtail pumping. Specifically, a June 17, 1987 OWR memo to file cited a flow of 100 to 110 cfs at Venedy Station (present Q7,10 of 57 cfs) as the threshold for imposing some restrictions on IP pumpage and recreational lockages. The State and the USACE also developed a drought operations plan to allow the navigation pool to rise 0.8 feet above normal during the week to provide storage to accommodate higher lockages on weekends, in addition to the voluntary cessation of withdrawals at Baldwin as a second level of protection. As a result, no navigation water was released during this drought and to date has never been released from the reservoirs.

<u>Study on the Kaskaskia Navigation Canal</u> - In June of 1987, the ISWS was contracted by the OWR to perform a study on the management of the Kaskaskia Navigation Canal. In June of 1989, SWS Contract Report 461 entitled “Optimal use of the Kaskaskia Navigation Canal: Management Strategies and Guidelines” by Ali Durgunoglu and Krishan Singh was completed. The report identified several alternatives to avoid deficits during low flow conditions. The first alternative analyzed deficit reductions in raising the lock and dam pool level from 368.00 to levels to 368.50 or 368.80. The report stated that if the lock and dam were to operate at 368.80 with a restricted lockage schedule, then no major deficits would be expected up to a recurrence interval of 50 years. Another alternative addressed was to ask Illinois Power to stop pumping during periods of low flows and days of heavy lockage demand. A third alternative identified was to pump

Mississippi River water back into the navigation pool. The actions which took place during the 1987-88 drought were a significant effort to avoid a navigation release.

C.17 River and Lake Impact Analyses of Water Supply Agreement Allocations

A water supply impact assessment was performed in early 2002 on the basis of what reasonably may be expected to occur given the current information and needs at that time as provided from the various entities seeking water supply. The OWR was working with Holland Regional, Gateway, Peabody (Prairie State), and Dynegy.

A <u>Projected Monthly Water Supply Demand Assessment</u> was made based on the maximum annual usages. The analysis assumed the ultimate projected demand of the regional water systems and the resulting need to limit Prairie State's average annual usage to 9.5 mgd. This demand analysis is based on four distinctly different climatological conditions in order to address the average and worst case impacts and their expected frequency of occurrence. It is important to note the difference in a lake withdrawal versus a river withdrawal. Gateway is the only entity requesting a lake withdrawal. Thus, storage demands by Gateway occur every month of the year. The water supply needs for the river withdrawals are normally met by existing river flows, and releases from water supply storage will most likely only be requested during low flow conditions.

Water supply demands from lake storage during "Normal to Wet" years will be very minimal since releases for river withdrawals will not be needed. The "Drier than Normal" demand analysis should be considered as a year with slightly lower than normal precipitation for the year and a fairly short drier than normal condition in the fall. A "Very Dry" year demand is considered as one typical of conditions expected to be experienced in about a 10-year drought event.

The "Extremely Dry" year assessment is the 50-year or near worst case scenario. This evaluation establishes maximum usage of the water supplies being requested, except for Peabody Energy. The analysis assumes full use of water supply by Gateway and Holland Regional (projected 20 years from now) and the necessary cutback to Peabody Energy as previously discussed. Full use analysis by the public water supply systems (versus Peabody Energy) is a more conservative analysis (greater impacts) to the lake and river as will be seen later. Also, it should be noted that though Holland Energy contracted for up to 8.0 mgd (peak usage), the 5.3 projected annual usage provided by Holland was used in the assessment.

Lake Level and River Flow Monthly Statistics were used to provide an assessment as to the frequency and occurrences of existing pool levels and river flows, and statistical changes we can expect as a result of providing water supply. Lake level data prior to 1978 was not included since the operating target rule level for the winter drawdown was much lower. The river flows are taken from ISWS Contract Report 499, "Kaskaskia River Basin Streamflow Assessment Model: Hydrologic Analysis" (H. Vernon Knapp, 1990).

The values listed are for present flow conditions and provide a probability of flow being exceeded for each month of the year at several gage stations along the Kaskaskia River. For example, the Q90 flow at New Athens for the month of October is 100 cfs, meaning on average, flow at New Athens exceeds 100 cfs 90 percent of the time during the month of October.

Lake Impact Assessment

Lake Shelbyville:

Elev.	**Surface Area**	**Storage ***
600	11,000 acres	-----------
599	10,700 acres	3535 mg
598	10,400 acres	3437 mg
597	10,100 acres	3340 mg
596	9,800 acres	3242 mg
595	9,500 acres	3144 mg
594	9,200 acres	3046 mg
593	8,900 acres	2949 mg
592	8,600 acres	2851 mg

Carlyle Lake:

Elev.	**Surface Area**	**Storage** *
445	24,600 acres	-----------
444	23,200 acres	7787 mg
443	21,800 acres	7331 mg
442	20,400 acres	6875 mg
441	19,000 acres	6419 mg

* This is the amount of storage in million gallons (mg) available per foot drop in reservoir level. For example, 3535 million gallons is estimated as the water storage between elevations 600 and 599.

In order to provide a general overall assessment of what we can expect the water supply impacts to be, the following is an attempt to provide the impacts in terms of "**how much - how often**."

Normal to Wet Years can be expected to occur about **60 percent of the time or roughly six out of ten years**. During such years, there will be virtually no water supply impacts to Lake Shelbyville or Carlyle Lake. Impacts to river flows due to normal water supply withdrawals may be seen during the months of September and October, with 10 to 15 percent reductions in flow downstream of the withdrawals.

Drier than Normal Years can be expected to occur about **25 percent of the time or roughly one out of every four years**. During such years, we may expect water supply lake impacts to begin in August. Lake Shelbyville could see additional drops (cumulative totals) due to the water supply of 1 inch by the end of August, 2.2 inches by the end of September, 3.1 inches by the end of October, and up to 3.6 inches by the end of November. Carlyle Lake could experience additional drops of three-tenths of an inch by the end of August, 1.5 inches by the end of September, 3.7 inches by the end of October and 4.8 inches by the end of November.

Normal river withdrawals would be mostly noticeable during the late summer and through fall. Flows on the Kaskaskia River downstream of the Holland Energy/Holland Regional intake would be affected most during the months of September and October, when river flows could be brought down to the 10 cfs permit condition level. River flows downstream of Prairie State's intake could be reduced roughly by 25 percent during the months of September, October, and November.

Very Dry Years can be expected to occur **<u>10 percent of the time or on average once every ten years</u>**. During such a year it is possible that lake levels never or barely reach normal pool in June. Water supply effects could begin to be seen as early as May when the rule curve calls for bringing the pool to normal and reservoir inflows are low as to cause near minimum releases.

Lake Shelbyville could see additional drops (cumulative totals) due to the water supply of 0.5 inches by the end of May, 2.8 inches by the end of June, 5.3 inches by the end of July, 7.9 inches by the end of August, 10.1 inches by the end of September, 12.3 inches by the end of October, 14.1 inches by the end of November, and up to 16 inches prior to winter pool drawdown in December. Carlyle Lake could experience additional drops of 0.2 inches by the end of May, 0.5 inches by the end of June, 1.5 inches by the end of July, 3.3 inches by the end of August, 5.6 inches by the end of September, 8.1 inches by the end of October, 10.5 inches by the end of November, and up to 1 foot prior to winter pool drawdown in December.

During such years, effects due to river withdrawals may be seen for all months except for possibly the month of March. Withdrawals by Holland Energy/Holland Regional could result in flow levels of 10 cfs from August through December immediately downstream of the intake. Withdrawals by Prairie State could result in Q7-day, 10-year flows during the months of September, October, and November. Water supply releases would most likely be required for all the river users at times from August into December. Releases for Holland Energy and Holland Regional would be more likely needed than for Prairie State and Dynegy, due to the small additional drainage area (between the Shelbyville dam and Holland's intake) and the minimum 10 cfs dam release expected to be occurring during such an event. When additional releases are needed, the river segment from the dam to the withdrawal location would actually experience enhanced flow volumes than what would normally be experienced. Releases for Prairie State and Dynegy could enhance river flows for at least 70 miles downstream of the dam.

The impact assessment data for an **Extremely Dry Year** was based on full use of the water supply allocation and impacts on river flows at values normally exceeded 98 percent of the time. These numbers are indicative of a 50-year drought. However, a drought of this severity has not occurred since Lake Shelbyville and Carlyle Lake were built, and thus there are no lake level data to directly estimate the impacts of such a drought without a hydrologic model. Since the reservoirs were completed, the 1988 drought is probably the best historical example of what we may expect under such a drought, and that drought might be expected to have closer to **<u>a 5 percent probability of occurrence in any given year</u>**. The 1988 drought began to occur in early spring or late in the fall the previous year, and under such conditions the reservoir levels would likely not reach normal pool in June and we would begin to see the water supply impacts as early as April. At Lake Shelbyville, about 0.5 feet of additional lake level drop due to the water supply could take place by the end of June and over 1 foot by the end of September. During the 1988 drought, full use of the water supply would have resulted in about 4 inches of additional drop by the end of June (597 vs. 597.3) to almost 1 foot of additional drop by the end of September (595.4 vs. 596.4). At Carlyle Lake, nearly 3 inches of additional drop could take place by the end of June and about 9 additional inches by the end of September. During the 1988 drought, full use of the water supply would have resulted in about 2.5 inches of additional drop by the end of June (443.8 vs. 444) to almost 10 inches of additional drop by the end of September (442 vs. 442.8). It is assumed that flows in the months following would be sufficient to bring the pool at least up to winter pool (594 at Shelbyville and 443 at Carlyle) by the end of March.

During such an extreme drought, releases to satisfy at least a portion of the water supply needs for Holland Energy and Holland Regional would probably be necessary for most months of the year, except for possibly the month of April. River flows at or near 10 cfs downstream of the withdrawal would occur for long periods of time during such a drought, only to be broken up by short spikes associated with occasional intense storm events. Releases for Prairie State and Dynegy during such an extreme event would probably be necessary during all months except for possibly May and June. There could be short periods within these months that storm events provide the flows needed due to the large watershed upstream of the withdrawal but below the dam. During such an event, the 50 cfs minimum release from Carlyle would be expected for most of the year. The releases on behalf of Prairie State and Dynegy would provide for over 70 miles of enhanced river flows downstream of Carlyle.

Overall Impact Discussion Summary

On average, roughly one year out of four, some lake impacts may be felt in the late summer and fall. If we consider the end of October as close to the end of prime lake recreational activities, the water supply impacts during such a drier than normal year could result in an additional lake drawdown of about 3 inches on Lake Shelbyville and nearly 4 inches on Carlyle Lake. On average, one year out of every 10 years during a moderate drought, a water supply lake drawdown of about 12 inches at Lake Shelbyville and 8 inches at Carlyle Lake could result by the end of October. For a drought similar in nature to what was experienced in 1988, it is estimated that a level of 594.88 could have resulted on Lake Shelbyville in October assuming full use of the State's water allocations, being about 13.5 inches less than the 596.0 historical mean elevation for that month. At Carlyle Lake, full use of the State's water allocations could have resulted in a pool level of 441.58 in October of 1988, nearly 12 inches lower than the 442.5 historic mean elevation for October.

The fact that we may not realize water supply impacts more often and at greater scales in comparison to other water supply reservoirs has to do with several factors. The lakes have a fairly large watershed to surface area ratio (above 60:1) providing for some base flow levels even during moderate droughts. In addition, operation and management of the lakes for flood control has historically kept the mean lake levels above normal summer pool. The percentage of the joint-use pool authorized for water supply is only 14 percent of the total volume below normal summer pool, not including the portion designated for dead pool storage. As an illustration, the total joint-use pool at Lake Shelbyville is about 180,000 acre-feet with a projected water supply usage of 17 mgd. Lake Springfield has a storage capacity of about 50,000 acre-feet and an average water supply usage of about 22 mgd. Another major reason has to do with where and when the majority of water supply is being withdrawn. Gateway is the only large projected lake user that will have constant daily withdrawals, regardless of lake level or climate condition. Holland Energy, Holland Regional, Prairie State, and Dynegy may under normal to slightly drier than normal conditions withdraw from the river without the necessity for a water supply release. This situation minimizes the lake impacts significantly during drier than normal conditions then what would have been expected if these projected users were to withdraw directly from the lake.

While a benefit of river withdrawals is a reduced frequency and magnitude of lake impacts, a detriment is an increased frequency and duration at which lower levels in the river are experienced. This “tempering” of flows results in a stabilization or reduction of flow fluctuations in normal response to storm events, obviously more noticeable in low flow events. The extreme high and low flows characteristics of the Kaskaskia River were originally tempered through construction of the reservoirs in an effort to provide some flood control for primarily agricultural benefits. With the minimum release requirements, the overall low flow and drought flow values were increased. On a monthly basis, the lower flow events show a decrease from “virgin” flows from February through June, and generally show nearly the same flow or a slight increase from virgin flow from August through December. The effects of reservoir construction and water supply withdrawals may be better visualized by looking at these effects on virgin Q 75 percent, Q 90 percent and Q 98 percent flows. For illustration, compare these values at Cowden and New Athens for the months of April and October, as follows:

COWDEN	**April**	**October**	**NEW ATHENS**	**April**	**October**
Virgin Q 75	561cfs	25 cfs	**Virgin Q 75**	1920 cfs	132 cfs
Present Q 75	273 cfs	29 cfs	**Present Q 75**	1557 cfs	138 cfs
Withdrawal Q 75	253 cfs	(10) cfs*	**Withdrawal Q 75**	1517 cfs	98 cfs
Virgin Q 90	346 cfs	9 cfs	**Virgin Q 90**	1131 cfs	92 cfs
Present Q 90	90 cfs	13 cfs	**Present Q 90**	580 cfs	100 cfs
Withdrawal Q 90	70 cfs	(10) cfs*	**Withdrawal Q 90**	540 cfs	(89) cfs*

*(10 cfs and 89 cfs are permit values)

The above illustrates the effects of water supply withdrawals without a water supply contract release. River withdrawals have a negative effect in reducing moderately low to low flows. The reduction of present flows due to water supply withdrawals is a subject of public policy and permit rules regarding withdrawal structures or associated discharges.

For withdrawals on public waters, the State has established permit criteria to provide conditions for protection of certain flows.

The water supply storage releases will increase river flows for roughly 100 total miles of river length during very low river flow cycles. Since withdrawals by Prairie State and Dynegy are located near the mouth of the Kaskaskia, fewer impacts may be realized than if the withdrawals were occurring elsewhere. If these industries were located on the lake, the impacts would be more severe and more often. The greatest impacted river reach may be downstream of the withdrawals by Holland Energy and Holland Regional.

C.18 References and Links to Publications and Reports

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Appendix C – Authorities, Water Allocations and Analyses

Appendix D

Streamflow Accounting Model for the Kaskaskia River Watershed

Background

The analysis of streamflow data is vital for judicious water management. Such management is important since surface waters of the Kaskaskia basin support aquatic life, industrial and agricultural production, transportation, wastewater assimilation, and the supply of potable water. The focus of this analysis was to characterize low flows and flow duration curves in the Kaskaskia River and tributaries. Such flow statistics are necessary to estimate waste load allocations, regulate flow at impoundments, design cooling plants, locate wastewater treatment plants, regulate inter-basin transfers, and assess water supply risks (Douglas et al., 2002).

The Illinois Streamflow Accounting Model (ILSAM) produces estimates of flow frequency for any stream location within a watershed. Flows are estimated to reflect the variability of flow conditions exhibited in long-term hydrologic records (over the past 60-plus years), juxtaposed with the current state of water resource projects and water use within the watershed (termed “flow modifiers”) that impact flow characteristics of the stream. ILSAM includes a utility that also allows the user to introduce changes in these flow modifiers, such as increasing the amounts of a water withdrawal or wastewater treatment plant, which can be used to estimate associated changes in streamflow. In using this utility, the water availability of a particular stream or the watershed as a whole may be assessed for various scenarios in future water use.

The ILSAM was initially developed in 1985 (Knapp et al., 1985), and over the years has been developed for 11 major watersheds in Illinois covering more than half the state. A previous version of ILSAM was developed for the Kaskaskia River watershed in 1990 (Knapp, 1990). Over the years, as ILSAM has been applied to additional watersheds, new capabilities of the model have been added and the numerical procedures used in preparing input into the model have been refined. In the version of ILSAM prepared for Kane County (Knapp et al., 2007), the model was expanded into a more complete water supply planning tool by adding a mapping interface and the ability to build and modify complete scenarios of future water use change.

The ILSAM model provides estimates of streamflow frequency based on an analysis of historical streamflow and water use records from the past 60-plus years. It does not provide a simulation of flows resulting from climatic events nor attempt to synthesize a time series of flow values such as a daily or annual record. Thus, in generating a set of streamflow values representative of “current watershed conditions,” as they existed roughly during the 2005–2010 time frame, the model does not simulate specific events that occurred in that time frame. For its use in estimating streamflow values associated with future water use scenarios, ILSAM assumes that the basic climate conditions of the region will remain unchanged, i.e., that the range of conditions expressed in the 1948–2009 base period is applicable for planning purposes. Although there are societal concerns about future climate change impacts, at this time predictions from the suite of accepted global and regional climate models are highly variable and uncertain, particularly with regard to potential changes in precipitation that would be expected to have the greatest effect on future streamflow conditions.

This appendix describes the process used to estimate low flow frequency values and flow duration curves at USGS gaging stations in the Kaskaskia River watershed in Illinois. Since most gages in the watershed do not have periods of record spanning this entire base period, adjustment procedures are used to extend the records of shorter-term "secondary" gages using two long-term "index" stations. In particular, this adjustment procedure can increase flow parameter values at secondary gages with periods of record containing the droughts of the 1950s and 1960s, while it can also reduce these values for periods of record that commence in the late 1960s or later. In addition, to produce estimates of unaltered, or "natural," flow conditions, gaging records are also adjusted when they are significantly modified by effluent discharges, water withdrawals, or reservoir storage.

Many different flow statistics, termed *parameters* in this report, can be used to guide these management activities. Short-duration low flows spanning periods of 1 to 150 days are particularly valuable for assessing acute hazards to navigation, aquatic ecosystems, wastewater assimilation (for example, the Illinois Environmental Protection Agency uses the 7-day, 10-year low flow in several of their flow regulations), and water supply systems that do not have any reservoir storage. Drought flows of a longer duration (6 to 54 months) are most useful for water supply planning for systems equipped with reservoirs, ranging from municipal utilities to power plants. In addition, annual and monthly flow exceedance values, also known as flow durations, serve as useful indicators for many water management applications. The following 181 flow parameters are estimated in this report:

a) 8 low flow periods, ranging from 1 to 150 days, with frequencies of 2, 10, 25, and 50 years (32 total parameters)
b) 11 drought flow periods, ranging from 6 to 54 months, with frequencies of 10, 25, and 50 years (33 total parameters)
c) 19 annual flow duration values from 1 to 99 percent and the mean annual flow (20 total parameters)
d) 7 flow duration values and the mean monthly flow for each of the 12 months (96 total parameters)

For the current ILSAM application, the number of streamflow frequency characteristics estimated by the model, or "parameters," was expanded from 154 to 181 to add more flow characteristics during drought conditions useful for evaluating reservoir yields. The process of changing the ILSAM model to accept more parameters required a considerable amount of reprogramming the model's code, which will not be described here in depth. In the same process, the model code was also updated to a newer version of Visual Basic and improved GIS functions.

Computation of Flow Characteristics for Streamgages

Flow frequency characteristics were computed using the daily records from over 25 streamflow gaging stations in the Kaskaskia River watershed that are currently or have previously been operated by the U.S. Geological Survey (USGS). Aside from the fact that gages are located at various sites on different streams, there are several other reasons why flow frequency characteristics computed for any particular gage may not be directly comparable to the frequency characteristics from other gaging records in the region. One of the most basic factors causing differences in flow frequency is the period of operation years for the gaging record. Just as precipitation amounts can vary substantially from year to year or from decade to decade, so also do streamflow amounts; in fact, the differences in streamflow tend to be magnified compared to the precipitation differences. As indicated by Singh and Ramamurthy (1990), a 10 percent increase in the average precipitation can lead to as much as a 40 percent increase in average streamflow amount for most locations in Illinois. To develop comparable streamflow amounts between various locations across a watershed, it is essential that the flow estimates be based on similar periods of record. For most streams in the Kaskaskia region, the analysis of flow records for ILSAM uses a consistent base period of 1948–2008 (at the time the analysis was initiated, the 2009 and 2010 flow records had not been released). The flow frequency estimates for gaging records that have a shorter period of record need to be adjusted to reflect expected conditions over the longer base period. Because of these adjustments, the flow frequency estimates provided by ILSAM usually do not match the frequency computed directly from the gaging record. The adjusted values are clearly more pertinent for water supply planning purposes when one considers that most streamgages were not installed until after 1970; whereas, in contrast, the most severe droughts in the region occurred prior to 1970. In estimating flow frequency on the mainstem Kaskaskia River, a slightly longer base period of 1941–2008 was adopted to take full advantage of extra years of pre-reservoir measurements available for most of the Kaskaskia River gages.

To extend the shorter gaging records in the watershed to reflect conditions over the selected 1948–2008 base period, it was necessary to identify longer-term gages that could be used as “index” or reference stations. The primary criteria for selecting index stations were:

1. There should be minimal anthropogenic modifications to flows at the gage since 1948; in particular, little urbanization and reservoir development should have occurred in the watershed upstream of the gage.
2. The hydrology of their watersheds should be representative of the hydrology in the two principal physiographical regions in the Kaskaskia watershed, the Bloomington Ridged Plain and the Springfield Plain (Leighton et al., 1948).
3. Gages should have periods of record that span the 1948–2008 base period, a period that includes both the severe drought of the 1950s as well as the relatively wet conditions of recent decades. Unfortunately, no other gages within or adequately close to the Kaskaskia watershed could meet all three conditions.

With the exception of the USGS gaging record for Shoal Creek near Breese and the mainstem Kaskaskia River gages whose flows are impacted by federal reservoirs, there are no gaging records in the watershed that span the 1948–2008 base period. The Breese station was thus adopted as the index record for extending gaging records at locations within the Springfield Plain physiographic region. To find an appropriate gage to serve as the index record for the physiographic region called the Bloomington Ridged Plain (the portion of the watershed north of Shelbyville), it was necessary to investigate gaging records from outside of the Kaskaskia watershed. The USGS gaging record for the Sangamon River at Monticello was selected as the most appropriate index station for the northern part of the Kaskaskia watershed.

Twenty-two short-term, or *secondary*, gaging stations whose records could be extended to cover the base period were identified (Table D-1). In general, only stations with at least a 20-year period of record were selected, although some consideration was also given to the coincidence of these periods with major droughts, e.g., 1952–1957. There were six gages (05590500, 05593520, 05593575, 05594450, 05594800, and 05595200) whose records were adjusted to account for the effects of effluent discharges and water withdrawals. In these cases, values of the flow parameters were calculated for both *present* and *unaltered* flow records.

Evaluation of Flow Modifications

Although there are streamflow records in the region during the 1950s droughts, for many locations there have been changes over the past 50 years that have altered flow amounts in the river. Other than the federal reservoirs and smaller water supply reservoirs, the most obvious change has been growth of communities and industries located in the region, associated increases in wastewaters discharged to the river, and, to a lesser extent but of essential consideration, water supply withdrawals from streams. As a result, even if identical climate conditions of the 1950s occurred again, the flow in the river would not be the same as that observed during these historical droughts. For water supply planning, it is necessary to identify, as best as possible, not only the current water conditions, but also future flow modifications to the river for use in projecting potential impacts on streamflow quantities in future droughts.

Municipal and industrial water users in the Kaskaskia River basin require water for their operations and use its rivers and streams as a means of discharging and diluting their effluent. The volume of water withdrawn and returned to the river has changed over time in many locales. The methods used in the Illinois Streamflow Assessment Model (ILSAM) to characterize the frequency of different flow indicators are based upon the assumption of stationarity, i.e., the probability of a given flow occurring does not change over time. For this assumption to be sufficiently valid, it is necessary to remove the component of the flow that withdrawals and effluent discharges from the gaging records to compute the *unaltered*, or natural, flows. Impacts of long-term climate change, land cover change and tile drain installation are assumed to be negligible unless a given hydrologic record does not appear to be stationary after historic withdrawals and effluent

Table D-1. Summary of USGS Gages with Adjusted Frequency based on Period of Record

USGS Gage Number	Start of Record	End of Record	Locations Description
05590000**	5/1/1949	4/30/1990	Kaskaskia Ditch at Bondville, IL
05590400** 05590500	5/1/1955	4/30/1979	Kaskaskia River near Pesotum, IL (1964-1979) Kaskaskia River near Ficklin, IL (1954-1964)***
05590800**	5/1/1973	4/30/2008	Lake Fork at Atwood, IL
05591500**	5/1/1951	4/30/1982	Asa Creek at Sullivan, IL
05591550**	5/1/1980	4/30/2008	Whitley Creek near Allenville, IL
05591700**	5/1/1980	4/30/2008	West Okaw River near Lovington, IL
05592000**	5/1/1941	4/30/1967	Kaskaskia River near Shelbyville, IL
05592050**	5/1/1980	4/30/2008	Robinson Creek near Shelbyville, IL
05592300*	5/1/1959	4/30/1982	Wolf Creek near Beecher City, IL
05592500*	5/1/1941	4/30/1967	Kaskaskia River at Vandalia, IL
05592575*	5/1/1989	4/30/2008	Hickory Creek near Brownstown, IL
05592800*	5/1/1971	4/30/2008	Hurricane Creek near Mulberry Grove, IL
05592900*	5/1/1980	4/30/2008	East Fork Kaskaskia River near Sandoval, IL (Fairman)
05593000*	5/1/1941	4/30/1967	Kaskaskia River at Carlyle, IL
05593520*	5/1/1975	4/30/1998	Crooked Creek near Hoffman, IL
05593575*	5/1/1968	4/30/2008	Little Crooked Creek near New Minden, IL
05593600*	5/1/1961	4/30/1982	Blue Grass Creek near Raymond, IL
05593900*	5/1/1964	4/30/2008	East Fork Shoal Creek near Coffeen, IL
05594450*	5/1/1967	4/30/2008	Silver Creek near Troy, IL
05594800*	5/1/1971	4/30/2008	Silver Creek near Freeburg, IL
05595000*	5/1/1941	4/30/1967	Kaskaskia River near New Athens, IL
05595200*	5/1/1970	4/30/2008	Richland Creek near Hecker, IL

**USGS Streamflow Gages Adjusted with 05594000 (Shoal Creek near Breese)*

***USGS Streamflow Gages Adjusted with 05572000 (Sangamon River near Monticello)*

**** The analysis combined the Ficklin and Pesotum records as part of an extensive analysis to quantify upstream flow modifications and unaltered flow conditions*

discharges have been removed from the gaging record. The calculation of unaltered flows also allows for the impacts of changes in water withdrawals and effluent discharges to be assessed. Finally, the impacts of impounding reservoirs must be taken into account, as they alter the timing of flows downstream and induce evaporation. The following sections describe the methods employed to collect data on these direct modifications to streamflow and estimate the likely rate at which these modifications occur at different flow frequencies.

Withdrawals

Current and historical annual withdrawals from municipal and industrial users were obtained from the Illinois Water Inventory Program (IWIP) and other records maintained at the Illinois State Water Survey. Systems that obtained an average of more than 0.10 cubic feet per second (cfs) between 2004 and 2009 were included in the model as withdrawal sites. Withdrawal rates were often assumed to be constant at all flow frequencies, primarily because the highest and lowest periods of water withdrawal do not typically coincide with periods of high or low streamflow. Periods of record other than 2004–2009 were used when substantial changes were made to a water system or there was a notable trend in use during this period.

Effluent Discharges

Data on effluent discharges typically from wastewater treatment plants are needed to estimate the impact on flows of different frequencies as well as to compute unaltered flows from historical gaging records. The locations of facilities that discharge effluent into the Kaskaskia River and its tributaries were acquired from monthly Discharge Monitoring Reports (DMRs) that the Illinois Environmental Protection Agency produced from December 1995 to March 2010. The effluent discharge rates reported between April 2004 and March 2010 were considered to be representative of current conditions. This six-year period of record includes two full calendar years that were significantly drier than normal (2005, 2007) and two years that were much wetter than normal (2008, 2009). These estimates were used for the 2004–2008 portion of the 1948–2008 base period and were also preserved to analyze the impact of present effluent discharges to virgin flows in watershed planning scenarios in the ILSAM model. Dischargers with a 7-day, 10-year low flow (Q7,10 or 7Q10) release of less than 0.01 cfs or an average release of less than 0.10 cfs were not included in the adjustments.

Historical Changes in Discharge Amount. When a flow duration curve, low flow frequency curve, or drought flow frequency curve of a gaging record indicated that an effluent discharge comprised a significant portion of the discharge at low flow rates, a time series of the effluent discharge component of the flow was computed for the 60-year study period. All current and historic effluent discharges upstream of such gages were identified using Discharge Monitoring Reports, the previous version of the Kaskaskia ILSAM model, and Q7,10 flow maps containing 1970, 1984, and 2001 effluent discharge measurements that the Illinois State Water Survey has produced. A 60-year time series of effluent discharges during Q7,10 flows was simulated from these data, and then the effluent discharges expected at other flow rates were computed using the same methods described in the calculation on current effluent discharges. All Q7,10 effluent discharges prior to 1970 were assumed to be the same as those observed in 1970 given the relatively low population and industrial growth that the watershed underwent during this era unless there was a reason known for them to be different, for example, the construction of the Urbana-Champaign Sanitary District's Southwest Treatment Plant in 1968. Linear interpolation was used to estimate the effluent discharges expected during Q7,10 flows in years for which no data were available. In some cases, streams into which effluents are discharged are dry during low flow periods. In these instances, it is necessary to account for the infiltration of the effluent into the streambed. The method to estimate infiltration losses is presented in Knapp (1990).

Reservoirs

The presence of a major reservoir can also significantly alter the flow characteristics downstream of the reservoir. Peak flows and daily high flows will usually be diminished, the extent to which depends on the storage versus outflow characteristics of the dam's spillway. The frequency of medium-level flows will usually be increased. The low flows can either be increased or greatly decreased, depending primarily on whether there is a withdrawal from the lake and if the outlet provides for a minimum flow release. The ILSAM model has a utility to estimate inflow-outflow relationships of lakes based on the results of numerous reservoir routing models as described in Knapp (1988). This utility is applicable to the most common situation in which reservoir outflow occurs over an uncontrolled spillway.

In the case of the two federal reservoirs, flow conditions downstream from the reservoir are considered regulated in that they are influenced by specific operation objectives. For these cases, a more complex modeling analysis was needed that simulates the inflow-outflow patterns in the reservoirs under present operation policies. The reservoir routing model that was used for simulating outflow from the reservoirs is described in Appendix E. Except for identifying the situation in which minimum flow releases have changed slightly over the past 40 years, the reservoir outflows as measured by USGS gages downstream would be sufficient in describing reservoir outflow over that time period (the period after the reservoirs were constructed and filled). However, those flow records do not provide us with an understanding of outflow conditions (or reservoir elevations) such as would have been expected during dry conditions and drought as occurred during the 1948–1972 period. To estimate expected flow conditions for the period prior to reservoir construction, it was necessary to use the existing flow records at Shelbyville and Carlyle as inflow into the prepared reservoir routing model and simulate the resulting outflow. Then, to estimate the duration and frequency characteristics of flow downstream of the federal reservoirs for the entire 1948–2008 base period, it was necessary to combine the observed (1973–2008) flow record with the simulated flow record for the period prior to reservoir construction. The ILSAM flow characteristics for locations downstream of the federal reservoirs are thus based on a flow series prepared using this hybrid (observed and simulated) approach.

Estimating Flow at Ungaged Sites

Differences in flow conditions from one watershed to another are associated with a variety of physical watershed characteristics, such as topography, geology, watershed size, and climatic differences. In developing the ILSAM model for numerous major watersheds in Illinois, three specific characteristics most consistently have been used to differentiate differences in low and medium flow conditions: 1) total drainage area of the stream; 2) permeability of the subsoil, and 3) the annual average excess precipitation (precipitation minus evapotranspiration). Regional equations have been developed using multiple linear regression to estimate each flow parameter for a stream location based on these three watershed characteristics. The regions for which these equations apply are typically delineated based on the physiographic division of the glacial geology of the region, as determined by Leighton et al. (1948). The Kaskaskia River watershed has two primary physiographic divisions: 1) the Bloomington Ridged Plain, the portion of the watershed north of Shelbyville, and 2) the Springfield Plain covering the remainder of the watershed. Equations for each of the 154 flow parameters were determined for these two regions in the previous ILSAM model for the Kaskaskia River (Knapp, 1990). These equations were reevaluated, and were determined to be applicable for the present study. Because the ILSAM model has been extended for this study to estimate 181 flow parameters, an additional 27 equations for each physiographic region were developed for use in the model. These estimates are subsequently used as inputs in the new version of the Illinois Streamflow Accounting Model (ILSAM) for the Kaskaskia River basin.

Selected Results

Table D-2 compares the most recent streamflow estimates with those from the previous 1990 ILSAM versions for selected locations in the Kaskaskia River watershed. Values are provided for six flow parameters that range from medium flows (Q_{50}) to low flows ($Q_{7,10}$), as well as the average annual flow (Qmean).

Precipitation amounts in the Kaskaskia River watershed over the past two decades have been greater than the previously determined (1990) long-term average conditions, such that with the most recent 21 years of data there is a noticeable shift (increase) in flows that appear to be directly related to climate factors, considered to be part of natural climatic variability. Overall, the climate of the past 40 years, including the period of record for most gages, is wetter than the previous 80 years (1890–1970). Although locations shown in Table D-2 for the Kaskaskia River have shown an increase in average flows and medium flows; for the tributary streams the results are mixed. It is possible that the change in estimation methods between the 1990 and 2011 versions of the models may also have a slight influence on the results, but such effects have not yet been analyzed.

Several locations appear to have noticeable increases in low flow amounts. Streams on the urban fringes of the watershed that receive effluent amounts, including the upper Kaskaskia River (Cooks Mills), Silver Creek, and Richland Creek, have shown increases in low flows. In all cases, these results can be directly traced to increases in population and wastewater discharges. Low flow releases from the two federal reservoirs also appear to have increased. Based on discussions with Corps of Engineers personnel, it appears that the higher amounts of water above the minimum flow level are released to enhance water quality downstream, such as to maintain higher dissolved oxygen levels. A more frequent increase in the low flow release is particularly apparent downstream of Lake Shelbyville. Some of the flow values for the Kaskaskia Lock and Dam such as the $Q_{7,10,}$ appear to have been miscalculated by equations in the 1990 model version.

Table D-2. Comparison of 1990 and 2011 Estimates of Present Flow Conditions

Location/Year of analysis	Q_{mean}	Q_{50}	Q_{75}	Q_{90}	Q_{98}	$Q_{7,10}$
Kaskaskia Lock and Dam						
1990	3893	2813	580	175	92	116
2011	4840	2500	650	220	117	100
Kaskaskia River at New Athens						
1990	3888	1767	404	178	102	89
2011	4360	2300	510	182	104	94
Kaskaskia River at Carlyle						
1990	2122	1053	152	52	41	40
2011	2386	1240	200	60	46	40
Kaskaskia River at Vandalia						
1990	1558	825	176	52	41	26
2011	1757	930	195	68	43	32
Kaskaskia River at Shelbyville						
1990	840	464	68	12	8	6
2011	922	540	48	20	18	15
Kaskaskia River at Cooks Mills						
1990	386	129	26	10.9	5.0	2.7
2011	433	191	46	18.5	8.7	5.8
Richland Creek near Hecker						
1990	98	26	14.5	10.9	7.4	5.2
2011	114	34	18.0	12.6	8.6	6.2
Silver Creek at Freeburg						
1990	340	69	18.4	7.9	4.4	3.1
2011	348	70	23	12.5	7.7	6.4
Shoal Creek near Breese						
1990	531	100	30	12	3.6	0.7
2011	529	104	28	12	3.1	0.7
Crooked Creek near Hoffman						

1990	201	25.2	8.9	3.4	1.2	0.7
2011	219	25.0	10.4	3.4	1.3	1.0
W. Okaw River at Lovington						
1990	105	30	1.8	0.02	0.0	0.0
2011	99	31	1.9	0.0	0.0	0.0

Notes: * Q_{mean} is the mean flow at the location; Q_{50}, Q_{75}, Q_{90}, and Q_{98} are flow duration exceedence parameters; $Q_{7,10}$ is the 7-day, 10-year low flow

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Appendix E

Hydrologic Modeling of the Kaskaskia River Watershed

Watershed Simulation Model

The Soil and Water Assessment Tool (SWAT) is the watershed simulation model used to develop the Kaskaskia River Hydrologic Model. It is one of the most widely used watershed models developed to predict the long-term impacts of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds with varying soils, land use, and management conditions (Arnold et al., 1999). The model incorporates a suite of algorithms that are capable of simulating hydrologic and water quality processes such as surface and subsurface flows, sediment transport, nutrient transport and cycling, and crop growth. In order to simulate these watershed processes, SWAT requires data on weather, topography, soil properties, vegetation, and land management practices, and model simulations are performed at a daily time step. The model has a weather generator tool that makes use of long-term monthly average data to estimate daily climate values for simulation or fills in gaps in observed records. SWAT has a GIS Interface that can be used in processing spatial data, including watershed delineation, preparation of input files, and visualization of model outputs. The minimum data required to run SWAT for watersheds are predominantly available from government agencies (Nietsch et al., 2001).

SWAT uses climate inputs for simulations of streamflows, potential evapotranspiration, snowmelt, crop growth, and others. Evapotranspiration can be simulated either by the model or computed outside of the model and incorporated into model simulations. Precipitation depths, minimum and maximum temperatures, solar radiation, relative humidity, and wind speed at the daily time step are required by the model for watershed simulation. SWAT uses a digital elevation model (DEM) for watershed delineation and its subsequent subdivision into subbasins. A user-defined critical source area, which sets the minimum drainage area required to form the origin of a stream, defines the detail of a stream network and thus the number of subbasins in the watershed. The DEM is also used to compute geomorphic parameters for each subbasin in the watershed. Digital land use and soil maps are used by the model to identify land uses and soil types in the subbasins of a watershed. Subbasins can be further subdivided into hydrologic response units (HRUs), which are patches of land areas with a unique intersection of land use, soil, and management conditions. However, the model provides two options with respect to HRU definition in a given subbasin. A subbasin can either be subdivided into a single HRU or multiple HRUs. The single HRU option represents the entire subbasin with the dominant land use and soil type in that subbasin and thus, HRUs and subbasins become the same entities. The multiple HRUs option employs threshold values for land use and soil categories to subdivide subbasins into two or more HRUs. Subdivision of subbasins into multiple HRUs introduces additional variability of model inputs that could impact watershed hydrology. However, that could also be achieved through detailed delineation of the watershed into smaller subbasins, and in this study, the single HRU option has been employed with detailed subdivision of the watershed into a number of subbasins.

Water balance is the main driving force behind everything that occurs in the watershed (Neitsch et al., 2001), and SWAT simulates the complete hydrologic cycle based on a water balance in a watershed; it is given as

$$SW_t = SW_o + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right)$$

Where SW_t is the final soil water content ($mm\ H_2O$), SW_o is the initial soil water content on day i ($mm\ H_2O$), t is the time (*days*), R_{day} is the amount of precipitation on day i ($mm\ H_2O$), Q_{surf} is the amount of surface runoff on day i ($mm\ H_2O$), E_a is the amount of evapotranspiration on day i ($mm\ H_2O$), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i ($mm\ H_2O$), and Q_{gw} is the amount of return flow on day i ($mm\ H_2O$). Surface runoff can be estimated by the SCS Curve Number procedure (SCS, 1972) or by the Green Ampt Infiltration Method (Green and Ampt, 1911); potential evapotranspiration can be estimated by the Penman-Monteith, Hargreaves, or Priestley method; percolation is simulated using a combination of a layered routing technique with a crack flow model; lateral subsurface flow or interflow is simulated using a kinematic storage model that accounts for variations in conductivity, slope, and soil water content; and groundwater flow is simulated using a linear reservoir approach subdividing an aquifer as deep and shallow (Arnold et al., 1993). Water routing through the channel network can be done either using the Muskingum river routing method (Brakensiek, 1967; Overton, 1966) or the variable storage routing method (Williams, 1969), both variations of the kinematic wave routing model. In this study, the SCS Curve Number, Pennman-Monteith, and variable storage methods were used to simulate surface runoff, potential evapotranspiration, and channel routing, respectively.

Kaskaskia River Watershed

The Kaskaskia River, which has a total drainage area of approximately 5800 square miles, is located in the southwestern part of Illinois. It originates in Champaign County and flows southwest for a total of 320 miles before its confluence with the Mississippi River. The river is the second biggest river system in Illinois draining approximately 10 percent of the State of Illinois. Figure E-1 is the Kaskaskia River watershed showing streams, subbasins, and subwatershed subdivisions used in developing a hydrologic model. The watershed area of Kaskaskia River is predominantly agricultural with corn and soybeans accounting for 60 percent. The types of land uses in the watershed include corn, soybeans, wheat, pasture, wetlands, water, forest, and urban areas. The Kaskaskia River watershed soils belong to hydrologic soil groups B (38%), C (46%), and D (17%). Hydrologic group B soils have a moderate infiltration rate and are mostly located in the upstream portion of the watershed, whereas more than half of the watershed area has soils of a slower infiltration rate or higher runoff potential; they are located in the central and downstream portion of the watershed. Table E-1 lists the land use and soil types and their percent coverage.

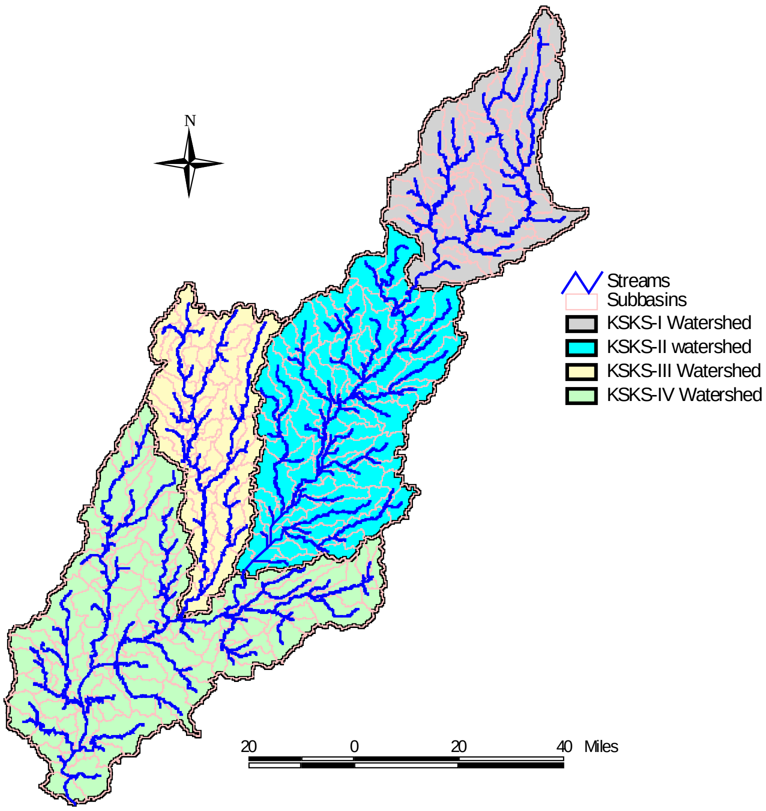

Figure E-1. Kaskaskia River Watershed

Table E-1. Land Uses and Soil Types in Kaskaskia River Watershed

Soil Types	Watershed Area (%)	Land use	Watershed Area (%)
Alford	2.7	Corn	28.8
Beaucoup	1.6	Soybeans	30.8
Bluford	14.4	Wheat	8.6
Camden	3.3	Pasture, hay	9.6
Catlin	15.3	Forest	10.8
Darmstadt	15.3	Urban areas	3.4
Drummer	0.8	Wetlands	6.3
Fayette	4.5		
Fishhook	1.0		
Herrick	8.2		
Hosmer	8.6		
Hurst	0.8		
Lenzburg	0.2		
Newberry	13.2		
Wakeland	9.7		

A total of 35 weather stations in or near the watershed as listed in Table E-2 were used in the hydrologic model development. Figure E-2 illustrates the average annual precipitation in the watershed, exhibiting a relatively uniform pattern throughout the watershed with an average annual total precipitation of 41.6 inches. The average annual total precipitation in the Kaskaskia River watershed ranges from a minimum of 39.7 inches at Mt Olive station (115917) to a maximum of 45.0 inches at Patoka station (116642).

Table E-2. Selected Weather Stations in Kaskaskia River Watershed

Station Name	Station ID	Latitude (°N)	Longitude (°W)	Elevation (ft)	Data Period
Urbana	118740	40.1	-88.2	226	1888 - date
Monticello #2	115792	40.1	-88.6	201	1964 - 2009
Hammond	113774	39.8	-88.6	207	1992 - date
Tuscola	118684	39.8	-88.3	198	1893 - date
Lexington	115219	39.7	-88.6	193	2000 - date
Mattoon	115430	39.5	-88.4	220	1893 - date
Shelbyville Dam	117876	39.4	-88.8	192	1941 - date
Windsor	119354	39.4	-88.6	210	1904 - date
Pana	116579	39.4	-89.0	214	1890 - date
Hillsboro	114108	39.2	-89.5	192	1895 - date
Mt.Olive 1 E	115917	39.1	-89.7	207	1940 - date
Nokomis	116185	39.3	-89.3	207	2000 - 2010
Beecher City	110500	39.2	-88.8	192	1974 - date
Ramsey	117126	39.1	-89.1	174	1974 - date
Brownstown 4 SW	111020	39.0	-89.0	162	1992 - 2009
Fillmore	113055	39.1	-89.3	198	1971 - 1988
Vandalia	118781	39.0	-89.1	153	1899 - date
Greenville	113693	38.9	-89.4	171	1887 - date
Highland	114089	38.8	-89.7	153	1977 - date
Patoka	116642	38.8	-89.1	157	1975 - date
Kinmundy	114756	38.8	-88.9	189	1975 - date
Salem	117636	38.6	-88.9	168	1915 - date
Carlyle RSVR	111290	38.6	-89.4	153	1962 - date
Belleville SIU RSRCH	110510	38.5	-89.8	135	1948 - date
Albers 1W	110050	38.5	-89.6	137	1977 - date
Centralia	111386	38.6	-89.1	168	1899 - date
Iuka	114400	38.5	-89.0	180	1997 - date
Nashville 1 E	116011	38.3	-89.4	140	1895 - date
Waterloo	119002	38.3	-90.2	220	1911 - date
New Athens	116072	38.3	-89.9	122	1969 - date
Coulterville 3 NW	111944	38.2	-89.7	180	1948 - 1982
New Athens 5 SW	116074	38.3	-89.9	120	1992 - 2001
Red Bud 5 SE	117157	38.2	-89.9	134	1947 - date
Sparta	118147	38.1	-89.7	165	1893 - 2009
Kaskaskia RIV NAV LO	114629	38.0	-89.9	116	1974 - date

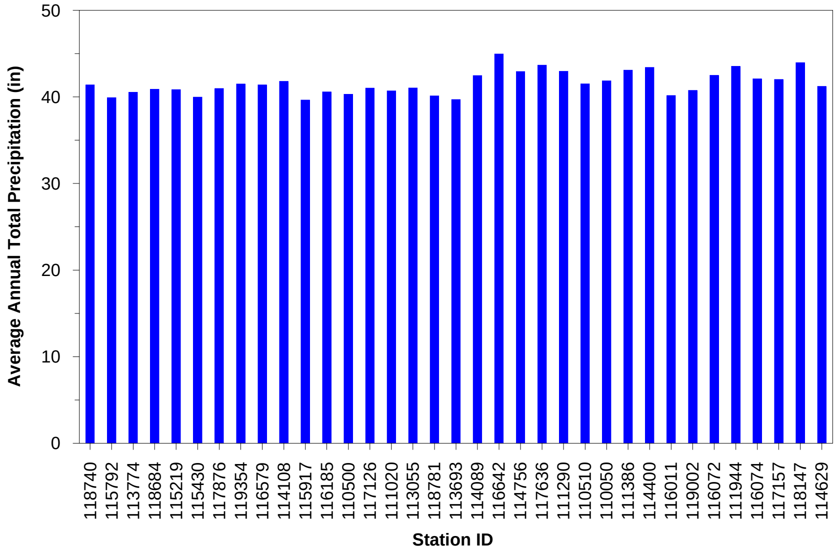

Figure E-2. Average annual total precipitation by station

For calibration and validation of a hydrologic model for the Kaskaskia River watershed, streamflow data from four USGS gaging stations were obtained. Three of the gaging stations are located on the main stem of the Kaskaskia River (i.e., USGS 05592000 at Shelbyville, USGS 05593000 at Carlyle, and USGS 05595000 at New Athens) and the fourth one is on Shoal Creek (USGS 05595000 near Breese), which is a tributary to the Kaskaskia River. Before the construction of Shelbyville and Carlyle dams in the late 1960s, the average annual peak flows at Shelbyville, Carlyle, and New Athens stations were 10,762, 16,848, and 28,672 cubic feet per second (cfs), respectively; however, the peak flows at these stations reduced to 3,798, 8,786, and 21,810 cfs, respectively, in the post-dam period.

Modeling Approach

The hydrologic modeling of the Kaskaskia River watershed was conducted using SWAT2005, which has both an open source code (FORTRAN) and an ArcGIS interface (ArcSWAT). The GIS interface of SWAT2005 is primarily used to generate model input files and default parameters of the model from a suite of digital data, including a DEM, land use map, soil map, and climate data. A 30 meter DEM for the Kaskaskia River watershed was derived from the National Elevation Data (NED) set for the upper and lower Kaskaskia River watershed that was downloaded from a website maintained by USEPA's Better Assessment Science Integrating Point and Non-point Sources (BASINS). The DEM is used to delineate the watershed and subbasin boundaries and derive average slopes for the subbasins. The stream network is defined based on a reach file obtained from the same website and using ArcSWAT's burn-in option for automatic watershed delineation. As shown in Figure E-1, the watershed is divided into four larger subwatersheds designated as KSKS-I, KSKS-II, KSKS-III, and KSKS-IV subwatersheds for model calibration purposes. These subwatersheds are further subdivided into 348 subbasins, out of which 65, 101, 50, and 132 subbasins make up KSKS-I, KSKS-II, KSKS-III, and KSKS-IV subwatersheds, respectively. During automatic model calibration, these subwatersheds are independently calibrated, and observed flows at upstream watershed outlets were used as inflows to the downstream subwatersheds (e.g., KSKS-I drains into KSKS-II). The total number of subbasins is set so as to incorporate sufficient variability of input factors such as weather, land use, and soils into the watershed simulation. For HRU definition, the land use data obtained from the Illinois Interagency Landscape Classification Project (IILCP), which is based on the 1999–2000 land cover inventory, was used. The State Soil Geographic (STATSGO) database was used to derive physical characteristics of soils in the watershed, including soil permeability and available soil water capacity, and it was obtained from the aforementioned BASINS’s website. Based on the dominant land use and soil categories in a subbasin, the Kaskaskia River watershed was divided into 348 HRUs, resulting in hydrologic connectivity between the HRUs because HRUs and subbasins are the same entities in this particular application.

Daily precipitation and maximum and minimum temperature data from 35 weather stations listed in Table E-2 were used for watershed simulation. Missing data gaps were filled in and shorter record periods were extended using data from nearby stations. Other climate inputs such as relative humidity, solar radiation, and wind speed were estimated using SWAT’s weather generation tool. Weather generation files for each climate variable were prepared based on 21-year (1989–2009) monthly average values derived from five Illinois Climate Network (ICN) stations. The ICN stations are Belleville, Bondville, Brownstown, Champaign, and Springfield. Potential evapotranspiration is estimated using the Penman-Monteith method, which utilizes climate inputs such as relative humidity, solar radiation, and wind speed. A weather station is assigned to each of the subbasins based on their proximity to centroids of the subbasins. For model calibration and validation, streamflow data from the four USGS gaging stations were used, and the annual total flow volumes at each of these stations are presented in Figures E-3 through E-6.

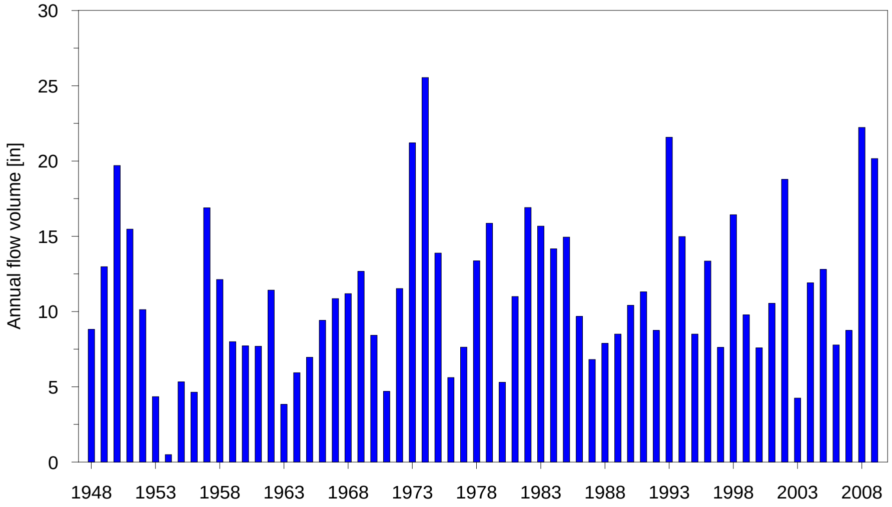

Figure E-3. Average annual flow for Kaskaskia River at Shelbyville

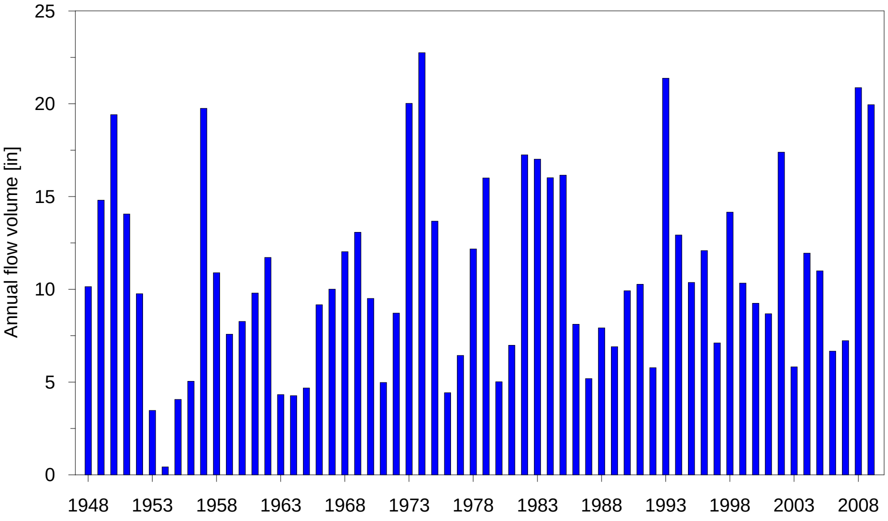

Figure E-4. Average annual flow for Kaskaskia River at Carlyle

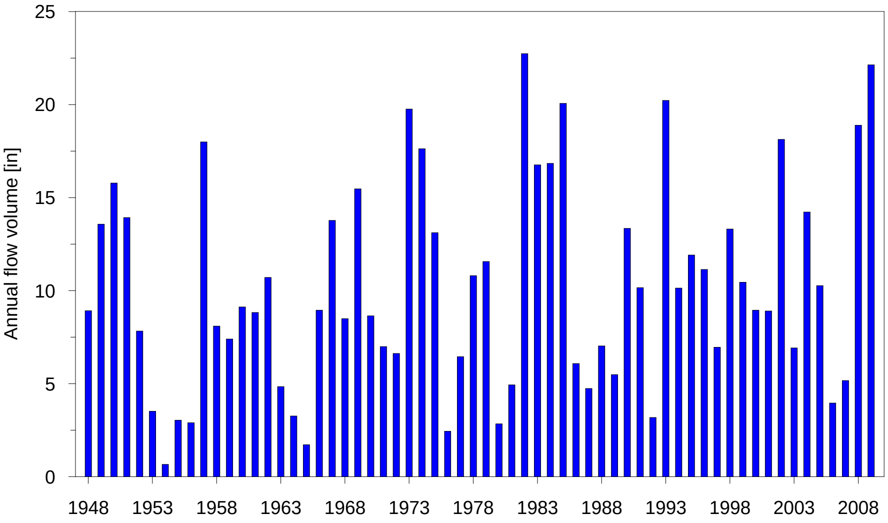

Figure E-5. Average annual flow for Shoal Creek near Breese

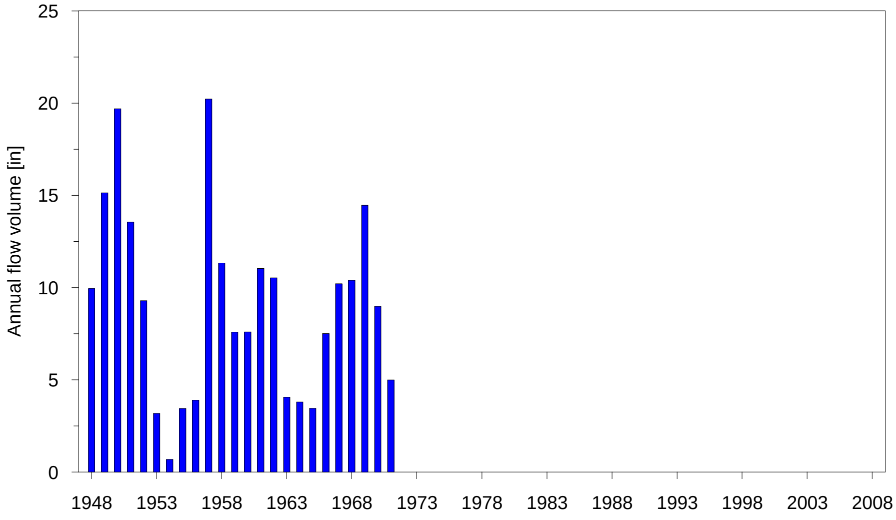

Figure E-6. Average annual flow for Kaskaskia River at New Athens

Model Calibration and Validation

As a distributed watershed model, SWAT uses a large number of parameters to represent spatial heterogeneity of watershed characteristics and processes into a simulation. This makes manual calibration using a trial-and-error adjustment of parameters a daunting and time-consuming task. To alleviate this problem, several automated calibration methods have been developed specifically for SWAT (Van Griensven and Bauwens, 2003; Bekele and Nicklow, 2007; Immerzeel and Droogers, 2008). In this study, a combination of SWAT's built-in automatic calibration tool has been employed, complemented by manual fine-tuning of model parameters. An automatic calibration routine uses objective functions as calibration criteria and optimization techniques to search for optimal model parameters. It generally involves searching for optimal model parameters that result in a close match between observed and simulated outputs.

The Nash-Sutcliffe efficiency (NSE) (Nash and Sutcliffe, 1970) and percent bias (PBIAS) (Gupta et al., 1999) were used as model performance metrics in evaluating streamflow simulations. The NSE is a normalized statistic quantifying the relative magnitude of the residual variance compared to the variance of the measured data, and it shows how well a plot of observed and simulated data fits the 1:1 line. It is given as

$$NSE = 1 - \left[\frac{\sum_{j=1}^{N} \left(O_j - S_j \right)^2}{\sum \left(O_j - \overline{O} \right)^2} \right]$$

where O_j and S_j are the j^{th} observed and simulated data, respectively, $\overline{O}$ is the mean of observed data, and N is the total number of data used during calibration. NSE values range from an optimal value of 1.0 for a perfect model to minus infinity. However, the values should be larger than zero to indicate minimally acceptable performance (Gupta, et al., 1999). NSE values less than or equal to zero show that the mean of the observed data is a better predictor than the model. The PBIAS measures the average tendency of the simulated values to be larger or smaller than their observed counterparts. The optimal value of PBIAS is zero, indicating exact simulation of observed values. In general, a lower value of *PBIAS* signifies accurate model simulation. *PBIAS* is computed as

$$PBIAS = 100 \times \left[\frac{\sum_{j=1}^{N} \left(O_j - S_j \right)}{\sum O_j} \right]$$

where O_j, S_j, and *N* are as defined earlier, further establishing performance ratings for each of these three recommended statistics. Model simulation can generally be judged as satisfactory if *NSE* > 0.5 and if *PBIAS* is within ±25 percent for streamflow simulations in a monthly time-step (Moriasi et al., 2007). In addition, graphical comparisons of observed and simulated hydrographs were used.

A total of 20 sensitive model parameters were selected for calibration of streamflows. These parameters govern the hydrologic processes, including rainfall-runoff relationships, accumulation of snow and snowmelt runoff, and groundwater flows. The Kaskaskia River watershed was subdivided into four larger subwatersheds as indicated earlier. KSKS-I has a drainage area of 1053 square miles and includes the area upstream of USGS 05592000 at Shelbyville. KSKS-II covers the area between the Shelbyville station and USGS 05593000 at Carlyle and has a drainage area of 1663 sq. mi. KSKS-III is the Shoal Creek watershed, and it drains an area of 915 sq. mi. KSKS-IV subwatershed, which covers the remaining part of the watershed downstream of the Carlyle Station and Shoal Creek watershed outlet, has an area of 2174 sq. mi. Subdivision of the Kaskaskia River watershed into four larger subwatersheds ensures distributed parameter calibration and helps reduce dimensionality of the auto-calibration problem. In addition, more observed data (e.g., measured discharges from upstream sub-watershed) can be used in the process of parameter estimation. Four hydrologic models were thus developed and calibration of each model was independently performed. Using optimal parameters obtained for each subwatershed model and further manual adjustments of those parameter values, the complete Kaskaskia River watershed model has been developed. Since this model is used to analyze the impact of potential climate change on low flow hydrology and surface water availability, historic drought periods are taken into account while selecting the calibration and validation periods. Therefore, flow records from 1960 to 1969 and from 1950 to 1959 were used for calibration and validation, respectively.

Calibration and Validation Results

The performance evaluation statistics for calibration and validation are presented in Table E-3. The daily NSE values for calibration and validation were greater than 0.6 for all calibration stations except USGS 05594000 for which it was 0.48 for calibration and 0.54 for validation. For monthly simulations, the worst NSE value was 0.71 with most having NSE values greater than 0.8. The maximum PBIAS was 7.6 percent for calibration and 8 percent for validation periods at all gaging stations. Values of the performance statistics generally show that monthly simulations were very good for all gaging stations. Applying the same performance guidelines as for monthly simulations, daily simulations were good for all stations except USGS 05594000 for which it was only satisfactory. Note that the performance guidelines for simulations at larger time-steps tend to be stricter. Model simulations of streamflows at annual time steps were very good for all stations as shown in the higher values of NSE (i.e., NSE > 0.85 in all cases). Graphical comparisons between observed and simulated monthly flow volumes are presented for each calibration station in Figures E-7 through E-10, showing the model's effective performance in simulating seasonal variations in streamflows.

Table E-3. Performance Evaluation Statistics for Calibration and Validation

USGS Gaging Stations	USGS 05592000	USGS 05593000	USGS 05594000	USGS 05595000
Calibration				
PBIAS (%)	4.8	6.0	7.6	-4.0
NSE (-)				
Daily	0.65	0.64	0.48	0.70
Monthly	0.79	0.81	0.71	0.83
Annual	0.90	0.88	0.90	0.93
Validation				
PBIAS (%)	-7.1	-0.2	-3.0	-8.0
NSE (-)				
Daily	0.73	0.70	0.54	0.76
Monthly	0.84	0.88	0.88	0.89
Annual	0.94	0.97	0.97	0.95

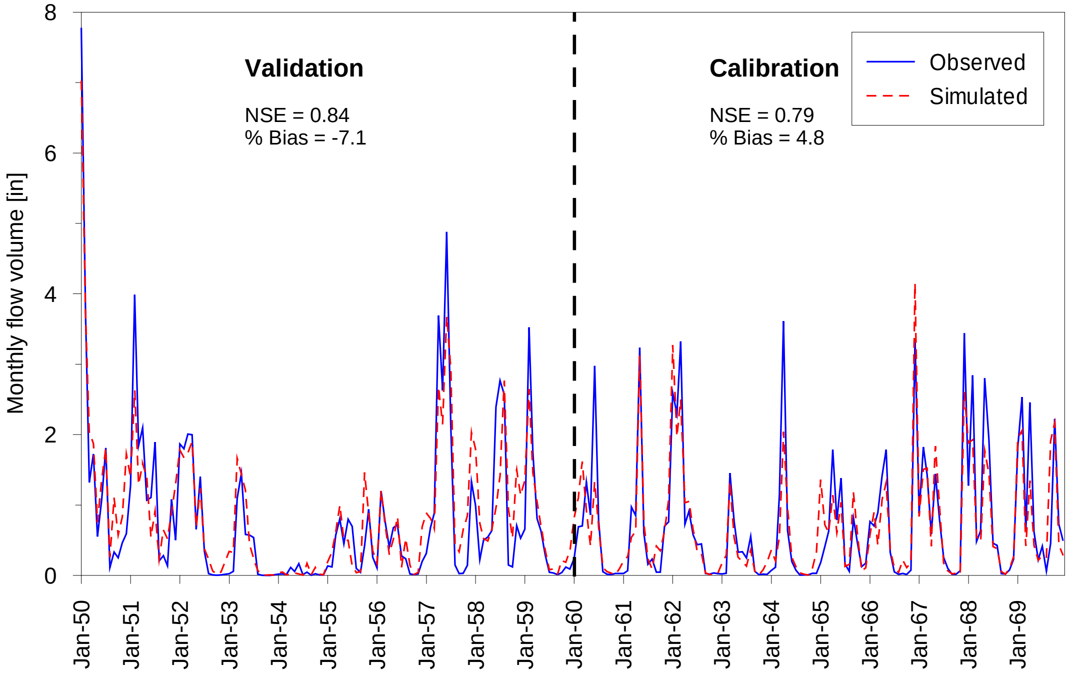

Figure E-7. Monthly flows for USGS 05592000 Kaskaskia River at Shelbyville

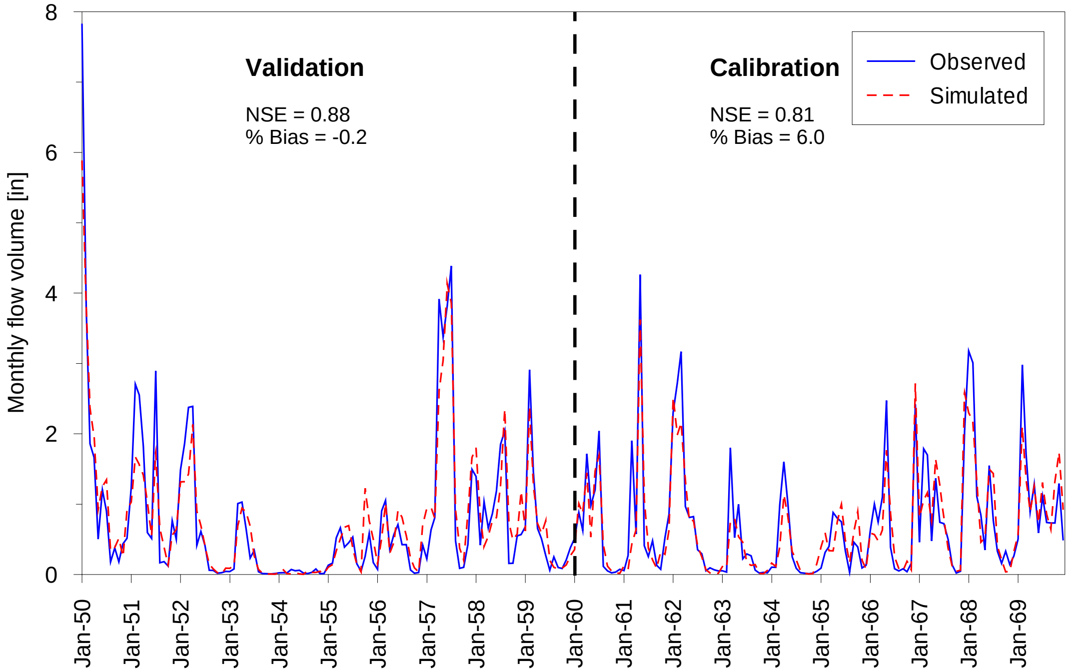

Figure E-8. Monthly flows for USGS 05593000 Kaskaskia River at Carlyle

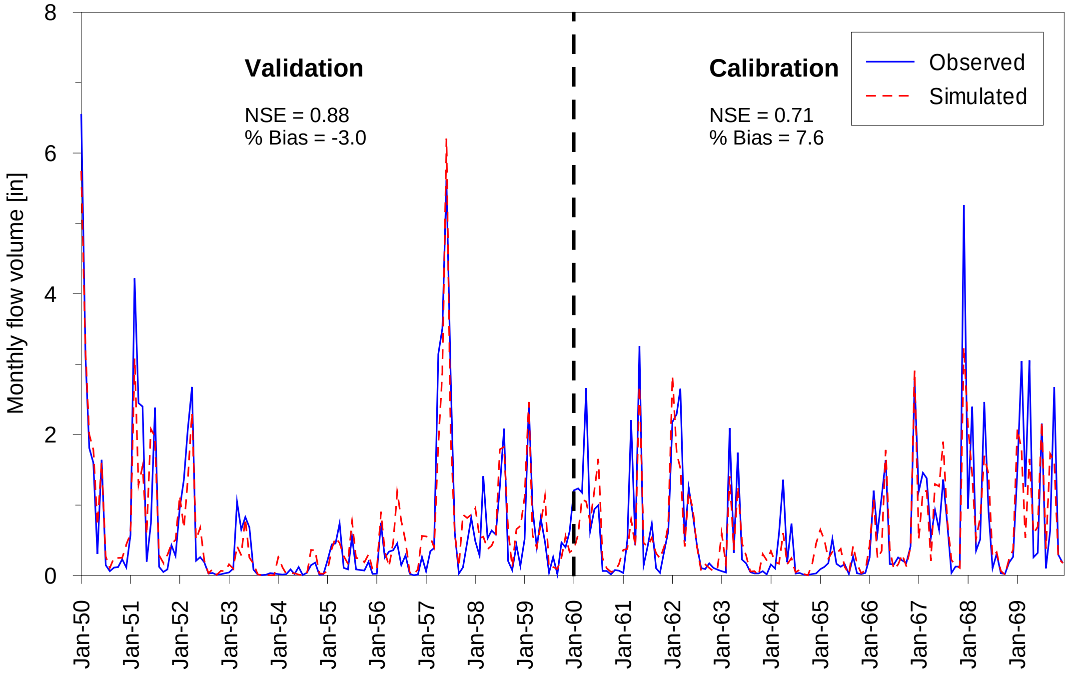

Figure E-9. Monthly flows for USGS 05594000 Shoal Creek near Breese

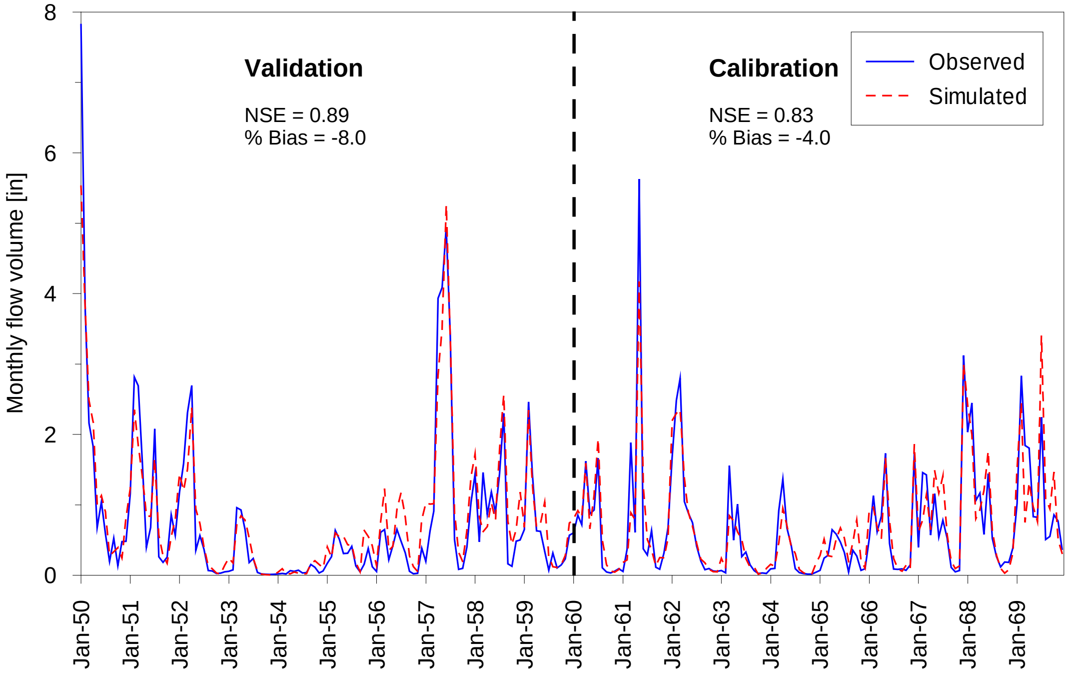

Figure E-10. Monthly flows for USGS 05595000 Kaskaskia River at New Athens

Hydrologic Reservoir Routing

The SWAT model used in this study performs reservoir routing using a simple water balance method in which the outflow volumes are computed using observed daily and monthly outflows, average annual release rates for uncontrolled reservoirs, or controlled outflow with target release. Since Shelbyville and Carlyle reservoirs have their own release schedules which cannot be handled by SWAT, a separate reservoir routing model using the Storage Indication or Pulse Method has been developed. The storage indication method makes use of the continuity equation in its finite difference form. The continuity equation is given as

$$I - O = \frac{\Delta S}{\Delta t}$$

where I is total inflows to the reservoir including reservoir inflows and precipitation; O is total outflows including reservoir outflow, evaporation and seepage; and ΔS is change in reservoir storage in simulation time step (Δt). Data required for reservoir routing simulations were obtained from various sources, and 15 years of data from 1990 to 2004 were processed for use in the simulations. Precipitation data were obtained from weather stations in or near the reservoir watershed areas, and lake evaporation is estimated as 75 percent of potential evapotranspiration in the area. Reservoir inflows, outflows, and pool elevations were obtained from the St. Louis district Corps of Engineers website (http://mvs-wc.mvs.usace.army.mil/archive/archindex.html).

Reservoir Routing Model for Lakes Shelbyville and Carlyle

To develop the reservoir routing model, storage-elevation, surface area-elevation, and storage-outflow relationships are required, and storage-surface area-elevation relationships are available for Lakes Shelbyville and Carlyle. Weekly release schedules for both lakes were determined based on target release schedules, 15 years of reservoir outflows, and pool elevation data from 1990 to 2004. These release schedules were determined by calibrating the lake pool elevations using a reservoir routing model coupled with an optimization algorithm. Figures E-11 and E-12 illustrate the weekly release schedules for Lakes Shelbyville and Carlyle, respectively. A comparison of observed and simulated monthly outflows from Lake Shelbyville is presented in Figure E-13. Similarly, Figure E-14 shows a comparison of monthly outflows for Carlyle Lake. Both figures indicate that there is a good match between observed and simulated values. In order to illustrate the attenuating and lagging effects the reservoirs have on inflow hydrographs, plots of inflows into and outflows from Lakes Shelbyville and Carlyle are presented for year 1996 in Figures E-15 and E-16, respectively.

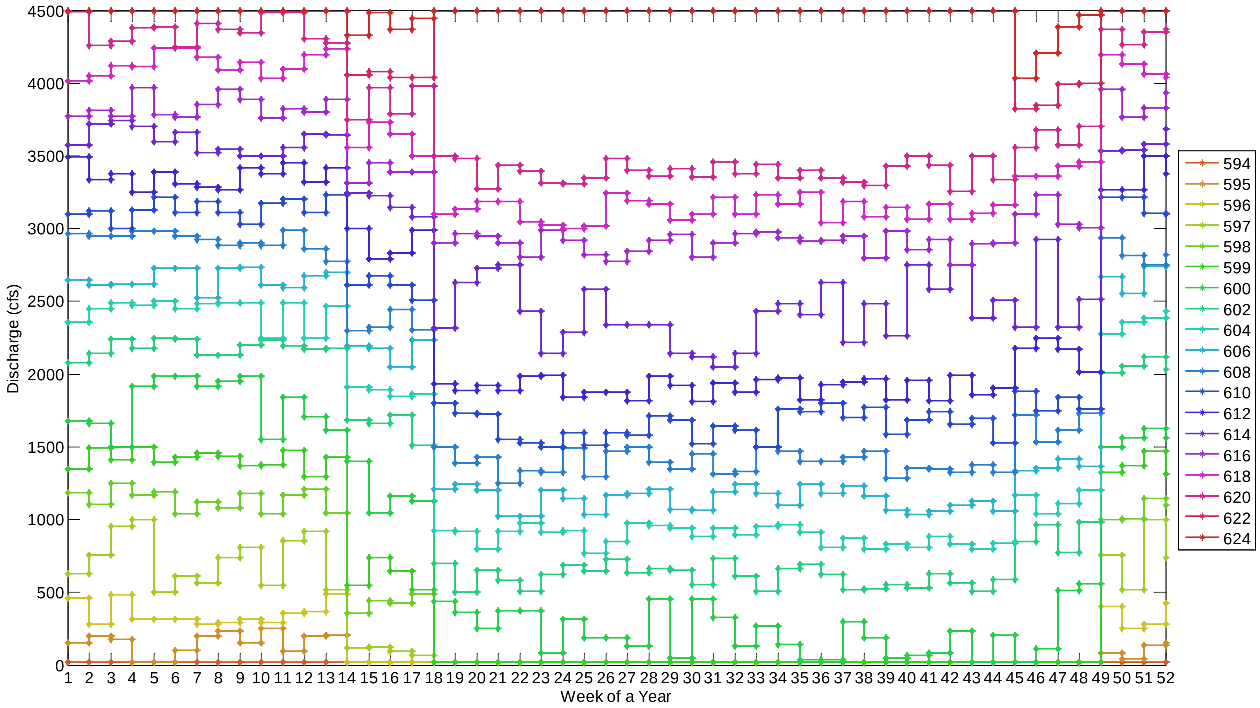

Figure E-11. Simulated weekly release schedule for Lake Shelbyville

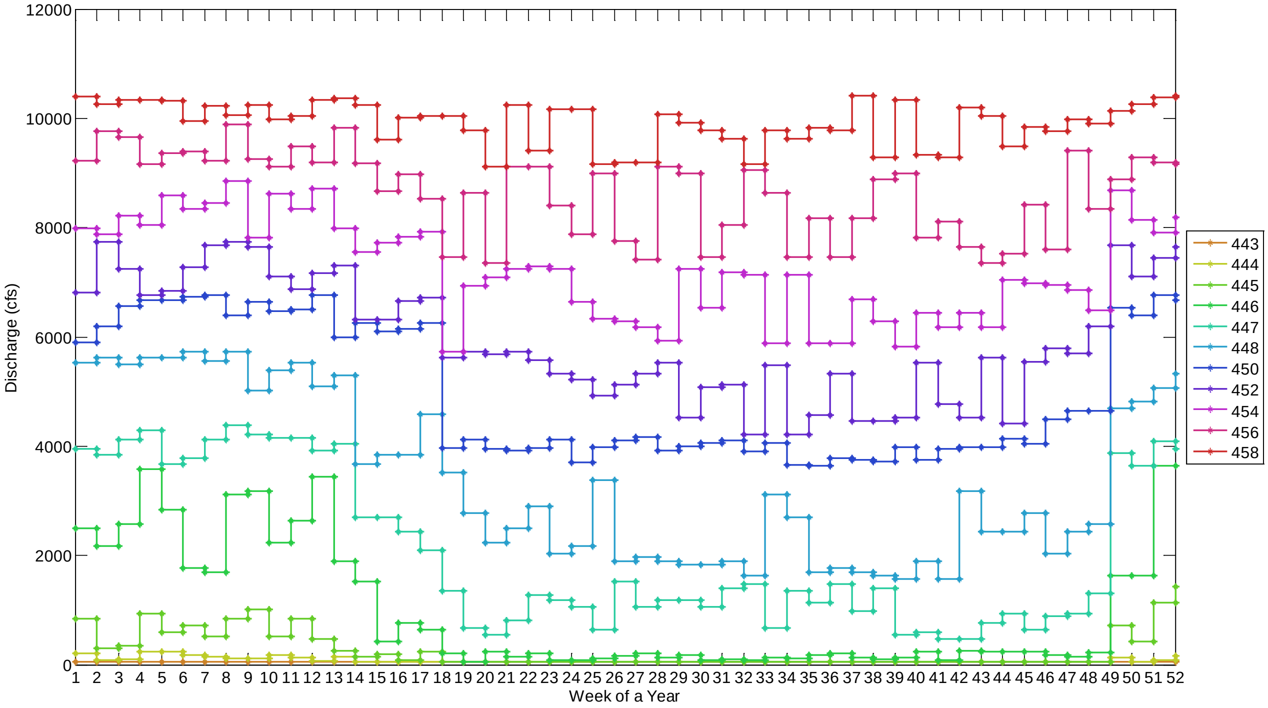

Figure E-12. Simulated weekly release schedules for Carlyle Lake

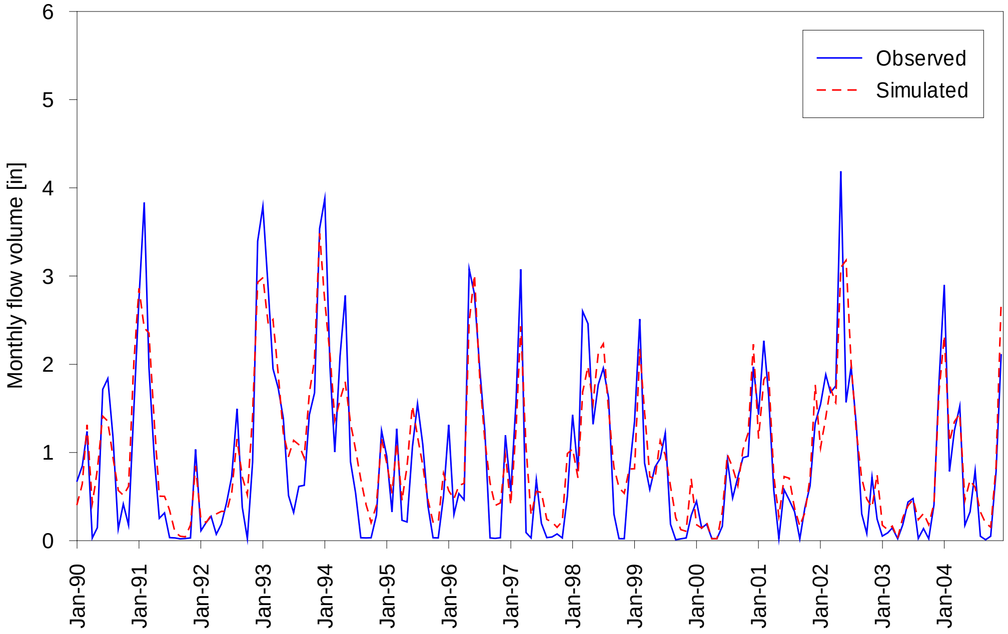

Figure E-13. Monthly outflows for Lake Shelbyville

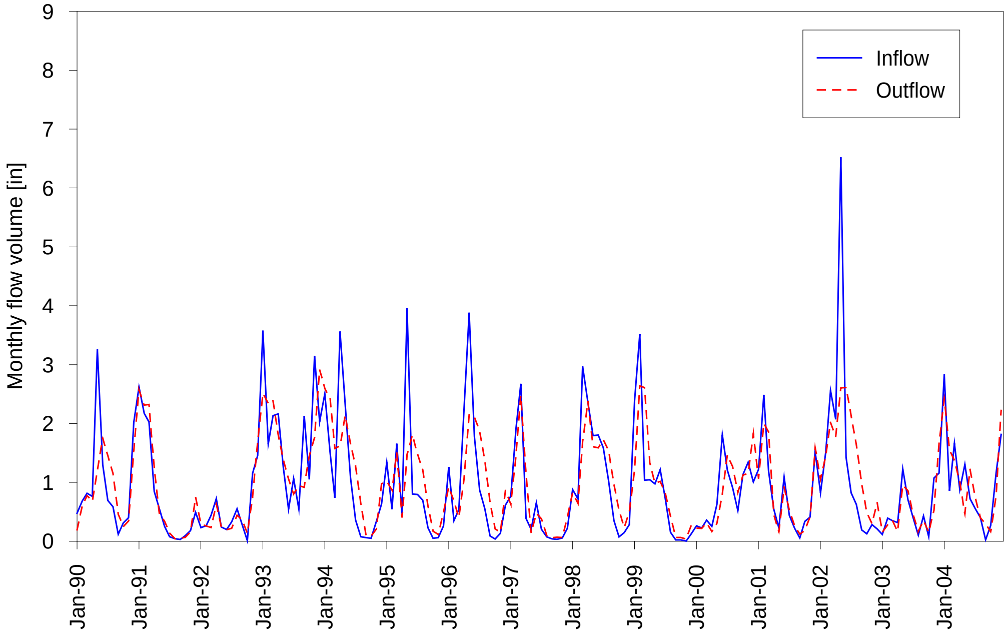

Figure E-14. Monthly outflows for Carlyle Lake

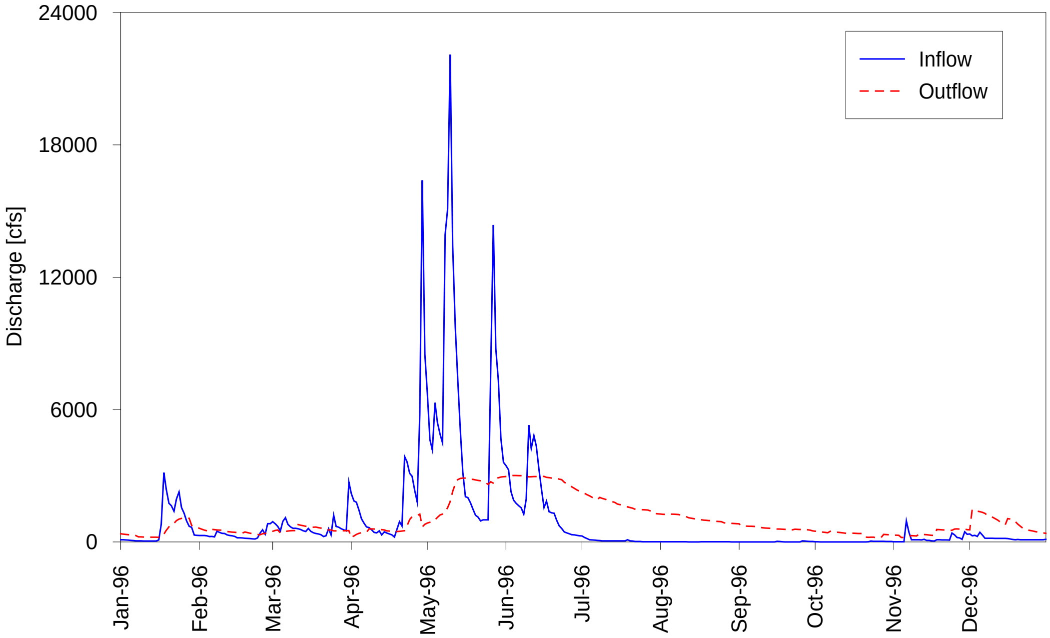

Figure E-15. Daily inflows and outflows for Lake Shelbyville

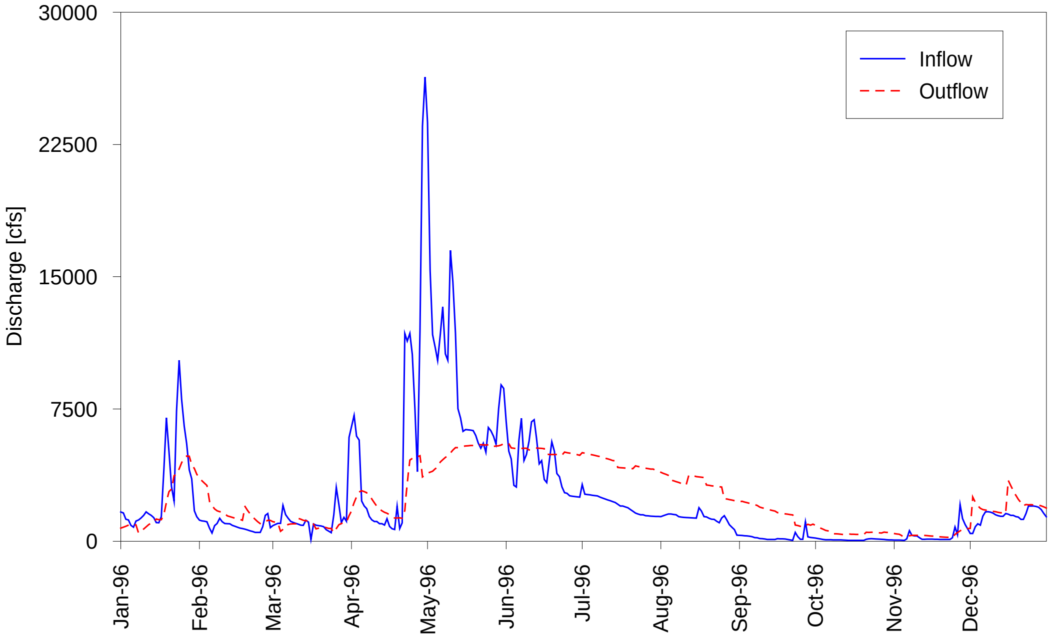

Figure E-16. Daily inflows and outflows for Carlyle Lake

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Appendix F

Groundwater Models

Sustainability Calculation for the Shelbyville Wellfield

Aquifer tests show that the aquifer is very permeable near wellfields (transmissivity = 130,000 gallons per day per foot [gpd/ft]), with general drawdowns in a production well of 10 feet at 300 gallons per minute (gpm) and 20 feet at 500 gpm. The drawdown drops off rapidly away from the test well. One test recorded 1.6 feet of drawdown in an observation well 97 feet from a production well pumping 440 gpm for one day. The wells are under unconfined conditions with a saturated thickness of 45 to 50 feet, making for an available drawdown of 22 feet before the 50 percent saturation threshold is reached and high flow rates become unsustainable due to decreasing transmissivity. With the eight active wells pumping an average of 71 gpm in 2008 (0.82 million gallons per day [mgd] total), the model calculated downs are 2.1 feet between the five wells at the north wellfield and 0.92 between the three wells at the south wellfield. If the city pumped each well at 300 gpm (3.5 MGD total), then the modeled drawdowns jump to 8.9 and 3.9 feet for the north and south wellfields, respectively. Combining the 8.9 feet of collective drawdown at the north wellfield with the 10 feet of drawdown within the individual production wells produces a total drawdown of approximately 19 feet, which is close to the sustainable limit. The capacity of the wellfield could be increased with additional wells properly spaced apart from the existing wells.

Sample Output from the Numerical Models

Predicted water levels from the Shelbyville and Vandalia models are shown in Figures F1 and F2 with contour intervals of 5 feet and 2 feet, respectively. For cells in the Shelbyville model, production wells are shaded red, river cells are shaded cyan, and the till uplands are shaded tan. The remaining white area is the active sand and gravel aquifer. For cells in the Vandalia model, the production is marked with blue symbols, river cells are shaded cyan or blue, seeps and springs are shaded green, and inactive areas are shaded gray.

Summary of Historical ISWS Analytical Model Aquifer Yield

The following paragraphs contain summaries that appeared in either Visocky et al. (1978) or Wehrmann et al. (1980). These describe the analytical modeling approach for estimating aquifer, or well field, yield for each community presented (Table F1). Summaries are included only for those 10 communities still using their local aquifer as a groundwater source since the summaries were prepared (circa 1980).

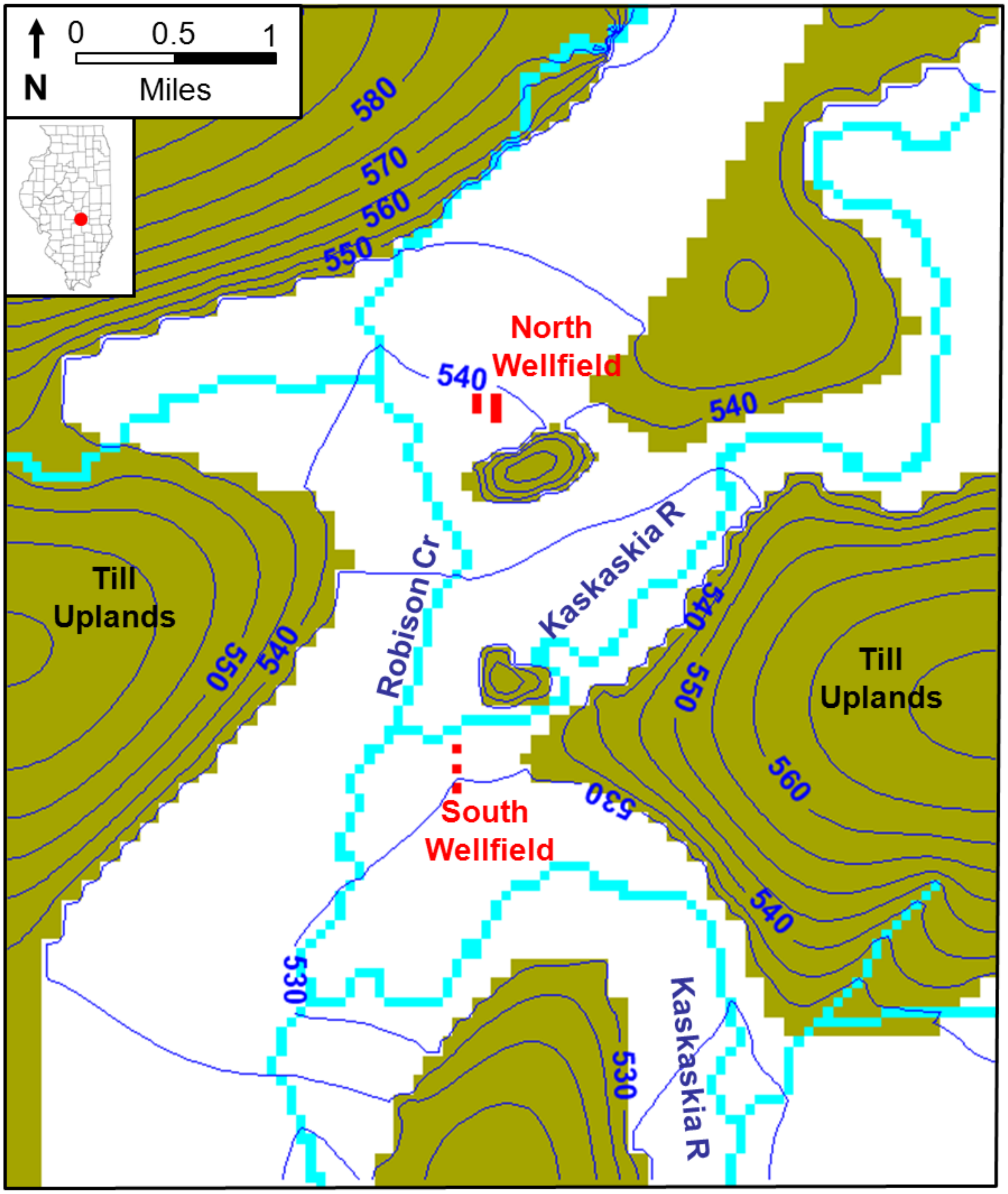

Figure F1. Predicted water levels from the Shelbyville model

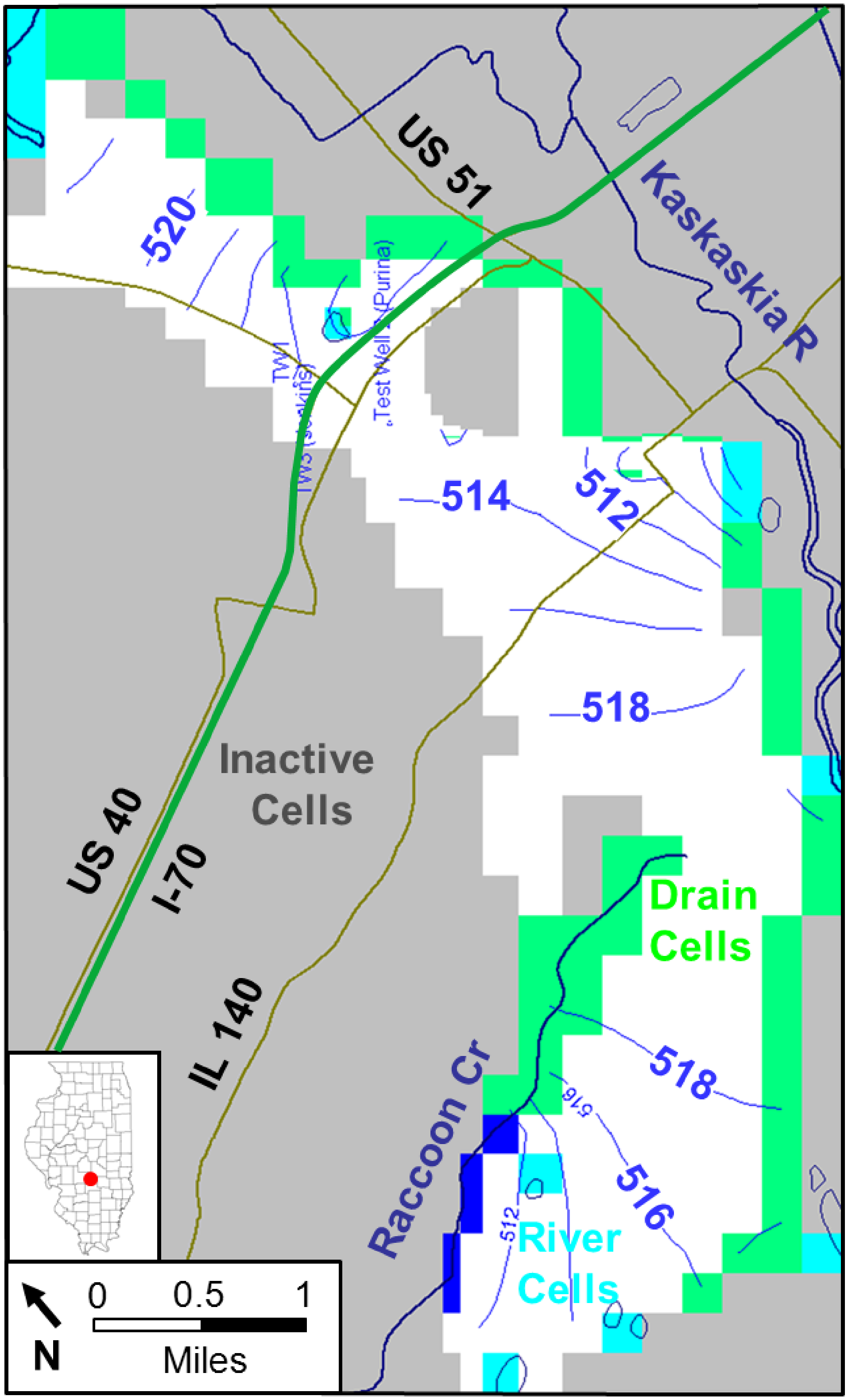

Figure F2. Predicted water levels from the Vandalia model

Three communities (Edinburgh, Nokomis, and Oreana) have a Use-to-Yield (UTY) value exceeding 1. The UTY values for three more communities (Fillmore, Germantown, and Percy) are very close to 0.9 (0.88, 0.85, and 0.82, respectively). Germantown purchases a portion of its water from Breese and could conceivably purchase additional water from this source and keep pumping rates from their aquifer near current rates. UTY values for the other communities are below 0.8 with values below 0.5 for Dieterich and Willow Hill. A value was not computed for Red Bud because the estimated yield is for an aquifer no longer used. Although the new well field has not been assessed, it is expected the yield of the Red Bud well field can be increased with additional wells whenever necessary.

Dieterich (from Visocky et al., 1978)

A 20-hour aquifer test was conducted on Test Hole (TH) 18 (located approximately 1180 feet north and 250 feet west of the southeast corner of Section 22, T7N, R7E) on July 2–3, 1951. The effects of pumping TH 18 at a rate of 25 gpm were observed in observation wells 92 feet to the south, 96 feet to the north, and 238 feet northeast of TH 18. The average values of transmissivity and storage coefficient computed by using time-drawdown and distance-drawdown data were 1500 gpd/ft and 0.002, respectively. The data were analyzed using leaky artesian graphical methods, and the coefficients of vertical permeability and leakage for the confining layer were determined to be 0.1 gpd/ft^2 and 0.000714 gpd/ft^3, respectively.

Using the aquifer and confining bed properties determined above, an idealized aquifer model was prepared for purposes of computing boundary effects by assuming conservatively that the image wells associated with aquifer boundaries were just beyond the extent reached by the cone of depression in the 1951 aquifer test described above. Image well theory was utilized to compute boundary effects at each well for an aquifer having properties determined from the test. Mutual interference was also calculated and added, together with image effects, to the estimated drawdowns in each well. Available drawdowns were limited to the top of the aquifer and also allowed for seasonal, dry weather declines in nonpumping levels.

By using the idealized aquifer model described above, it was estimated that the long-term sustained yield of the 5-well field at Dieterich may be limited to about 45,000 gpd. This agrees quite closely with the operational experience in 1975, when the village found it necessary to purchase additional water as pumpage averaged 40,000 gpd. The aquifer is shallow and quite sensitive to drought conditions as well as periods of heavy recharge, and, therefore, larger withdrawals would be possible on a short-term basis during periods of adequate rainfall.

Edinburgh (from Visocky et al., 1978)

In order to estimate long-term boundary effects, an idealized aquifer model was used. Transmissivity and storage coefficients of 3580 gpd/ft and 0.2, respectively, were assumed for the model aquifer. The effects of image wells associated with boundaries from a 1000- and 2000-foot strip aquifer were calculated and added to theoretical drawdowns caused by aquifer losses, dewatering, and mutual interference between wells.

Total drawdowns were limited such that dewatering was 50 percent or less of the saturated thickness of the aquifer at each well. The results indicated that a 1000-foot strip was too conservative when compared with the operational experience at Edinburg. The aquifer was idealized, therefore, as a 2000-foot strip for image-well computations.

The model aquifer analysis indicated that the optimum development of the aquifer could be made by utilizing a three-well scheme of pumpage rather than all four present wells. The three-well system would not include Well No. 12, since its mutual interference effects with Wells 10 and 11 are significant. This is in agreement with actual reported operating conditions. Based on available information, therefore, the long-term sustained yield of a three-well system would be approximately 75 gpm (110,000 gpd).

Fillmore (from Visocky at al., 1978)

Early data from a production test on Well No. 1 indicated a coefficient of transmissivity of 11,200 gpd/ft. The later data were affected by geo-hydrologic boundaries. A test conducted July 26, 1977 on Well No. 2 also revealed the presence of boundaries, indicating an aquifer width of less than 400 feet. Transmissivity and storage coefficients were calculated to be 3620 gpd/ft and 2.6×10^{-4}, respectively.

The long-term sustained yield of Well No. 1 was estimated in 1962 to be about 26 gpm or 38,000 gpd. The well was generally pumped at rates of 35 to 40 gpm (according to a 1977 Public Water Supply Report) until the summer of 1976, when there occurred a severe reduction in its well capacity due to extended drought conditions. Between 1976 and the time when the report was written (August 1977), the well was able to sustain pumping rates not exceeding 16 gpm. An ISWS study at the time concluded that the long-term sustained yield of the well might be only 14 gpm or about 20,000 gpd. In 1977, when Well No. 2 was drilled and tested, an analysis of the test data, along with available information, concluded that due to the limited extent of the aquifer, the sustained yield of Well No. 2 might be 10 gpm or less. Drought conditions in recent years have put a severe stress on the aquifer tapped by Well Nos. 1 and 2 and have in effect provided a measure of the capability of the aquifer under such stress. It is, therefore, concluded that the combined sustained yield of Well Nos. 1 and 2 is probably just under 24 gpm or approximately 33,000 gpd.

Germantown (from Wehrmann et al., 1980)

A production test was conducted on September 24, 1976 on Well No. 4, but the data did not lend themselves to conventional analysis because of water table gravity drainage effects. Well No. 4 was operated at a rate of 30 gpm for four hours, and the final specific capacity (corrected for de-watering) was 19.4 gpm/ft. Based on theoretical specific capacity vs. transmissivity graphical relationships, the transmissivity was estimated to be 21,500 gpd/ft. In estimating the long-term sustained yield of the well, however, the ISWS assumed a lower value of transmissivity of 11,000 gpd/ft, based on reasonable assumptions concerning the nature of the test data. Based on geologic data for the Germantown area, a geohydrologic boundary was assumed to be present to the north and east of the existing well field at an effective distance of 1 mile. At this distance, image well effects associated with the boundary were determined to be negligible. Mutual interference effects were calculated using distances between wells and the theoretical distance-drawdown relationship for an aquifer whose average transmissivity and storage coefficient were 11,000 gpd/ft and 0.2, respectively. Pumpages were assumed to be continuous for six months. Drawdowns were limited to amounts that would produce a maximum dewatering of 50 percent of the aquifer saturated thickness. The results of the analysis indicated that on a long-term basis the 4-well field at Germantown appears capable of yielding as much as 93,000 gpd. Since available drawdown is small, however, a sustained drought could reduce the aquifer capacity by up to 50 percent.

Nokomis (from Visocky et al., 1978)

For purposes of computing long-term effects of groundwater pumpage schemes, an idealized aquifer model was used, consisting of a wide, semi-infinite strip aquifer, 10,000 feet in width and extending to infinity in a southwesterly direction from the well field. The aquifer effectively ends 6000 feet to the northeast of the well field. Average aquifer properties were 41,000 gpd/ft and .001 for transmissivity and storage coefficient, respectively. Available drawdowns were limited to the top of the aquifer, and nonpumping levels were assumed to be those extant during the original development of the well field. The effects of boundaries were computed from image-well theory.

In an October 1963 study by the ISWS it was estimated that the practical sustained yield of the well field (Wells 1–6 at that time) was about 175,000 gpd and that another well field a mile to the northeast might develop another 80,000 gpd. Since that time, Well No. 5 has been abandoned and replaced by Well No. 7, and an eighth well has been drilled approximately 1/2 mile to the northeast. The ISWS, in analyzing test data from Well No. 8, estimated that 50–55 gpm (72,000–79,200 gpd) could probably be developed from the well.

With the idealized aquifer model described above, it was estimated that the seven existing wells could sustain a long-term development of about 150 gpm or 216,000 gpd under normal conditions of precipitation. As was evidenced last summer, however, when dry conditions prevailed and water level declines forced round-the-clock pumpage, below normal precipitation could reduce the sustained yield by 12 to 13 percent.

Oreana (from Visocky et al., 1978)

A well production test conducted January 1965 on Well No. 2 indicated the coefficients of transmissivity and storage to be 28,000 gpd/ft and 1.0×10^{-4}, respectively. Test data also revealed the presence of multiple boundaries. In May 1977, another test on Well No. 2 resulted in similar values of these coefficients: 26,000 gpd/ft and 1.2×10^{-4}, respectively. A test conducted on Test Hole 9 in the NW 1/4 of Section 10 indicated values for these coefficients to be 21,000 gpd/ft and 8×10^{-5}, respectively. In none of the above tests were data sufficient to allow direct computation of boundary distances.

Because of the limited nature of the aquifer underlying Oreana, it is felt the practical sustained yield of that aquifer has been nearly reached already. Any greater withdrawals of water in the future will likely cause dewatering of the upper portions of the aquifer. New wells will only compete with each other and not appreciably increase the total aquifer yield. During years of normal precipitation, the practical sustained yield of the aquifer is estimated to be 75,000 to 85,000 gpd. During periods of drought, however, this figure could drop to as little as 45,000 gpd.

Percy (from Wehrmann et al., 1980)

Comparison of the water level decline and average daily pumpage shows that, in general, water level declines have been proportional to pumpage. The data are somewhat scattered, owing to variations in measurement procedures and pumpage schemes, but there is an apparent consistent relationship between decline and pumpage. Approximately 2100 gpd were pumped with each foot of decline. This consistent relationship between decline and pumpage and the fact that water levels appear to stabilize after each increase in pumpage indicates that in the past recharge has balanced withdrawals.

Analysis of the available well test data, historical pumpage, and water level data indicate the aquifer conditions at Percy are leaky artesian. Transmissivities and hydraulic conductivities were determined by graphical analyses of six production tests and specific capacity analyses of two tests. Transmissivity values obtained ranged from 290 to 2100 gpd/ft with corresponding hydraulic conductivities of 2.5 to 10.2 gpd/ft^2. Storage coefficient values could not be determined, as observation well data were not available.

To account for the historical decline in nonpumping water levels, a leaky artesian model was used. The log of Well No. 1 indicates the aquifer is overlain by 35 feet of shale (confining bed through which leakage occurs), which is in turn overlain by 25 feet of sandstone (source bed). Since well No. 1 has been the primary source well over the years, it was assumed to be the point of withdrawal for the model. Using a value of 1700 gpd/ft for transmissivity and 0.1 gpd/ft^2 for the vertical hydraulic conductivity of the confining bed, the historical decline of 67 feet in 45 years could be duplicated. The model indicates that in the past steady state conditions have been reached shortly after each increase in pumpage. As long as future pumpage does not exceed that projected by the Division of Water Resources (99,180 gpd was projected for year 2000), there should be little more decline of water levels.

Toledo (from Visocky et al., 1978)

Aquifer tests were conducted on Well No. 2 in 1948 and on Well No. 3 in 1952. Data from these tests show the aquifer transmissivity to range from 5400 to 14,500 gpd/ft. Calculations made from observation well data gave a storage coefficient of 0.10, which is in the water-table range. Data taken in 1952 suggested the presence of a geohydrologic boundary, but the location of that boundary could not be determined with any confidence from the data collected.

The aquifer was mathematically modeled by an idealized infinite strip aquifer, using a transmissivity of 6000 gpd/ft, a storage coefficient of 0.1, and an aquifer width of 1400 feet (assumed from the geologic reports). The idealized model aquifer was used to estimate the practical sustained yield of the aquifer by using steady-state leaky artesian equations and image well theory, and by limiting long-term pumping levels to the tops of the screens in the pumping wells. The long-term yield was determined to be 129,000 gpd from three wells pumping 30 gpm apiece. Should dry weather conditions prevail for an extended period of time, the yield could drop to 86,000 gpd.

Willow Hill (from Wehrmann et al., 1980)

The observation well data also showed evidence of a geohydrologic barrier boundary, which creates drawdowns larger than would be expected with the given pumping rates. Analysis of the data suggests the boundary is roughly 1100 feet from Well No. 2, but the direction cannot be determined without further testing. The "boundary" is probably not the edge of the aquifer, as well logs clearly indicate the sandstone is continuous in the area of Willow Hill, but is more likely a change in hydraulic conductivity or aquifer thickness. The difference between the hydraulic conductivities calculated from the testing of Wells 1 and 2 (less than 1 gpd/ft) and the hydraulic conductivity calculated from the testing of Well No. 3 (greater than 2 gpd/ft^2) makes this explanation plausible.

A 1964 analysis of the aquifer yield potential showed the 3-well system in Willow Hill was capable of producing a total of 30 gpm (43,000 gpd) without dewatering a significant portion of the aquifer in any of the wells.

Windsor (from Visocky et al., 1978)

Aquifer tests conducted at seven sites in the Windsor area between 1935 and 1974 revealed an average aquifer transmissivity in the "South Field" (Wells 6 and 8) of 10,000 gpd/ft and in the "West Field" (Wells 5 and 7) of 16,000 gpd/ft. Storage coefficients could not accurately be evaluated but were in the artesian range. Data from the tests also revealed the presence of geohydrologic boundaries. Hydrologic conditions at the South and West Fields were simulated by assuming infinite strip aquifers 900 feet and 2500 feet wide, respectively.

Based upon available geohydrologic information and on operational experience at the West and South Fields and on Well No. 2 in town, it is estimated that the total sustained capability of the wells at Windsor is of the order of 140,000 gpd.

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Table F1. Summary of Public Groundwater Supplies Assessed by Visocky et al. (1978) and Wehrmann et al. (1980)

Public Supply	County	Aquifer	Estimated Aquifer Yield, in gpd*	Most Recent Pumpage, in gpd	Aquifer Use/Yield	Comments
Edinburg	Christian	Sand/gravel	110,000	112,000 (2004)	1.02	
Germantown	Clinton	Sand/gravel	93,000	78, 653 (2009)	0.85	Also purchases sw from Breese
Lerna	Coles	Sandstone	30,000	16,682 (2009)	--	Purchases from Clear Water
Toledo	Cumberland	Sand/gravel	129,000	101,300 (2008)	0.78	
Hindsboro	Douglas	Sand/gravel	57,000	41,644 (2009)	--	Purchases from Embarras Area Water District (IL-Amer.)
Dieterich	Effingham	Sand/gravel	45,000	21,700 (2008)	0.48	
Watson	Effingham	Sand/gravel	50,000	46,443 (2009)	--	Purchases from EJ Water
Farina	Fayette	Sandstone	58,000	122,973 (2009)	--	Now use self-supplied surface water/borrow pit system
Willow Hill	Jasper	Sand/gravel	43,000	19,100 (2009)	0.44	
Oreana	Macon	Sand/gravel	75-85,000	100,200 (2008)	1.25	
Hamel	Madison	Sand/gravel	86,000	67,495 (2009)	--	Purchases from Bond/Madison Water Co.
Marine	Madison	Sand/gravel	NA	64,175 (2009)	--	Purchases from Bond/Madison Water Co.
Worden	Madison	Sand/gravel	80,000	61,978 (2009)	--	Purchases from Bond/Madison Water Co.
Farmersville	Montgomery	Sand/gravel	NA	92,000 (2004)	--	
Fillmore	Montgomery	Sand/gravel	33,000	29,000 (2007)	0.88	
Nokomis	Montgomery	Sand/gravel	216,000	261,000 (2002)	1.21	
Gays	Moultrie	Sandstone	36-42,000			Served by Moultrie County WD
Percy	Randolph	Sandstone	~100,000	82,500 (2009)	0.82	
Red Bud	Randolph	Sandstone	500,000	390,000 (2007)	--	Now use and/gravel aquifer in Kaskaskia bottoms
Noble	Richland	Sandstone	NA	51,866 (2010)	--	Purchases from Olney
Windsor	Shelby	Sand/gravel	140,000	73,964 (2009)	0.65	Used 91,600 in 2007
Millstadt	St. Clair	Sandstone	NA	292,093 (2009)	--	Purchases from IL-Amer., ESL

*NA – Aquifer yield not assessed, but supply was evaluated as marginal in Visocky et al., 1978