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Ground-Water/Surface Water Interactions at Sand Lake, Mason County, Illinois

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GROUND-WATER/SURFACE WATER INTERACTIONS AT SAND LAKE MASON COUNTY, ILLINOIS

by

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ABSTRACT

This report summarizes the investigation of Sand Lake conducted by the Illinois State Water Survey and the Office of Water Resources, both within the Department of Natural Resources. The report investigates the ground-water/surface water interactions at a local area near the City of Havana, Illinois, which cause the occurrence, persistence, and recession of Sand Lake. This investigation was accomplished through monitoring well network data collection and analysis and through the creation of a numerical ground-water flow model for the area. The report also gives practical strategies for potential mitigation of future flood impacts based on past efforts and interpretation of data collected at the study site.

Sand Lake has become a notorious natural resource feature in the Havana area. The lake, appearing intermittently, creates considerable concern regarding its projected impact throughout the area. The appearance of this shallow lake is associated with heavy rainfall seasons and flooding problems in the area. Some individuals even cite the lake as the main cause for flooding in and around the City of Havana. The objectives of this project were to study the interaction of surface and ground water through data analysis and interpretation and to assess their role in the existence, persistence, and recession of this lake; model the natural conditions; and use these tools to recommend strategies for planning and mitigation of future flooding events.

Ground-water resource information was collected from May 1995 through December 1996. Interaction between the atmospheric, surface, and subsurface realms in and around the lake were used to investigate the movement of water within the area. The analysis indicated that the regional ground-water movement is the main driving force in the existence, persistence, and recession of this lake. Sand Lake is not a cause for flooding in this area but an indicator of high ground-water elevations throughout the entire region.

INTRODUCTION

The extraordinary 1993 spring, summer, and fall precipitation events resulted in unparalleled flooding in the Mississippi River watershed exceeding those in the historical record in regard to magnitude, duration, and impact on the rivers and their floodplains (Kunkel et al., 1994). The Mississippi, Missouri, and lower reaches of the Illinois Rivers all reached unprecedented levels of flood inundation, and the flood waters wreaked havoc on rural and urban property and transportation systems. Never has such an event occurred in the Mississippi watershed since the floodplains have been intensively managed for agricultural, recreational, and urban land uses. Because of its great magnitude and catastrophic consequences, this event has been termed "The Great Flood of 1993" (Bhowmik et al., 1994).

During this catastrophic event, much attention was given to swelling and levee breaching episodes of the major rivers in the Mississippi drainage basin (Changnon et al., 1996). However, the large precipitation events that initiated the high river flows also caused record high groundwater levels within the same watersheds (Bhowmik et al., 1994). In the Havana area of central Illinois, ground-water levels actually rose above the land surface and created surface water flooding that caused costly damage to homes, businesses, and transportation systems (Bhowmik et al., 1994). One surface water body that rose to unprecedented levels during 1993 was Sand Lake. This lake caused substantial flooding (encompassing more than 300 acres) and costly damage in the local area. Prior to this flood event, Sand Lake was considered an intermittent lake, existing about half the time during the growing seasons over the last 30 years. However, after its reemergence in the fall of 1993, the lake persisted continuously for more than 2 years and did not receded until the fall of 1995. The long existence of Sand Lake puzzled the local residents as well as scientists within governmental agencies and has caused concern over future flooding episodes and potential roadway and property damage. This concern has given rise to scientific investigations of the lake and is the stimulus for the research described in this report.

This study was designed to investigate the relationships between surface and groundwater processes and surface water levels at Sand Lake; to determine the cause(s) of this lake's emergence, persistence, and disappearance; and to suggest potential strategies for mitigating any future flood events at this site. Several economic and political factors have created the concern over this lake. First, the Illinois Department of Transportation (IDOT) is given the responsibility to provide safe and uninterrupted transportation roadways throughout Illinois. As a consequence of the rise of Sand Lake, this agency had to increase some road surface elevations by more than 3 feet (ft). Not only were these modifications costly, but this flood also caused major traffic rerouting over roads not designed to handle large traffic loads. The IDOT is concerned about the potential for roadway and property flood damage in the future. Second, this lakebed usually is used for corn and soybean farming. The extended existence of this lake from 1993-1995 represented a loss of valuable agricultural income to property owners. Third, Sand Lake is classified within the National Wetlands Inventory as an intermittently exposed, unconsolidated bottom wetland within the Palustrine System (PUBG code). This classification indicates the area is an intermittent wetland, meaning surface water ponding exists only part of the time. Wetlands are important discharge points for ground water; thus, a wetland environment is a zone of surface and ground-water interaction. Understanding the relationships between surface and ground-water flows within these systems is very important in determining their role in our environment. Fourth, many residents of this region believe that Sand Lake is the cause of the flooding elsewhere in the Havana area. The local governing bodies have created committees that are actively soliciting drainage proposals for this site. For these reasons, it is important to understand the ground-water and surface water interactions and their influence on the regional ground-water and flooding problems in the Sand Lake area.

Acknowledgments

The 22-month study of Sand Lake was made possible by the Department of Natural Resources, Water Resources Division (formerly the IDOT-Division of Water Resources). This office has provided financial support to the Illinois State Water Survey (ISWS) for the installation and maintenance of a measurement network for monitoring ground and surface water levels at this site and for the analysis of the resulting data. This investigation would not have been possible without the willing cooperation and permission of the owners of the lakebed property, mainly Mr. Daryl Fornoff.

Randy Locke, Assistant Hydrologist, ISWS, conducted the Global Positioning System well casing elevation determinations and analysis. Bryan Coulson operated the ISWS well drilling equipment, and ISWS staff members John Blomberg and Dan Mayer assisted in the well construction. Climate data were provided by ISWS staff members Drs. James R. Angel and Stephen E. Hollinger. Editing and coordination of this document was conducted by Dr. Scott A. Isard, Associate Professor, Department of Geography, University of Illinois, Urbana, Illinois. Linda Hascall prepared the graphics. Eva Kingston and Agnes Dillon conducted the technical editing.

The views expressed in this report are those of the authors and do not necessarily reflect the view of the sponsor or the Illinois State Water Survey.

PROJECT RESEARCH OBJECTIVES

This project was designed to investigate hydrogeologic theories associated with ground- and surface water interaction as they relate to the emergence, persistence, and recession (existence) of Sand Lake. Two basic questions were the focus of this project. The first centers on the physical structure of the land surface (i.e., geology), in that there may be a geologic control to the existence of this lake. The presence of an impermeable layer underlying the lake creating a "bathtub-like" geologic structure could trap ground and surface water and cause its existence and persistence.

The second question centers on the potential for the ground-water flow system (hydrologic) to influence the existence of Sand Lake. Typically, ground water moves at very slow velocities. This movement is dependent upon many factors but generally is mostly influenced by gravitational forces. To this end, ground water moves toward topographically low points and discharges into lakes, rivers, streams, wetlands, etc. It often is useful to classify this movement on the basis of spatial scale into three flow systems: local, intermediate, and regional. The identification of a flow system at Sand Lake will determine potential mechanisms for the lake's existence.

The objective of this study was to evaluate the roles of geologic and hydrologic controls on ground/surface water interaction and ultimately the emergence, persistence, and recession of Sand Lake. The two objectives were explored in two water budget-based analyses. A numerical model of shallow ground-water flows also was developed to help aide in the understanding of this phenomenon and to provide a tool in identifying strategies for mitigating potential future impacts.

HYDROLOGIC STUDIES IN THE HAVANA AREA

Regional Studies

The water resources of Mason County have intrigued scientists since 1908 (Walker et al, 1965). Initially, interest was focused on the Peoria-Pekin area in the extreme northwest portion of the region, which was experiencing major industrial growth during the early 20th century. Several other documents (reports, maps, etc.) written during the first half of the century also mention these resources; however, the first major effort to document hydrologic and geologic conditions throughout the region began in 1957 as a cooperative venture by the ISWS and the Illinois State Geological Survey (ISGS). Walker et al. (1965) discussed the geography, geology, and ground/surface water resources throughout the entire region. Their purpose in doing so centered around the perception of what they labeled "one of the largest underdeveloped aquifers in the state."

To date, no other document has been published that investigated the hydrogeology of this area in more detail than Walker et al. (1965). Sanderson and Buck's (1995) report compared ground-water elevation maps from 1960 (Walker et al., 1965) to more recent investigations in the area. They established a network of 290 existing wells to monitor water levels during the fall of 1992, spring of 1993, and the ground-water flooding in the fall of 1993. This systematic measurement program was initiated because of heightened public awareness of the importance of this region's ground-water resources, severe climatic and drought conditions during 1988-1989, ground-water quantity management legislative initiatives during these drought years, and concerns related to the impact of ground-water pumpage for crop irrigation on domestic water wells (Sanderson and Buck, 1995). These same concerns stimulated the creation of the Imperial Valley Water Authority, the agency that sponsored their research. Sanderson and Buck (1995) found that ground-water elevations were generally within ±5 ft of the elevations reported by Walker et al. (1965). They concluded that the extensive increases in irrigation practices in this region had not lowered ground-water levels over the last four decades.

One other investigation also has examined ground-water levels and their impact in this region, not by direct data collection but by computer model simulation using the data collected by Sanderson and Buck (1995). Clark (1994) applied the MODFLOW7 (McDonald and Harbaugh, 1988) three-dimensional finite-difference ground-water model to simulate aquifer water levels in Mason County. The model was developed for long-term resource planning in the county and was used to estimate inflows and outflows to the aquifer system as well as lakes and ditches. The model was configured so that aquifer response and the resulting economic and environmental impacts of ground-water level fluctuations could be calculated based on a variety of climate and cultural scenarios. Clark's simulations (1994) showed that even two consecutive drought conditions similar to 1988 would only lower water levels a maximum of 15 ft throughout the entire region.

Local Studies

Few natural resource studies have focused specifically on the City of Havana area. Environmental Science & Engineering, Inc. (ESE) was contracted to investigate and recommend management strategies related to the flood events at the City of Havana from September 10 to 24, 1993. At the conclusion of their investigation, a report was drafted (ESE, 1993) to the Mason County Board of County Commissioners, City of Havana, describing the flood events and potential solutions to water flow problems. The report provides a detailed summary of the problems that concerned city officials during these flood events and baseline water level estimates throughout the Havana area.

At the time the report was written by ESE, floodwaters from the southwest end of Sand Lake were flowing into the southeast part of the City of Havana at a rate of approximately 5 cubic feet per second (cfs), and more rain was predicted for the next few weeks. Consequently, ESE developed strategies to stop and divert the advancing waters, recognizing that no option was without negative consequences.

Visocky (1995) also studied the ground-water hydraulics associated with the 1993 flooding in the City of Havana. Specifically, he determined the frequencies of ground-water flooding and the location of ground-water flood-prone areas for the Federal Emergency Management Agency and the state counterpart, Illinois Emergency Management Agency. Visocky (1995) created maps that indicated areas subject to ground-water flooding at a frequency of 1 percent or at a 100-year flood event. The study involved the analysis of high resolution orthophoto maps combined with statistical analysis of historic ISWS observation well data at Snicarte, Illinois (approximately 15 miles south of the City of Havana). The end products of this study were maps depicting the location of potential 100-year ground-water flood areas in and around the Cities of Havana and Bath.

THEORETICAL PERSPECTIVE

In nature, water continually moves from the land surface to the subsurface. Although the interface between these environments is not commonly observed, the interaction is apparent in some areas. When the interaction persists for much of the year and the zone of interaction is relatively shallow, a wetland is created. Wetlands are transition zones between the land and aquatic environments; and, by definition, they are important discharge points for ground water. Wetland acreage within Illinois has been declining for over 50 years. The environmental benefits of these ecosystems include the capture and retention of sediment and the cleansing of polluted water. Equally important, wetlands support a wide diversity of important biota (Mitsch and Gosselink, 1993). Surface and ground-water hydrology is the most important factor in the development and maintenance of the wetland ecosystem. Consequently, our ability to manage these important ecosystems must be based on understanding the relationships between surface and ground-water flows within these systems. Sand Lake is classified within the National Wetlands Inventory as an intermittently exposed unconsolidated bottom wetland within the Palustrine System (PUBG code). This system is composed of nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and waters with ocean-derived salts below 0.5 parts per thousand (Mitsch and Gosselink, 1993). This classification indicates the area is an intermittent wetland, meaning surface water ponding exists only part of the time. When the soil is dry, agricultural farming is allowed and practiced over the wetland area.

In order to fully understand the interaction between surface and ground-water flows, a detailed description of the budgets of all hydrologic components is necessary. The role of each component (infiltration, evaporation, base flow, etc.) in this interaction may be significant in determining the total "balance" for the surface water body. Hydrogeologic classification of lakes is based upon the relative importance of the surface or ground-water components in the annual hydrologic balance of the water body (Fetter, 1994).

The geology of an area governs movement and availability of surface and ground waters. The permeability of geologic materials and the intensity of precipitation determine the water flows above and below the land surface. Permeability is defined as the property or capacity of a porous rock, sediment, or soil for transmitting a fluid under unequal pressure (Driscoll, 1986). When geologic materials are highly permeable, fluid flow is relatively fast. Conversely, when geologic materials have low permeability, fluid flow is slow. Each geologic material exhibits its own permeability based upon its chemical and structural composition.

After rainfall events, materials with low permeability will cause water to pond whenever the water input (recharge) exceeds the capacity of the materials to hold the water. Ponding of water will then cause water movement across the land surface and/or into the subsurface. Surface movement of water will follow elevational differences on the land surface, thus water will eventually spill into lakes, streams, rivers, etc. Water in the subsurface will: remain temporarily in the soil zone, be returned to the atmosphere through evapotranspiration of plants, move laterally above the ground-water table, or infiltrate directly down into the water table. The water table is defined as the surface of a body of unconfined ground water at which the pressure is equal to that of the atmosphere (Driscoll, 1986). In most cases, the water table is in direct contact with surface water bodies; however, its role can be either as input or output to such bodies.

The interaction of surface and ground water at Sand Lake is essential to its existence and is summarized through the analyses of measurements conducted for this project. The hydrologic theories associated with surface and subsurface interaction of water are explored through the analyses of the collected information and through the development of a numerical flow model.

SAND LAKE SITE DESCRIPTION

Sand Lake is located in Sections 7 and 8 of Township 21 North, Range 8 West of the third principle meridian within Mason County, Illinois. It is situated about 1.5 miles southeast of the City of Havana (population 3,600) adjacent to the Illinois River (Figure 1). Extensive water-bearing sand-and-gravel deposits extend from the land surface to bedrock and allow substantial ground-water irrigation operations in the area. Mason County leads the state in the pumpage of ground water for agricultural irrigation.

The sand-and-gravel deposits within the unconsolidated sediments above bedrock provide abundant ground-water resources. The unconsolidated materials consist of glacial drift, wind-blown silts (loess) and sands, and recent stream deposits. The drift is differentiated into that deposited directly from the melting ice (till) and that modified by the associated meltwater into glacial river (glaciofluvial) and glacial lake (glaciolacustrine) deposits. The till is a mixture of fragments of all sizes with little stratification. It occurs in the form of ridges (end moraines) and

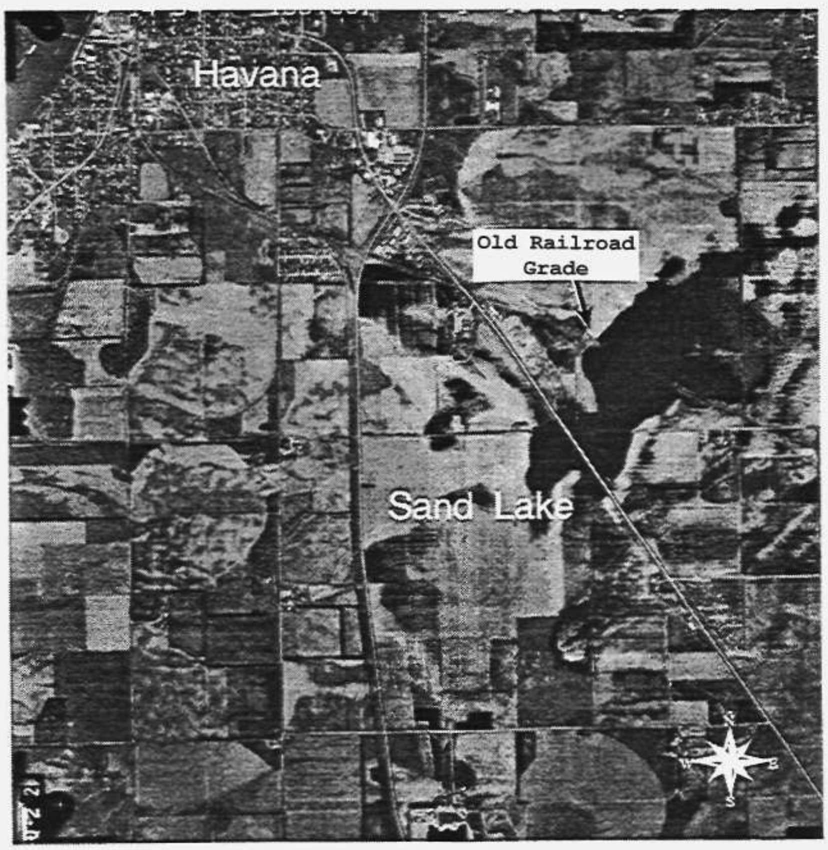


Figure 1. Areal photograph of the Sand Lake area

intervening undulatory plains (ground moraines). The end moraines were deposited when the melting of the ice was equivalent to the advance of the glacier, so that the ice front was relatively stationary. The ground moraines were deposited when the melting of the ice front exceeded the forward advance of the glacier. Glaciofluvial deposits were laid down by meltwater that was discharged along the front of the ice and through crevasses and channels extending back into the ice (Walker et al., 1965).

The regional ground-water flow (in the Sand Lake area) is northwest toward the Illinois River (Sanderson and Buck, 1995). The river is a ground-water discharge point within the area. The elevations within the region range from 472 to 516 ft above mean sea level (ft-msl) and across the study area range from 480 to 508 ft-msl. An old railroad grade bisects the lake area from northwest to the southeast (Figure 1). This creates a topographic high that divides Sand Lake into two distinct smaller lakes. In this study, the two small lakes are termed the northeast and southwest lakes, and collectively these lakes are referred to as Sand Lake.

AREAL GEOLOGY

Sand Lake is located in an area of wide, low, rolling sandy plains underlain by thick sequences of Pleistocene sand-and-gravel formations that in turn overlie layered bedrock units. Four distinct sand dunes form a rim around the western edge of the lake. The sand-and-gravel deposits near Sand Lake were deposited by glaciofluvial and eolian processes. Glaciofluvial materials were deposited by meltwater that discharged along the front of the ice sheets during the Kansan, Illinoisan, and Wisconsinan Stages of the Pleistocene Series. These materials were subsequently reworked by prevailing winds to form the small sand dunes along the margins of the lake.

Geologic information suggests that the broad bedrock valley underlying the Havana lowlands region originated through erosion by the ancestral Mississippi River prior to advancement of the Kansan glacier. Sand and gravel deposited by the receding Kansan glacier filled the bedrock valley to an elevation of about 500 ft, or about 200 ft above the bedrock surface. These basal deposits are known as the Sankoty Sand and were derived from sandstones and crystalline rocks in Wisconsin and Minnesota.

The Illinoisan glacier advanced from the northwest and built low, discontinuous moraines over parts of the Havana lowlands region. During the Illinoisan time, abundant meltwater was channeled into the Havana region, resulting in the deposition of sandy drift. After the Illinoian glacier receded, the drift was weathered and extensively eroded. Today, there are no Illinoian Stage deposits in the immediate area around Sand Lake.

The start of the Wisconsinan Stage of glaciation was marked by deposition of additional outwash in the Illinois River valley. Later advancements of the Wisconsinan glacier (near the Peoria, Pekin, and Delavan areas) created the Bloomington Moraine. Meltwater from the glacier built a thick valley train (outwash fan) of sand and gravel that cut well into the older Sankoty Sands. Subsequently, when the great ice sheet to the north melted, a great flood of meltwater (the Kankakee flood) poured down the Illinois River valley, eroded channels in the Bloomington outwash fan, and built sand bars. One such sand bar is referred to as the Manito Terrace. This glaciofluvial deposit covers the Sand Lake study area. During low-water stages of the Kankakee flood, the sands comprising the bars were reworked by winds into the sand dunes that are now prominent on the western side of Sand Lake.

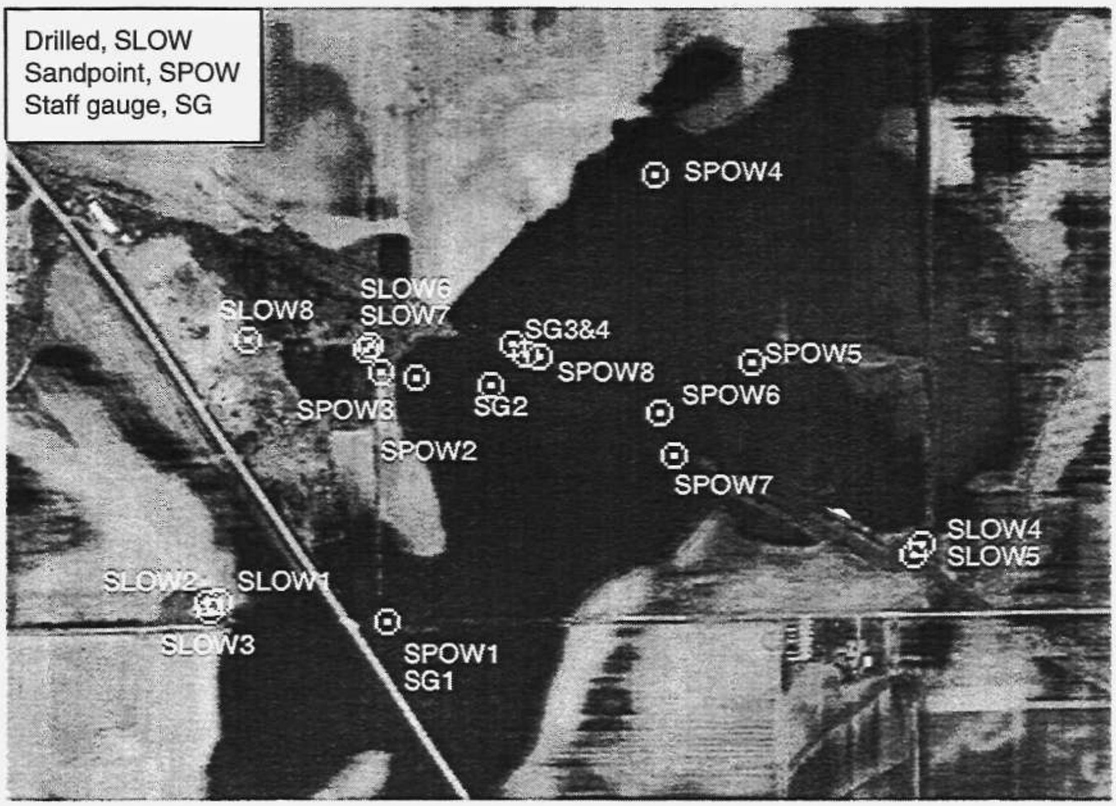
Underlying the unconsolidated Pleistocene deposits at Sand Lake is a shale formation that has been variously described by investigators. Walker et al. (1965) mapped the bedrock immediately underlying the area around Sand Lake as the Salem Formation, consisting mainly of dolomite, sandstone, and shale. Willman et al. (1975) suggest that the Salem/St.Louis Formations were eroded from the Sand Lake study area and that the Mississippian Warsaw Formation is the uppermost consolidated rock encountered at this site. A soil boring done at the site of Sand Lake Observation Well 1 (at the southwest corner of the lake) encountered shale at an elevation of approximately 371 ft-msl (113 ft below land surface). The elevation of the bedrock surface at this boring site suggests that the shale encountered by the boring may be from near the contact between the Pennsylvanian Spoon Formation and the Mississippian Warsaw Formation. Both formations are predominately comprised of shale, and both dip to the southeast at about 15 to 20 ft per mile toward a "deeper" erosional feature in the Havana lowlands bedrock surface.

Numerous soil borings were taken by the ISWS and the Office of Water Resources in the Sand Lake study area. Borings taken on the perimeter of the lake indicate the unconsolidated geologic deposits are comprised mainly of materials that have grain sizes ranging from fine sand to coarse gravel. Some evidence of very thin discontinuous clay streaks, clay nodules, and silty materials were identified in the upper 10 ft of the soil borings. Soil borings taken in the lake bottom near Sand Lake staff gauge 4 (SG4) indicate the presence of silty and clayey sands to a depth of 5 ft below land surface. A sandy clay also was noted between 5 and 6 ft below land surface. At all soil boring locations, no appreciable amount of material was found to be finer grained than fine sand, below a depth of 10 ft.

METHODOLOGY

Field Measurement Program

Hydrologic gauges and observation wells were used to monitor lake and ground-water levels at Sand Lake from April 1995 through December 1997. Trends in these parameters are discussed in the "Characterization of Control Processes" section and are listed with hydrographs in Appendix A of this report. When possible, bi-monthly measurements of water levels were collected from each lake and each monitoring well. A total of four surface water staff gauges, eight sand point wells, and eight drilled wells comprise the monitoring network at the lake. A detailed map indicating the locations of the monitoring devices can be found in Figure 2.



SLOW1 = 75 ft; SLOW2 = 35 ft; SLOW3 = 55 ft; SLOW4 = 40 ft;
SLOW5 = 20 ft; SLOW6 = 43 ft; SLOW7 = 24 ft; SLOW8 = 47 ft

SPOW1 = 10 ft; SPOW2 = 9 ft; SPOW3 = 21 ft; SPOW4 = 11 ft;
SPOW5 = 11 ft; SPOW6 = 10 ft; SPOW7 = 11 ft; SPOW8 = 11 ft

Figure 2. Sand Lake water-level monitoring network

The theories set forth in this study require different methodologies for investigation; fortunately, the construction of the monitoring wells served a dual purpose. Drilling a borehole to examine the geology of the area also allowed the construction of a monitoring well within the same borehole. The lithology of the materials passed through during this construction was recorded and is described in Appendix B.

Surface Water Level Monitoring

To determine surface water levels, installation of staff gauges was necessary. A staff gauge is typically a 5 ft measuring board demarcated with 1/10 ft increments, attached to a metal or wood board pounded into the lake bottom at a deep location within a lake. This allows surface water level fluctuations to be accurately determined over time. A total of four staff gauges were installed. Staff gauge No. 1 was installed along Rt. 92 and Sand Lake Road. Originally designed to measure water depth at the southwest extent of the lake, this gauge could only be used for three measurements during the study period. The area where it was installed dried up early in the investigation. Staff gauges No. 2, 3, and 4 all were installed within the body of Sand Lake; however, because an old railroad track divides the study area, two small lakes have been created at the site. Initially, two staff gauges (No. 2 and 4) were installed into the deepest part of each lake (along the railroad topographic high) to allow monitoring of lake level fluctuations. Staff gauge No. 2 was installed in the southwest lake and No. 4 in the northeast. Early in the study, staff gauge No. 4, because of its short length (3 ft), was overtopped with water during a rise in lake levels. Staff gauge No. 3 was subsequently installed at the same site as staff gauge No. 4, extending the measurement capability at this location another 2 ft.

Ground-Water Monitoring

To monitor shallow ground-water levels throughout the Sand Lake basin, a shallow (10 to 15 ft) observation well network, consisting of eight "sand point" wells, was established. The term "sand point" is derived from the screen construction of this particular type well. A well screen holds back the aquifer material and allows water to enter into the casing. In this type of construction, the screen has a pointed "advance cap" on it and can be physically driven into the sand by repeated hammer blows. This is an effective and economical observation well for shallow monitoring in sandy geologic materials. This shallow network was designed to investigate the movement of shallow ground water surrounding the site.

In order to investigate the deeper ground-water levels and their influence on this lake, three "nests" of wells were constructed. A "nest" is a site at which wells of various depths are placed very close together to observe differences in elevation at depth. These elevational differences create pressure gradients that induce vertical ground-water movement. Seven wells (nests of 3,2, and 2) were drilled to varying depths at three locations around the lake. Geologic samples were taken for analysis at each site. The construction of these holes was accomplished by the hollow stem auger drilling method and continue to bedrock at only the first site. The Mobile B-57 hollow stem auger drill rig, owned by the ISWS, was used for this purpose. All the bore holes were fitted with 2-inch diameter schedule 40 PVC threaded pipe well casing and 2-inch schedule 40, 0.010-inch slotted screens. The casing length varied, depending upon the depth of the hole, and the screens were all 5-ft lengths set at the bottom of each borehole. A bentonite (illite clay) plug from land surface to approximately 1 ft below land surface and 6-inch square metal well protectors were installed at each well.

Site 1 was located west of Rt. 92 along Sand Lake Road. Three wells (No. 1, 2, and 3) were drilled to depths of 75, 35, and 113 ft (backfilled to 55 ft), respectively. Wells No. 4 and 5 were drilled at the east extent of the lake (at its largest size) along a field access road. These wells were drilled to depths of 45 and 25 ft, respectively. Wells No. 6 and 7 were drilled immediately to the west of the lake on the topographic high (sand dune) along an access road to the lake area. These wells were drilled to depths of 43 and 25 ft, respectively. Well No. 8 was constructed to a depth of 47 ft and located to the west of this topographic high. Appendix B contains complete well construction and geologic descriptions of all drilled observation wells. The locations of these monitoring devices are shown in Figure 2.

Each well was "developed" by airline method until ground-water discharge from the well was clear. Air development of a well involves the insertion of an airline (attached to an air compressor) fixed with an in-line gate valve, to the bottom of the well casing. Air pressure is allowed to build in the well, then the gate valve is quickly opened, driving all the water in the well up the casing and on to the land surface. The air is lifting the water out of the well. Development is needed to clear the well screen of any materials that may have accumulated on or within it during the drilling process that might inhibit free movement of water into the screen and up into the casing.

Observation Well Network Hydrographs

Water-level trends from each type of monitoring device (sand point, drilled well, and staff gauge) are assembled in Appendix A. Water levels, when possible, were measured for all 20 devices over the course of the study, from April 1995 through December 1996. Hydrographs, time-series of water elevations plotted with precipitation and evaporation estimates, and a table of the measured values for each monitoring device are also included. Depth to water values, measured from the top of the well casing, were converted to elevations. Elevations above mean sea level were determined for the top of each well casing using a Global Positioning System (see "Other Data Sources: Elevation Determinations-Global Positioning System" section).

Geologic Descriptions-Particle Size Analysis

Soil texture analysis was used to determine the size and consistency of materials that comprise the soil at Sand Lake in order to identify whether fine-grained material, such as silt or clay, exists beneath Sand Lake and, if so, whether they are present in sufficient quantity to cause an effective barrier to water movement. In general, soil particles are stratified into "soil separates," which refer to specific sizes of the soil particles but not to their composition. Certain minerals usually are dominant in each "separate." These are identified within seven distinct classes. Sands predominate the classes and range from very coarse (2.0 millimeter [mm]) to very fine (0.05 mm) particles. There are only two separates other than sand: silt and clay. These separates contain particles that are finer than sands and act to increase the soil particle surface area where they exist in a soil matrix. Water is held as a film on the surfaces of the individual soil particles; thus, fine-textured soils have large surface areas and have the capacity to hold relatively high amounts of water (Sopher and Baird, 1978).

Soil scientists often group soils with similar amounts of sand, silt, and clay into groups called soil textural classes. These classes differentiate soils that are composed of different combinations of the separates. There are four broad textural classes: sands, silts, clays, and loams. These four classes are further broken down into 12 textural classes that describe the sample based upon percentage of the four broad classes. Examples of this breakdown would include a "loamy sand" or a "sandy loam." A textural triangle was developed for soil texture identification purposes. This triangle is a graphic representation of the amounts of sand, silt, and clay in the soil textural class. These descriptions include techniques for determining classes and were used in the soil sample analysis at Sand Lake. The size distributions for each soil separate, descriptions, and techniques for determining textural classes are included in Appendix C.

Four methods of analysis were used to investigate the geologic materials in and around Sand Lake: geologic descriptions of borehole cores, soil core examinations in the field, gamma logging of boreholes, and mechanical analysis of soil samples.

Borehole Core Analysis. Observation well installation not only allows the construction of a water level measuring tool at depth, but also provides a borehole core of subsurface materials extending from the land surface to the total depth of the hole. A geologic description of the core can be a valuable guide to the more precise analysis of particle grain size and distribution of subsurface materials at the site. Seven drilled observation wells were constructed at Sand Lake for water level measuring purposes. The drill cuttings at each hole were described and labeled in the field.

However, in any reporting of geologic materials, it must be understood that the materials are subject to interpretation by the geologist or driller. In this regard, the geologic description given to these zones may imply that more clay exists in the structure than was actually encountered during the drilling process. A "clayey sand" indicates more sand than clay; a "sandy clay," just the opposite. Also, interpretation of exact depths from drill cuttings can be as much as a few feet off. During the auguring process, the geologic material comes to the land surface slowly, depending upon the speed of the auger. The geologist uses the depth of the auger "flights" in combination with the observed material at land surface to correlate the geologic material to a specific depth.

Field Soil Core Examination. In the field, particle size and texture can be estimated by feel. A sample of the soil can be manipulated by hand in a variety of ways to identify different textures. For example, sand, when squeezed, will form a cast that will fall apart when the hand is opened. Conversely, clay can be formed into a ball that will not fall apart when the hand is opened. The finer the clay, the more apt it is to form a long, thin ribbon that will support its own weight. This method is not a precise method for determining soil texture; however, it is an effective means of obtaining an approximate idea of soil material texture in the field.

The soil sample interpretation consisted of using the Unified Soil Classification System from the Geotechnical Gauge (W.F. McCollough, Beltsville, Maryland) and the Munsell® Soil Color Chart (Macbeth Division of Kollmorgen Instruments Corp., New Windsor, New York) descriptions. Textures of the sample material were determined using field textural definition techniques as described previously. Generally, a sample of wet soil was put between two fingers and rolled. The characteristics of the sample were then compared to the texture class descriptions detailed in Appendix C. Color classification was done for dry and wetted samples with both the McCollough Geotechnical Gauge and the Munsell® Soil Color Chart. Both techniques use example color patches matched to specific descriptions for consistent identification purposes. The color code descriptions for the two soil samples can be found in Appendix D.

Gamma Logging of Monitoring Wells. Gamma logging of the deep observation wells around the lake also was used in this study as a guide to geologic material textures at Sand Lake. This type of logging is used mainly as a qualitative guide for stratigraphic correlation and is useful for identifying highly permeable materials for correlation with more intrusive types of sampling (e.g., analysis of borehole cores).

Gamma logging was provided by the ISGS for the three deep drilled monitoring wells, Sand Lake Observation Wells 1,4, and 6 (SLOW1, SLOW4, and SLOW6, respectively). Gamma logging involves the measurement of the naturally occurring radiation emitted from the materials within a borehole. A probe that can detect the amount of decay from geologic materials was lowered into each borehole. Clays and shales contain high concentrations of radioactive isotopes and thus emit high amounts of radiation, whereas mature sands and gravels, containing primarily silica (a stable substance), emit only very low levels of radiation. The variation with depth of radiation emitted by different geologic materials provides a "downhole" view of the formations below land surface. The gamma logs for the three holes are assembled in Appendix E.

Mechanical Analysis. Mechanical analysis is a method that involves particle size determination through dispersing or separating the soil particles in water, removing the sand with a sieve, and/or measuring the silt and clay by their rate of fall in water. Mechanical analysis of a soil sample can precisely define the particle size and thus its texture classification. The two soil core samples obtained on the outer edge and within the deep part of the lakebed (near SLOW7 and SG3, respectively, see Figure 2) were sieved by the ISGS, Mechanical Geology Department to determine soil particle sizes. The larger sand sizes were determined through this process; however, the clay (< 0.004 mm) content within each sample was determined through pipette analysis. Silts (0.063 to 0.004 mm) were determined through subtracting the clay percent from the total "fines" weight. The complete analyses for the Sand Lake soil samples are described in Appendix F.

Many other methods of analysis, such as infrared spectrometry, microscopic and magnetic techniques, etc., can be used for this type of research; however, these other methods involve resources that were unavailable for this study.

Other Data Sources

Other sources of information were necessary in order to more fully understand the interactions between the various environmental realms at Sand Lake. This information either was provided by individuals or determined through various techniques. The following are those sources and/or techniques used that did not involve direct observation at Sand Lake.

Elevation Determinations-Global Positioning System

Water level elevations were calculated with respect to reference elevations determined with a Global Positioning System (GPS). The GPS is a satellite-based radio navigation system developed and operated by the U.S. Department of Defense. This system allows land, sea, and airborne users to accurately determine their latitude, longitude, elevation, velocity, and time of the day, anywhere in the world. The GPS uses 24 operational satellites in six circular orbits 20,200 kilometers (km) above the earth. The satellites are spaced in orbit so that at any given time a minimum of six satellites are in "view" of any location on earth. The satellites broadcast position and time data through monitor stations and ground antennas throughout the world. The GPSs are able to receive this information and calculate location and elevation precisely. Typically, these measurements are within centimeters. The ISWS owns and operates three Wild GPS System 200 receiver units, which were used for this investigation.

The GPS was used to determine elevations for the top of all well casings. Water level elevations were subsequently determined from measurements of the distance between the water surface in the well and the top of the well casing. Land surface elevations also were determined at various points in and around Sand Lake for reference purposes. All measurements were taken in feet and are considered accurate to the hundredth of a foot.

Climate Information

Precipitation and temperature were measured at the City of Havana and the Peoria Climate Network stations. Evaporation estimates were calculated from air temperature data using the Thornthwaite (1948) method. The equations used to calculate these values are given in Appendix G.

Seepage Determinations

Two seepage meters were constructed to monitor the direction and volume of lake water flux through the bottom sediments. They were constructed from 55 gallon drums that were cut in half. A 1-inch hole was drilled in each half drum. The half drums were pushed into the lake bottom sediments, with their open side face down. A tube was run through a rubber stopper, fit snugly into the 1-inch hole in the half drum, to a two-way valve, then to an intravenous medical bag that floated beneath the water surface and above the drum. When the valve was opened, water could move freely into or out of the bag. One thousand milliliters of water were added to the bag prior to hook-up at the valve. Upward movement of ground water into the lake causes the pressure in the drum to increase and water to flow into the bag. Conversely, movement of water downward through the sediments decreases the amount of water in the bag. Prior to each measurement, the seepage meters were allowed to equilibrate (i.e., flow into or out of the drum) for about 15 minutes. Each measurement was then started, and after an hour the bags were checked and the volume of water within each was determined.

Volume Calculations

Volume of water within Sand Lake was required to investigate the various water budget components and their response to atmospheric, surface, and subsurface realm events. Volume of water was determined through known lake elevations and a comparison with a digital topographic map of the area. The digital map was created by inputting GPS land surface data into Surfer® Contouring and 3D Surface Mapping software (Golden Software, Inc., 1994). The digital map served as a general replica of the area in and around Sand Lake. Observed lake elevations during the study period were used as a horizontal base elevation. The Surfer® (Golden Software, Inc., 1994) software was able to interpret the volume of material, in this case surface water, between the horizontal elevation (lake level) and the digital map (land surface).

Correlation Analysis

Correlation analysis involves the studying of the relationships between two or more variables through time. Many methods are available to measure this relationship. The strength and efficiency of each type of analysis varies and depends upon the type of data collected and the scale of measurement in which they are expressed. It is generally recognized that the product-moment or Pearson's correlation coefficient (r) is the most powerful (Shaw and Wheeler, 1994). Regardless of the form of correlation analysis, however, the outcome is always expressed as a numerical coefficient that describes the direction and character of the relationship between the two variables. The values of the coefficients can vary only between -1.0 and +1.0. These extremes represent perfect negative or positive relationships, respectively. If negatively correlated, the value of one variable increases as the other decreases. If positively correlated, the values of each variable increase simultaneously. A value of 0.0 indicates the complete absence of any statistical relationship.

The product-moment is based on the idea of covariance. Variance is used to measure the variability of a sample about its mean; covariance measures the correspondence of two variables together. The quantitative solution for this analysis is represented by r. In order to relate some significance to this value, a P-value is reported for each correlation as well. The P-value is the probability of concluding that there is a true association between the variables. The smaller this value, the greater the probability that the variables are correlated. To this end, a P-value of less than 0.05 indicates that there is a 95 percent certainty that an association exists between variables ($\alpha = 0.05$). This is a commonly accepted standard in statistical analysis and, for the purposes of this study, will be used as a tool in assessing the interrelationships of variables at Sand Lake.

Ground-Water Gradient Determinations

A quantitative assessment of vertical movement of ground water can be determined through an analysis of the ground-water elevation measurements from observation wells of different depths. This assessment can be used in combination with observed ground-water elevations to better define movement of ground water in an area.

The elevation of ground water is termed hydraulic head. The difference between the hydraulic head values of wells at the same location is the basis for determining vertical movement of ground water, termed hydraulic gradient. This gradient is the difference in total hydraulic head (elevation) divided by the vertical distance between the finished well depths and is reported as a foot per foot (ft/ft) value. It represents a ground-water measurement that can be compared with other gradients in a study area to determine magnitude and direction of ground-water flow.

At Sand Lake, three piezometer "nest" sites were constructed. One site located to the west of Sand Lake consisted of three wells, SLOW1, SLOW2, and SLOW3, which were finished at depths of 75 ft, 35 ft, and 55 ft, respectively. As described earlier, a second site was located on the down slope-eastern edge of the topographic high and consisted of two wells, SLOW6 and SLOW7. These wells were finished at depths of 43 ft and 24 ft, respectively, and are critical for the analysis of the potential for stagnation point identification under the lake. The third site was located to the east of the lake and consisted of two wells, SLOW4 and SLOW5, which were finished at depths of 40 ft and 20 ft, respectively. These sites were chosen to look at ground-water gradients from the west to the east across the Sand Lake basin.

The gradient calculations for these nested wells were based upon the calculated difference in observed ground-water elevations between wells. These elevations were collected using an electronic measuring device (dropline) with an accuracy of 0.01 ft. At Nest 1, the elevational differences ranged from 0.00 to 0.03 ft. Because the measurements from this nest are at the limits of the collection device, there is a strong likelihood that the fluctuations are more likely attributed to sampling procedure and error than hydrologic conditions. This is less likely at Nests 2 and 3 based upon the tenths differences observed from these observation wells.

Ground-Water Model

The ground-water modeling effort for this study utilized Visual MODFLOW 2.0 (Guiguer and Franz, 1996), a software package developed by Waterloo Hydrogeologic, Inc. (Waterloo, ON, Canada). This fully integrated pre- and post processing modeling package is an enhanced version of the MODFLOW finite difference, modular ground-water model developed by McDonald and Harbaugh (1988) for the USGS. MODFLOW (McDonald and Harbaugh, 1988) is one of the most popular ground-water flow models used by government agencies and consulting firms. MODFLOW (McDonald and Harbaugh, 1988) analyzes ground-water flow by solving a partial differential equation that describes the three-dimensional movement of ground water of constant density through porous material. This equation in combination with the specification of boundary and initial conditions represents a complete mathematical expression of a ground-water flow system. MODFLOW (McDonald and Harbaugh, 1988) uses the finite difference numerical method to obtain an approximate solution to this equation. Hydrogeologic layers can be simulated as confined, unconfined, or a combination of both. External stresses such as wells, recharge, evapotranspiration, drains, rivers, and streams also can be simulated. Boundary conditions include specified head, specified flux, and head-dependent flux. Four iterative solution techniques-the Strongly Implicit Procedure, Slice Successive Over Relaxation, Preconditioned Conjugate Gradient, and the Bi-Conjugate Gradient Stabilized method-are available within visual MODFLOW (Guiguer and Franz, 1996) to solve the finite difference equations.

The visual MODFLOW (Guiguer and Franz, 1996) software package also includes the advective particle tracking program called MODPATH® (Guiguer and Franz, 1996). MODPATH® (Guiguer and Franz, 1996), which was developed for the USGS by Pollock (1989), uses cell-to-cell fluxes to calculate advective flow paths and travel times. MODPATH® (Guiguer and Franz, 1996) is used to determine the flow paths of a ground-water system and can define the location of ground-water sources or sinks.

Model Boundaries. The general flow direction in the modeled area is from east to west when not influenced by nearby streams and drainage ditches. The modeled area is bounded on the west by river cells representing the Illinois River and adjacent backwaters and lake complexes. The initial elevation of the Illinois River was set at 430 ft-msl for steady state model calibration. The elevation of 430 ft-msl is the normal low water elevation for the managed navigation pool in this reach of river. For transient model runs, the river boundary varied in elevation from 430 to a high of 445 ft-msl, which occurred during the flood of 1993. The southern border of the model is bounded mostly by river cells representing White Oak Creek, and the northern border of the model is bounded by river cells representing Quiver Creek. The elevations selected for White Oak and Quiver Creeks were based on elevations selected from USGS topographic maps.

The east edge and northeast and southeast corners of the model are represented by variable head cells that were set to elevations determined from the three potentiometric contour maps developed by the ISWS for the fall of 1992 and spring and fall of 1993 mass water level measurements. These variable head elevations ranged from 465 to 501 ft-msl. Variable head elevations for individual cells ranged from 5 to 10 ft over the 13-month transient simulation period.

Model Grid. Finite difference modeling is based upon solving mathematical equations at nodes on a predefined grid. The grid used for this modeling effort is shown in Figure 3. This grid covers a square area that is 8.25 miles long on each side and is divided into 49 rows and 54 columns. The largest cells are at the edge of the grid and are 1/4 mile by 1/4 mile square. The smallest cells are located in the interior of the grid in and around the Sand Lake wetland complex. These cells are 1/8 mile by 1/8 mile square. Inactive cells are located west of the Illinois River, north of Quiver Creek, and south of a small portion of White Oak Creek. The model grid was rotated 35 degrees northwest to align with the primary ground-water flow direction as indicated on the ISWS potentiometric contour maps.

A single layer model was used for steady state model calibration and initial transient model simulations. Final ground-water flow, mass balance, and advective transport model simulations used a 21-layer model with each model layer varying from 4 to 5 ft in thickness.

Model Development. The basic MODFLOW (McDonald and Harbaugh, 1988) model requires input data for each active grid cell in the model grid for aquifer properties, which include hydraulic conductivity, storage coefficient, aquifer top and bottom elevations, and recharge. A completed working model also requires input for boundary condition factors for river and variable head cells and well pumpage information. The parameters used for each of these items follow.

Hydraulic Conductivity. Values for hydraulic conductivity were initially selected from the input data used for the regional model developed by Clark (1994). Hydraulic conductivity values varied from 200 ft per day east of Sand Lake to 600 ft per day in the area generally west of Sand Lake.

Storage Coefficient. A storage coefficient of 0.1 was used for the entire model grid. This value was used by Clark (1994) and was suggested by Walker et al. (1965) as a realistic value for the western portion of the Havana Lowlands area. A porosity value of 20 percent was used for the advective flow path modeling.

Aquifer Top Elevation. The top of the aquifer was set at land surface. The top elevations of model cells were developed from input selected off of high quality orthophoto maps. These maps were developed for a part of a study (Visocky, 1995) to determine 100-year surface and 100-year basement flood danger zones for the area in and around the City of Havana. These detailed maps were available for approximately 20 percent of the model grid. The rest of the surface elevations were based on elevations selected from USGS topographic maps.

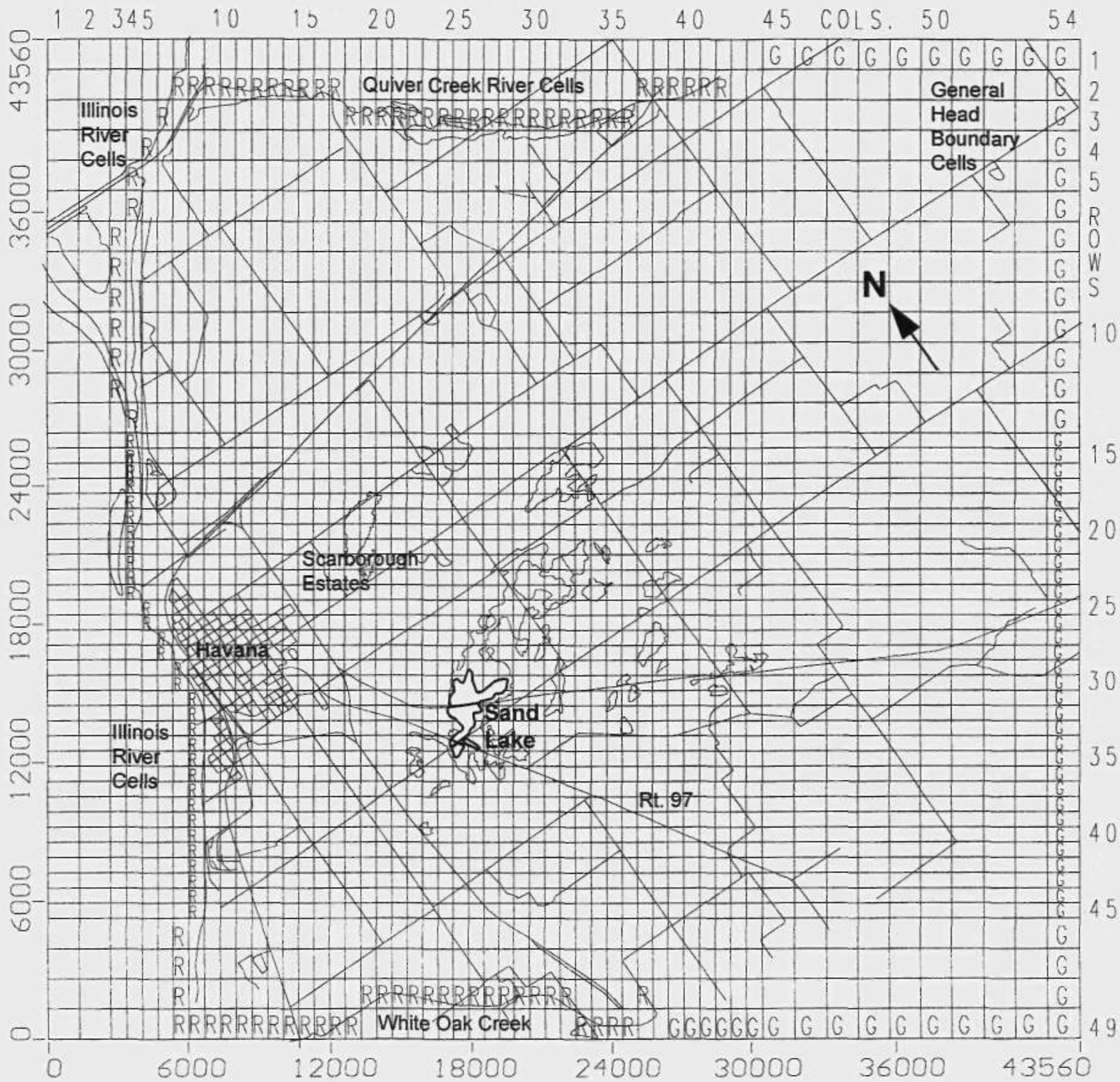


Figure 3. Finite-difference grid and boundaries

Aquifer Bottom Elevation. Aquifer bottom elevations representing the top surface of the bedrock formation varied from 360 to 390 ft-msl These values were obtained by Clark (1994) from the evaluation of over 430 well records.

Recharge. An extensive evaluation of recharge rates for the modeled area was conducted by Clark (1994). In the development of the regional model for the Mason County area, Clark (1994) realized that recharge parameters would have a significant impact on model accuracy and transient simulations. For the development of rainfall event-specific recharge estimates, Clark in his 1994 study used the Precipitation Augmentation for Crops Experiment-GC (PACE-GC) model provided by Durgunoglu et al. (1987).

The PACE-GC soil moisture model is a submodel of the PACE watershed model (Durgunoglu et al., 1987) developed through the PACE project, which was initiated in the mid 1980s by the ISWS. The PACE model is a quasi-distributed-parameter model designed and constructed to simulate the movement of water through the hydrologic system for the purpose of analyzing the effects of changes in precipitation. The overall PACE model is modular in construction with major components for soil moisture, ground water, and surface water. The PACE-GC model is a subset of this modular structure that computes a water balance between rainfall and recharge into shallow ground-water-based daily rainfall and temperature values along with crop type and soil characteristics. Recharge rates developed through application of the PACE-GC model are listed in Table 1 for the 24-month period of 1992-1993, which covers the modeled simulation period.

Table 1. PACE-GC Monthly Recharge Rates for Simulation Period

	1992		*1993*	
Month	*PACE-GC (in.)*	*PACE+runoff (in.)*	*PACE-GC (in.)*	*PACE+runoff (in.)*
Jan	0.90	0.90	1.83	3.23
Feb	1.00	1.07	0.65	0.67
Mar	0.48	0.48	4.53	4.53
Apr	0.62	0.62	3.61	4.02
May	-0.08	-0.08	-0.15	-0.15
Jun	0.00	0.02	0.00	0.00
Jul	2.43	2.91	3.65	4.49
Aug	-0.17	-0.17	1.04	1.05
Sep	0.00	0.00	4.41	7.03
Oct	0.00	0.00	1.14	1.14
Nov	4.23	4.39	1.30	1.30
Dec	1.21	2.62	1.40	1.56

WATER BUDGET

The movement of water within the environment can be analyzed using the hydrologic budget. In environmental systems, water moves, or cycles, on a continual basis at rates that are dependent on both physical and human factors. Monitoring water movement within this cycle allows description of its various components and the effects they may have on the state of the system. The hydrologic budget concept is relatively simple. It has three basic components: inflows, outflows, and storage. The inflows must equal the outflows plus or minus the change in volume of water stored within the system (Fetter, 1994). Although the concept may appear simple, the water flows and changes in water storage within the system can be difficult to measure. Water moves through the atmosphere, the ground, and across the earth's surface in liquid, vapor, and solid forms, making it virtually impossible to precisely measure and account for each component in the budget. Also, each component can be affected by a large number of variables. Naturally, water moves within three basic realms in the hydrologic budget: the atmosphere, the land surface, and the subsurface. The relevant water flows in each of these realms can be combined quantitatively to evaluate the fluctuations of water in a hydrologic system.

Atmospheric Water Flows

The components of the atmospheric realm are precipitation and evaporation. Precipitation and temperature were measured at the City of Havana and the Peoria Climate Network stations. Evaporation was calculated from air temperature using the Thornthwaite (1948) method and is assumed to equal evaporation from the open water surface of Sand Lake. Because precipitation is an input of water into the system and evaporation is the output, a net value termed "atmospheric flux" was calculated for each observation period. A positive atmospheric flux indicates greater precipitation than evaporation, and a negative atmospheric flux just the opposite (i.e., evaporation greater than precipitation). The rainfall, evaporation, and atmospheric flux estimates are subsequently compared to estimates of lake storage or volume changes calculated from lake level measurements. This analysis provides one method of ascertaining the potential effect that the atmospheric changes may have on the land and subsurface water flows at Sand Lake.

Land Surface Water Flows

Generally, the surface hydrologic realm is comprised of stream flow, overland flow, and outlet stream flow. Surface movement of water is a function of many variables that include rainfall intensity and duration, permeability of the ground surface, type of vegetation on the land surface, area of the drainage basin, distribution of the rainfall, lake-channel geometry, depth to the water table, and the slope of the land surface (Fetter, 1994) . Each component interacts with the others to influence the amount of water transported on the land surface or transferred into the subsurface environment or back into the atmosphere.

At Sand Lake, the land surface topography is very flat, with no evidence of surface channels. The highly permeable soil matrix allows immediate infiltration of water into the subsurface environment (ESE, 1993). For these reasons, land surface hydrologic flows are assumed to have little or no influence on the emergence, persistence, and recession of Sand Lake.

Subsurface Water Flows

The subsurface environment is comprised of ground-water flows into and out of the lake. This realm is composed of baseflow into the lake and seepage out of the lake. Ground-water flow begins when the soil moisture deficit is filled. Variables such as soil composition, evapotranspiration, and regional ground-water flow all impact the movement of water from the land surface to the subsurface.

Water Balance for Sand Lake

For the purpose of this study, the atmospheric, surface, and ground-water realms have been combined. The general hydrologic equation is:

$$\text{Inflow} - \text{Outflow} = \pm \text{Change in storage (dS)} \qquad \text{(Equation 1)}$$

The specific variables within this equation are described in Equation 2.

$$\underset{\text{(Inflow)}}{(P + SF + OF + BF)} - \underset{\text{(Outflow)}}{(E + OSF + S)} = \underset{\text{(Change in storage)}}{\pm dS} \qquad \text{(Equation 2)}$$

where, P is precipitation, SF is stream flow, OF is overland flow, BF is baseflow, E is evaporation, OSF is outlet stream flow, S is the seepage from the lake, and dS is the change in storage. Table 2 depicts these variables in regard to the hydrologic balance at Sand Lake.

Table 2. Hydrologic System Inputs and Outputs

System	*Inflows*	*Variable*	*Outflows*	*Variable*
Atmospheric	Precipitation	P	Evaporation (lake surface)	E
Surface Water	Stream flow Overland flow	SF OF	Outlet streams flow	OSF
Subsurface	Baseflow (accumulation into lake)	BF	Seepage (depletion from lake)	S

CHARACTERIZATION OF CONTROL PROCESSES

Two water budget-based control process analyses were developed to evaluate the role of geology and ground-water flows in the emergence, persistence, and recession of Sand Lake. For each analysis, the surface water influence (SF, OF, OSF) was assumed to be unimportant. Environmental Science & Engineering, Inc., in their hydrologic investigation of the flooding problem at Sand Lake, found, "Because the surficial soil materials are so permeable and transmissive, rainfall during even relatively wet periods either percolates or evaporates. Consequently, natural surface drainage systems were never formed by erosional processes" (ESE, 1993). For this reason, all potential land surface flows at Sand Lake are considered negligible.

Control Process I: Geologic (Clay Layer)

Clay has the capacity to retard or stop the infiltration of water causing ponding. Clay liners are commonly used as protection devices above and below landfills to stop the movement of water through the landfill materials, stopping or slowing the discharge of leachate into the environment. A clay layer may play a similar role at Sand Lake. If a layer of clay exists just below the lake bottom, water could pond above it. For Sand Lake to emerge and persist under a clay layer scenario, precipitation would have to be greater than evaporation (positive atmospheric flux) causing a positive change in water storage on the land surface. Under this scenario, ground-water base flow into the lake would not exist due to the premise that any clay material under the lake would retard or stop upward flow of ground water. This clay layer also would impede downward surface water movement or seepage from the lake into the subsurface.

In order to access whether there was evidence in support of this control, the various data collected at Sand Lake were examined. This examination consists of a short objective description of the data in relation to characterization for potential control at the lake. These descriptions are then summarized within the "Control Process I: Discussion" section.

Field Measurement Analysis

Borehole Geologic Cores. Table 3 shows measurements of the elevation of the bottom of Sand Lake and the elevations of clayey sand layers in the borehole cores. Based on the measurements from staff gauges 3 and 4, the average elevation of the lake bottom is approximately 475.39 ft-msl. Table 4 summarizes the clay material zones reported during observation well construction. The lowest elevation where clay-type material (clayey sand) was reported was at 473.89 ft-msl in SLOW1. This is 1.5 ft below the lake bottom. SLOW1 is located approximately 0.25 miles west of Sand Lake.

Because this clay material zone is close to the elevation of the bottom of Sand Lake, a regional clay zone may exist. Observation wells SLOW2 and SLOW3 also indicate clay intervals below the lake bottom at 475.01 and 474.04 ft-msl, respectively. However, these wells are

Table 3. Sand Lake Lakebed Elevations

Staff gauge	*Elevation (tog)*	*Reported lake bottom (ft below tog)*	*Lake bottom elevation (ft-msl)*
SG3	478.03	2.60	475.43
SG4	480.74	5.40	475.34
Average lakebed elevation			475.39

Notes: tog = top of gauge
SG = staff gauge

located within 3 ft of SLOW1. The geologic descriptions from the observation wells nearer to the lake (SLOW 6 and SLOW7) do not substantiate the presence of a "regional" clay layer. The elevations of the clay material (clayey sand) zones at 478.54 and 478.69 ft-msl in SLOW6 and SLOW7, respectively, are both above that of the lake bottom.

These wells (SLOW6 and SLOW7) are within 500 ft of the lake. SLOW4 and SLOW5 also indicate a clay loam layer from 0 to 3 ft, which corresponds to elevations of 485.72 to 482.77 and 485.60 to 482.60 ft-msl, respectively. These wells are approximately 0.5 miles east of the deepest part of Sand Lake, and the clayey sand zone elevations are well above the lakebed.

Field Soil Core Samples. Soil core samples collected at Sand Lake from two different sites near SLOW7 and SG3 (see Figure 2) also indicate zones of materials with relatively low permeability at the bottom of the lake. Appendices D and F detail these soil cores. Core sample

Table 4. Reported Clay Material Zones of Sand Lake Observation Well Boreholes

Observation well	*Elevation (toc, ft-msl)*	*Casing above land surface (cals-ft)*	*Land surface elevation (toc-cals)*	*Reported clay zone (ft below land surface elevation)*	*Clay zone elevation ranges (ft-msl)*
SLOW1	485.09	1.2	483.89	6-10	477.89-473.89
SLOW2	486.11	2.1	484.01	6-9	478.01-475.01
SLOW3	485.44	1.4	484.04	6-10	478.04-474.04
SLOW4	488.57	2.8	485.77	0-3	485.77-482.77
SLOW5	488.10	2.5	485.60	0-3	485.60-482.60
SLOW6	486.74	2.2	484.54	5-6	479.54-478.54
SLOW7	485.79	1.1	484.69	5-6	479.69-478.69

Notes: toc = top of casing
cals = casing above land surface
ft-msl = feet above mean sea level

No. 1 was taken to the east of Sand Lake at the lake edge. Core sample No. 2 was taken at the deepest part of the lake after the water had almost completely receded.

Core sample No. 1 showed a consistent sand structure throughout, although the first sample interval (0 to 7 inches) did contain some silt-like material. Core sample No. 2, however, had several distinct zones in which the soil separates contained silt, clay, or both. Only one zone (60 to 72 inches) contained a substantial amount of visible clay material. Whether or not the sandy clay layer is uniform under the lake is unknown by this analysis; however, it is clear from the core samples that there is clayey material present which may impact the vertical flow of water beneath Sand Lake.

Monitoring Well Gamma Logs. The gamma logs (Appendix E) of three wells confirm a layer or mixture of materials that emit higher levels of radiation than sand (i.e., less permeable) at elevations similar to those described during the drilling process. Higher radiation emissions are indicative of less permeable materials, such as clay. Although the exact type of material cannot be determined from the gamma log, a less permeable zone would cause ponding, or at least slowing of vertical water movement through the materials. Gamma logs were conducted on three observation wells at the lake: SLOW1, SLOW2, and SLOW4.

Soil Core Mechanical Analysis

The mechanical analyses of the two soil cores are included in Appendix F. The sieve analysis revealed smaller size silt particles in the lakebed as opposed to the outer edge of the lake, corroborating the field examinations of the soil cores. The "Fines" category for core sample No. 2 indicates that, from the land surface to 60 inches, approximately 14.6 to 22.3 percent of the sample contained particles within the silt size range (0.063 to 0.004 mm). However, neither core contained significant amounts of clay (<0.004 mm).

Control Process I: Discussion

It is evident from the results of the four methods of analysis (three subjective and one quantitative) that a layer of geologic material exists at Sand Lake which may impede water movement. The quantitative mechanical analysis showed that, at the deepest part of the lake, fine-grained geologic material is present in quantities that could impact water movement into the subsurface. The textural classes determined for the first 3 ft of soil from the lake bottom indicate a "loamy sand" soil type. Table 5 lists typical infiltration rates for the major textural classes. Although "loamy sand" is not specifically identified in this table, the major textures that make up a loamy sand are and, as such, can be used as an indication of infiltration rates. The infiltration rate for the "sand and silty soils" type is 10 to 20 mm per hour (mm/hr), whereas the value for the "loams" soil type is 5 to 10 mm/hr. The soil type at the bottom of Sand Lake is between these categories. Consequently, the mechanical analysis shows that an impermeable silt/clay layer does not exist under Sand Lake. Infiltration of surface water into the subsurface realm likely occurs directly under the lake, however, at a slower rate than at other areas surrounding the lake in which sandy soils exist at the land surface. The "Water Balance" and "Correlation Analysis" that follow are used to more fully evaluate the flow of water through the bed of Sand Lake.

Water Balance. The water balance also can be used to evaluate the clay layer scenario. If an impermeable silt/clay layer is present at Sand Lake, the surface water levels (storage) would rise and fall in a consistent pattern in response to the atmospheric flux (positive or negative), independent of ground-water level changes. Under this scenario, lake volume elevations would decline through the growing season and only increase when heavy precipitation exceeded evaporation in the Havana area.

This analysis consisted of calculating volume estimates of water for the atmospheric and surface hydrologic realms at the Sand Lake area. Volume estimates were used to create a means to quantitatively identify the effects of precipitation and evaporation measurements in the system. This was accomplished by first creating a high resolution digital topographic map of the Sand Lake bed using GPS elevation information with Surfer® (Golden Software Inc., 1994) contouring software. Observed lake elevations for specific dates (August through December 1995) during the project were then used to determine the lake area and the volume of material (i.e., water) between the lake surface and the lakebed. The period from August through December 1995 was used because, during this period, surface water at Sand Lake was present and monitoring device measurements were most reliable. After this time period, lake volume, for the most part, decreased to zero. The time series lake volume calculation, based on staff gauge and GPS topographic measurements, is shown in Figure 4 and is termed "observed lake volume."

A second estimate of lake volume based on the previous observed lake volume value, plus and minus the precipitation and evaporation volumes accumulated during the intervening period, respectively, is given and termed "predicted lake volume." This "predicted" volume can be compared to the "observed" lake volume estimate (of the period) to assess variable responses in the system (Figure 4). The vertical bars at the bottom of the plot represent precipitation and evaporation observations and are accumulated values (in inches) for the period between measurements. The combined value of these measurements, the atmospheric flux, also is

Table 5. Infiltration Rates for Major Soil Types
(Adapted from Hillel, 1982)

Soil type	*Infiltration rate (mm/hr)*
Sands	>20
Sands including silty soils	10-20
Loams	5-10
Clayey soils	1-5

graphed. This value subtracts the evaporation estimate from the precipitation aggregate and indicates the potential influence (positive or negative) attributed to atmospheric conditions in the system. As mentioned, a positive atmospheric flux indicates precipitation greater than evaporation, and a negative atmospheric flux indicates evaporation greater than precipitation for the period.

Figure 4 shows there is a general response by both the observed and predicted volume estimates to precipitation and evaporation over the short detailed period. The graph represents what would typically be expected from any surface water and atmospheric system interaction. Water levels decline during periods of high evaporation (negative atmospheric flux) and generally increase during rainfall events (positive atmospheric flux). However, if an impermeable clay layer existed that would hold water at the land surface, the observed and predicted volume estimates would be the same, and each would change similarly in response to precipitation and evaporation events. The difference of the observed and predicted lake volume shown on this graph suggests another factor-seepage into the subsurface-is most likely affecting lake volume.

The predicted volume estimates rise and fall in response to positive and negative atmospheric flux, respectively. However, the observed lake volume decreases when the negative flux is greatest (high evaporation) and shows little or no fluctuation in response to a large

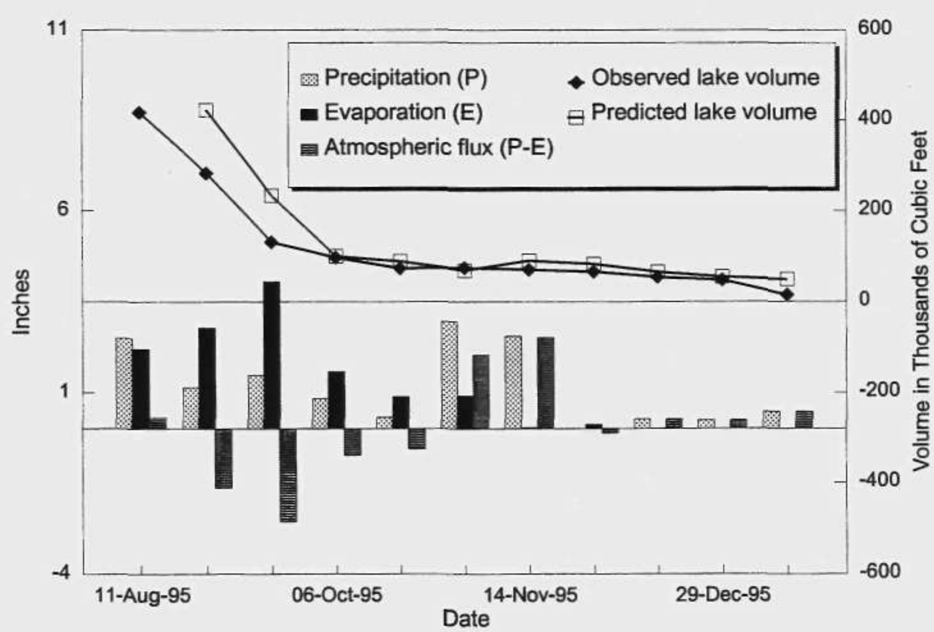


Figure 4. Observed vs. predicted lake volumes

positive atmospheric flux during the first two weeks of November. During this period evaporation is moderate but large precipitation events occur that only cause relatively minor changes in lake volume. This suggests that seepage into the ground-water environment may be "countering" the volume increase that would normally be attributed to precipitation. When an increase in volume occurs due to precipitation, an equal amount of water is displaced into the subsurface by way of seepage though the lake bottom. Figure 5 shows the observed lake volume estimate with ground-water elevations from Sand Point Observation Well 2 (SPOW2). As earlier noted, this well is located about 100 ft to the southwest of the surface water staff gauge, which is inside the lake extent (Figure 2). The time-series of the observed lake volume and SPOW2 ground-water elevations show relatively similar fluctuations by these two variables through the detailed period. However, close examination during the period from October through December 1995 shows that, as the lake volume slowly decreases, SPOW2 ground-water elevation slowly rises. During this time (autumn) little evaporation of open surface water, as well as through plant transpiration, typically occurs in Central Illinois. The only factor that could be playing a significant role in decreasing lake volume and increasing ground-water levels is seepage of surface water into the subsurface realm.

This analysis indicates there is a link between the surface and subsurface realms at Sand Lake. Upon close examination of ground-water levels inside and outside Sand Lake (SPOW2 and SPOW7, respectively), there appears to be a slight difference in response to atmospheric conditions between the two sites. Figure 6 shows the time-series of ground-water elevations of

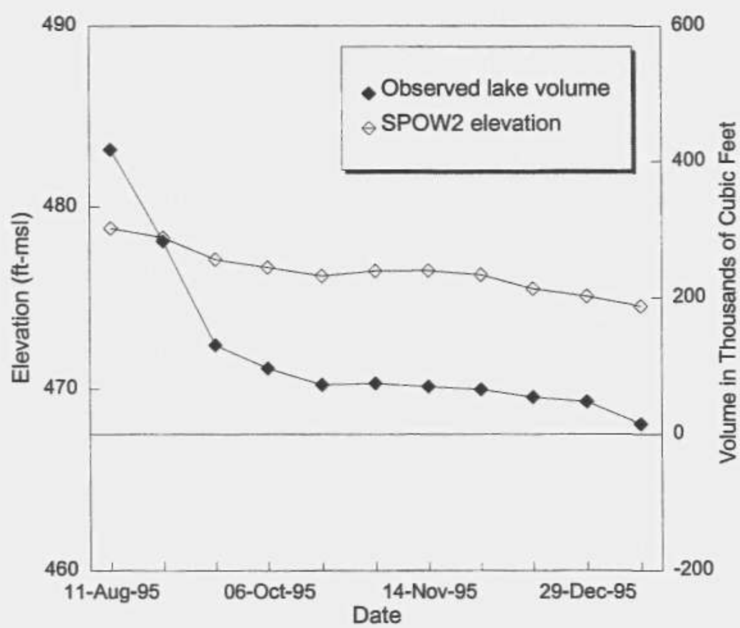


Figure 5. Observed lake volume vs. shallow ground-water elevation

the two wells with precipitation, evaporation, and atmospheric flux estimates for the project period. SPOW2 is located within the lake body; SPOW7 is located on the lake's outer edge. The mechanical analysis of soil samples at these sites (soil sample No. 2 and No. 1, respectively) shows that there is a difference in the soil composition between them. At SPOW2, the composition of the upper 4 ft of soil averaged just under 20 percent silt; at SPOW7, the upper 4 ft of soil averaged under 9 percent silt. Both wells respond to evaporation losses; however, there is a difference in response to precipitation events.

Throughout the study period, precipitation causes more timely positive responses in ground-water elevations in SPOW7 than in SPOW2. Declines in precipitation cause corresponding declines in both wells; however, there are some instances when water levels in SPOW2 decline slightly after declines are observed in SPOW7. This, coupled with the mechanical analysis information, suggests that the semipermeable lake bottom soils allow seepage but also hold water in the surface system for a short period of time. Although the surface and shallow subsurface systems respond to precipitation at Sand Lake, there is a slight lag in the decline in the two systems that is specific to the lake bottom. This delay most likely is a contributing factor in the persistence of the lake.

Another factor that may add to a delay in response to precipitation seepage into the subsurface realm under the lake is the presence of organic matter within the bottom sediments of Sand Lake. This lake was determined to be an "intermittent wetland" through the National

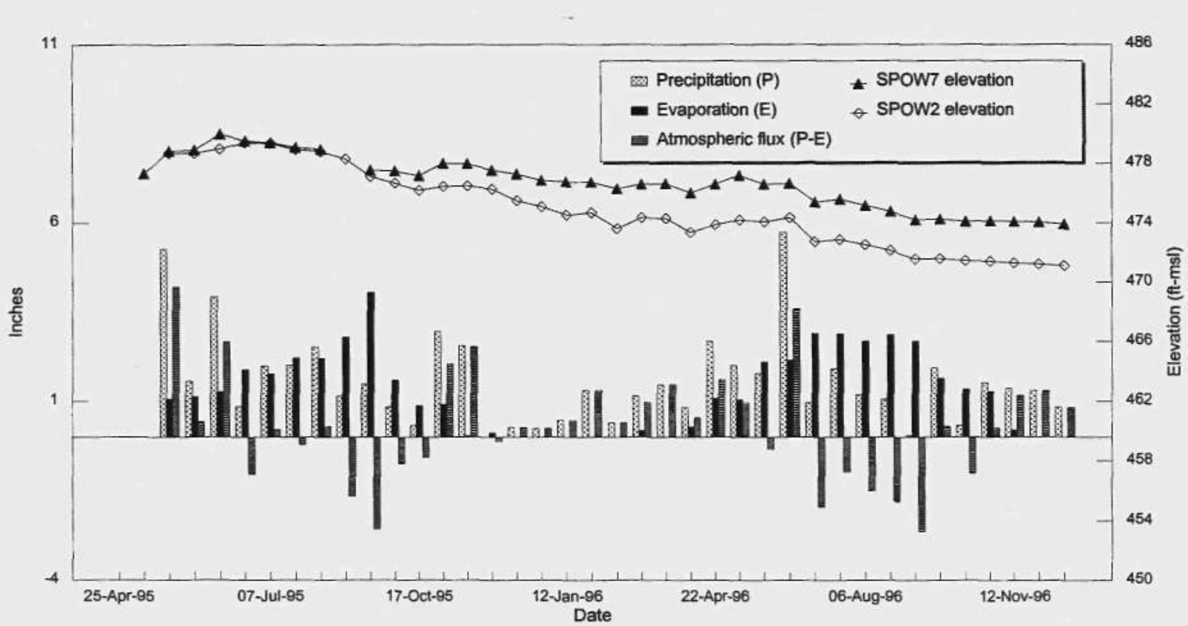


Figure 6. Shallow ground-water levels in and outside the lake extent

Wetlands Inventory. One aspect of a wetland delineation is that the soils at the site must fall into the hydric category. A hydric soil implies that the soil is saturated, flooded, or ponded long enough to enable anaerobic conditions to develop (Mitsch and Gosselink, 1993). The soil sample color classifications determined through the Munsell® Soil Color Chart investigation (Appendix D) confirm typical hydric soil chroma descriptions at Sand Lake (≤ 2). Hydric soils tend to have concentrations of organic material that create increased water-holding capacity. An increase in water-holding capacity due to the make-up of these types of soils also will contribute to slowing of infiltration of surface water into the subsurface system (Mitsch and Gosselink, 1993). Although organic matter analysis was not conducted for the Sand Lake samples, organic matter within the upper 3 ft of soil was observed.

A third factor that may play a role in the delay in seepage of surface water into the subsurface realm is the regional ground-water level influence at Sand Lake. Decline in surface water volume due to seepage is dependent upon the presence of ample void space between the lake bottom and the upper surface of ground water and the permeability of the soil matrix. This combination can alter the existence and persistence of surface water bodies. When ground-water elevations are at the same level as the lake bottom, surface water cannot move downward, thus creating a ponding effect. This type of situation at Sand Lake was evident during the fall of 1993. At that time, Sanderson and Buck (1995) measured the ground-water elevation from a well located approximately 3,000 ft to the northwest of the lake as 479.62 ft-msl, which is more than 4 ft above the bottom of Sand Lake. This would indicate that seepage of surface water into the ground-water realm was not possible during that time, which would explain the persistence of the lake over the following years as a result of the 1993 floods. When ground-water levels began to decline at the start of the study, Sand Lake began to slowly decline in volume.

Surface water appears to become trapped above the less permeable material at Sand Lake. Water that is trapped can flow only within the land surface system, evaporate into the atmospheric system, or seep into the subsurface system. There are no structures (creeks, streams, etc.) for water to move on the land surface at Sand Lake, evaporation estimates are well below the lake volume change, and precipitation observations are greater than the lake volume change estimates. These factors all imply that trapped water has no other mechanism for movement other than by seepage at Sand Lake, its rate depending upon the depth of the ponded water, the amount of saturation of the soil below the lakebed, and the permeability of the bed materials (Fetter, 1994).

The depth of the ponded water exerts a pressure (hydraulic head) that forces vertical downward movement. This movement can occur only when the soil is unsaturated (void space in the soil matrix) directly under the surface water body (Fetter, 1994). This implies that the top of the ground-water elevation must be below the bottom of Sand Lake (475.39 ft-msl) for movement to occur, otherwise stagnation would result. Unfortunately, no direct measurements of ground-water elevations near Sand Lake were taken between the fall of 1993 (Sanderson and Buck, 1995) and the start of this project to ascertain ground-water levels during the persistence of Sand Lake through 1995.

Correlation Analysis. Graphically, the rise and fall of these measurements over time suggests a correlation between the variables. In order to quantitatively assess these relationships, the Pearson's correlation coefficient was calculated for pairs of variables and used to evaluate the statistical significance of the correlation.

The results calculated for the comparisons between data measurements for selected variables are listed in Table 6. Observed lake volumes, ground-water elevations, and atmospheric flux values during the measurement period were used for this analysis. See the "Methodology" section for discussion of this analysis. Table 6 lists the r-value and corresponding P-value for the measurements over the study period.

The analysis suggests positive relationships between observed lake volumes and ground-water elevations of both SPOW2 and SPOW7. The r-values of 0.90 and 0.79 with corresponding P-values of 0.001 and 0.007, respectively, indicate a significant positive relationship between the variables. A P-value of less than 0.05 indicates there is a 95 percent certainty that an association exists between variables. This is an acceptable standard in statistical analysis. These values imply there is a relationship between the surface and subsurface realms at Sand Lake. The only mechanism that could cause this relationship is seepage of surface water into the subsurface realm. The positive nature of these values implies that, when lake volume increases, ground-water elevations also increase. Because of the composition of the geologic materials between the surface and subsurface realms (i.e., sand), this relationship is what would be expected in the surface/ground-water interaction situation at Sand Lake. The correlation analysis corroborates this expectation.

The correlation analysis also indicates a significant positive relationship between SPOW2 and SPOW7. Because these measurements are both ground-water elevations, one variable does not necessarily depend upon the other in this situation; however, the positive sign of the coefficient indicates that both increase and decrease simultaneously. This movement suggests

Table 6. Pearson's Product-Moment Correlation Analysis for Sand Lake Variables

Variable	*Compared to*	*Correlation coefficient (r)*	*P-value*
SPOW2	Observed lake volume	0.8955	0.001*
SPOW2	Atmospheric flux (P-E)	-0.5919	0.071
SPOW7	Observed lake volume	0.7847	0.007*
SPOW7	Atmospheric flux	-0.0025	0.995
SPOW7	SPOW2	0.7113	0.021*
Observed lake volume	Atmospheric flux	-0.4430	0.200

Notes: *Indicates significant relationship with 95 percent confidence ($P < 0.05$)
SPOW- Sand Point Observation Well

ground-water response to volume changes is uniform throughout the basin. No other significant relationships were indicated by the analysis.

Lake volume changes were expected to be correlated to the atmospheric flux variable given that surface water volume relies on this variable for its existence; however, an r-value of -0.4430 with a corresponding P-value of 0.200 indicates no statistically significant relationship. Similar results are shown in Table 6 for the shallow wells with atmospheric flux. Two factors may be influencing these results. First, the statistics were generated using only ten data points. This is a small data set for statistical analysis and invites erroneous interpretation. Second, fluctuations in the regional ground-water level may primarily govern storage in Sand Lake and the ground-water table level in its immediate vicinity. The ground-water realm could dominate the flows of water to and from the lake overshadowing the contribution from the atmospheric realm.

Control Process I: Conclusions

The observed relationships among surface water volume, ground-water elevation, and atmospheric flux events, coupled with the mechanical and correlation analyses results, suggests that the soil under Sand Lake acts like a "leaking" bathtub. There appears to be enough fine-grained material and organic matter to temporarily hold water on the land surface at Sand Lake; however, this pond is short-lived. The material is porous enough to allow slow movement of water into the subsurface realm when ground-water elevations fall below the lake bottom. There is no evidence that an impermeable clay layer exists at Sand Lake which would cause the existence and persistence of the lake.

There is evidence, however, that fine-grained materials and organic matter in the upper soil matrix play a role in the persistence of the lake, temporarily holding the water in the surface system even when ground-water elevations declined below the lake bottom. Ground-water elevations within SPOW2 ranged from 475.31 to 471.04 ft-msl, which were below the bottom of Sand Lake (475.39 ft-msl) throughout the study period. This allowed seepage of surface water into the subsurface realm; and, coupled with evaporation, resulted in declines of surface water volumes. The permeability of the soil plays an important role in movement of water into and through the soil. The less permeable a material, the slower the infiltration and the longer the retention of water on the land surface. At Sand Lake, the moderately permeable "loamy sand" and wetland-type characteristics of the lake bottom soil cause a slowing of water movement from the surface to the subsurface realm, which is reflected in lagged response of ground-water elevation decline under the lake when there is less precipitation or less evaporation.

This analysis clearly indicates that an impermeable clay layer is not responsible for the existence of Sand Lake. It also has shown that the water-holding capacity of the less permeable "loamy sand" and the wetland soil characteristics of the lake bottom sediments are contributing factors in the persistence of the lake.

Control Process II: Ground-Water Flow System

Typically ground water moves at very slow velocities. This movement is dependent upon many factors but generally is influenced most by gravitational forces. To this end, ground water moves toward topographic low points and discharges into lakes, rivers, streams, etc. It is often useful to classify this movement on the basis of spatial scale into three flow systems: local, intermediate, and regional.

Local flow systems reflect shallow ground-water reserves and generally can be identified when local relief is pronounced. Regional systems encompass an entire basin and have their recharge area at the basin divide (an area in which water moves in all directions) and the discharge area at the valley bottom or at major hydrologic features such as a river (Fetter, 1994). Flow systems intermediate in spatial scale between the local and regional systems containing at least one local flow system between their recharge area (area of ground-water influx) and discharge area (area of ground-water outflux) are called intermediate systems. For the purpose of this study, only the local and regional flow systems will be discussed because the information is not available to reliably define an intermediate flow system in the Havana area, and thus the term "regional flow system" is used to refer to the ground-water flow regime that occurs at a scale larger than that of the local system.

Within the local flow system regime, the local relief may influence the existence and persistence of the lake by causing a reversal of ground-water flow with respect to flow in the regional system. This could result in a point of stagnation where the local and regional flows converge (Fetter, 1994). If no point of stagnation exists, the existence and persistence of the lake could depend entirely upon the regional flow system.

To evaluate the evidence in support of this process control, the well data collected at Sand Lake were analyzed. This examination consisted of a short description with an analysis followed by a summary within the "Control Process II: Discussion" section. The analysis is designed to answer three basic questions related to the flow system at Sand Lake. First, does a local flow system exist? Second, is there a stagnation point development within the local system? Third, does the regional flow system dominate the local system and cause the existence, persistence, and recession of Sand Lake?

Sand Lake Monitoring Network

Sand Lake "Nested" Observation Well Network Data

Local flow systems are defined by shallow ground-water movement in response to pronounced local topographic (elevational) relief. At Sand Lake, topographical highs may directly influence shallow ground-water flow and result in the existence, persistence, and recession of the lake. The lake bottom elevation was determined to be 475.39 ft-msl. The topographic high to the west rises to approximately 508 ft-msl resulting in an elevational difference of over 32 ft. A smaller high also is evident on the eastern edge of the basin near SLOW4 and SLOW5. The land surface elevation was determined to be approximately 485.77 ft-msl at this location, indicating a difference of 10.4 ft to the east of the lake. In order to assess whether these differences influence ground-water flow at Sand Lake, ground-water gradients determined from "nested" (two or more wells of different depth at the same location) observation well measurements can be analyzed. Nested observation wells identify elevational gradients (or direction of flow) caused by varying pressures of ground water at depth. Only the period when surface water existed in the lake and observation well measurements were reliable (August through December 1995) was used for this analysis.

As mentioned in the "Methodology" section, three "nests" were constructed at Sand Lake. Average, minimum, and maximum hydraulic gradients for each nest are listed in Table 7. The sign of the gradient calculation indicates movement in the direction of the well depth sequence. For example, a positive gradient calculated between a comparison of a shallow well to a deep well indicates downward movement of ground water based on the shallow-to-deep sequence. When the calculation of the shallow-to-deep well gradient is negative, upward flow is indicated. Table 7 indicates small, but consistent, gradients from the nested observation wells during the detailed study period. At Nest 1, a slight upward gradient is indicated, meaning that ground water at depth is exerting a small upward pressure influence on the ground water near the land surface. At Nest 2, there is evidence of a noticeable downward gradient. This nest is located on the downward eastern edge of the topographic high near the lake. At this location, the information suggests that shallow ground water is exerting more pressure downward than that of the deeper ground water. At Nest 3, another slight downward gradient is observed.

Sand Lake Observation Well Network

A comparative time-series analysis of water levels in several wells of varying depth throughout the study area can be used to determine the existence and relative importance of a local and/or regional flow system at a location. To identify where local flow systems exist and whether their influence is great, trends of both shallow and deep well ground-water fluctuations can be graphed and compared. The influences of each can be characterized by the dependence or independence of their comparative trends. If the regional flow system is dominant, shallow ground-water fluctuations would reflect the deep ground-water elevational trends. If the local flow system was dominant, the shallower well trends would be synchronous with the lake level but would differ from those of the deep wells.

Control Process II: Discussion

This discussion is organized to answer the three basic questions related to the local and regional flow systems at Sand Lake. To summarize: does a local flow system exist, is there stagnation point development within the local flow system, and does the regional flow system dominate and control the lake?

Table 7. Hydraulic Gradient Calculations from "Nested" Observation Wells

	*Nest 1** *SLOW1 (75 ft) - SLOW2 (35ft) - SLOWS (55 ft)*			*Nest 2*	*Nest 3*
Gradient	*SLOW1/ SLOW2*	*SLOW1/ SLOW3*	*SLOW2/ SLOW3*	*SLOW6(43ft)/ SLOW7 (24 ft)*	*SLOW4 (40ft)/ SLOW5 (20ft)*
Average	-0.0006	-0.0012	-0.0002	0.0339	0.0062
Minimum	0.0002	0.0010	0.0000	0.0174	0.0055
Maximum	0.0007	0.0015	0.0010	0.0516	0.0070
Direction	upward	upward	upward	downward	downward

**Note: ***Hydraulic gradient comparisons of all combinations of the three wells at this site.

Local Flow System Existence

A local ground-water flow system is defined through the identification of elevational highs and shallow ground-water gradients at the site. The topographic high point at which precipitation recharges the water table is termed a "divide," in that water moves in all directions from this point, and its movement is literally being divided into different directions by elevational relief. Typically this is reflected by a "high" in the water table (Fetter, 1994). Table 7 lists ground-water gradients from the nested wells at three locations. These calculations indicate that there is movement of ground water toward Sand Lake from the west (Nest 2) and the east (Nest 3). Consequently, Sand Lake must lie between two divides in a local flow system.

Stagnation Point Existence

When a divide is present, the maximum ground-water elevation at all depths from a piezometer nest located at the divide indicates the existence of a stagnation point. If the ground-water elevation at all depths is greater than the elevation of the lake surface, then conditions are correct for stagnation point development (Fetter, 1994). Table 8 lists ground-water elevation observations from the wells of Nest 2 (SLOW6 and SLOW7) and the lake surface elevation for the detailed study period (August through December 1995). Nest 2 was constructed on the down slope side (eastern) of the topographic high at Sand Lake. SLOW6 and SLOW7 make up this nest and were constructed to depths of 43 ft and 24 ft, respectively.

Comparison of ground-water elevations to lake surface elevations indicates that the lake level was higher than each of the ground-water elevations at all depths during the entire study period. This indicates that conditions were not conducive for stagnation point development and subsequent control at Sand Lake.

Regional Flow System at Sand Lake

The regional flow of ground water in the Havana area was determined by Sanderson and Buck (1995) to be northwest, toward the Illinois River. No direct measurements were conducted to determine ground-water flow directions outside the Sand Lake area in this study. However, ground-water elevational changes from the observation network wells finished at varying depths can be used as indicators of the flow regime at Sand Lake. A combination of time-series ground-water elevation information from several wells of varying depth were analyzed.

Figure 7 shows a time-series of ground-water elevations from four wells, SPOW2, SLOW5, SLOW6, and SLOW1 with atmospheric flux and lake elevations. The wells were finished at depths of 9, 20, 43, and 75 ft, respectively. The trends of these wells throughout the study period indicate similar fluctuations with lake levels in response to atmospheric flux.

Figure 7 shows that wells of each depth located in and around Sand Lake experience similar ground-water elevational trends. Differing trends would indicate local relief control of the lake. There is no evidence of differing shallow and deep trends from the data collected for this study. The similar fluctuations of ground water at all depths during the entire study period indicate that the regional flow system, not the local flow system, is the dominant factor in the existence, persistence, and recession of Sand Lake.

Correlation Analysis

The results calculated for the comparisons between data measurements for ground-water elevations from the four wells and lake level elevations used for time-series analysis are listed in

Table 8. Nest 2 Observation Well Ground-Water and Lake Elevations

Date	*Days from first measurement*	*SLOW6 Ground-water elevation well depth = 43 ft (ft-msl)*	*SLOW7 Ground-water elevation well depth = 24 ft (ft-msl)*	*Observed lake level (ft-msl)*
Aug. 11, 1995	0	476.61	477.39	478.44
Aug. 24, 1995	13	475.68	476.66	478.02
Sept. 19, 1995	39	475.11	475.90	477.15
Oct. 6, 1995	56	474.78	475.46	476.83
Oct. 17, 1995	67	474.48	475.12	476.55
Nov. 1, 1995	82	474.67	475.37	476.57
Nov. 14, 1995	96	474.72	475.34	476.51
Nov. 30, 1995	112	474.70	475.36	476.45
Dec. 15, 1995	127	474.05	474.48	476.28
Dec. 29, 1995	141	473.77	474.25	475.39
Jan. 12, 1996	155	473.57	473.90	475.39

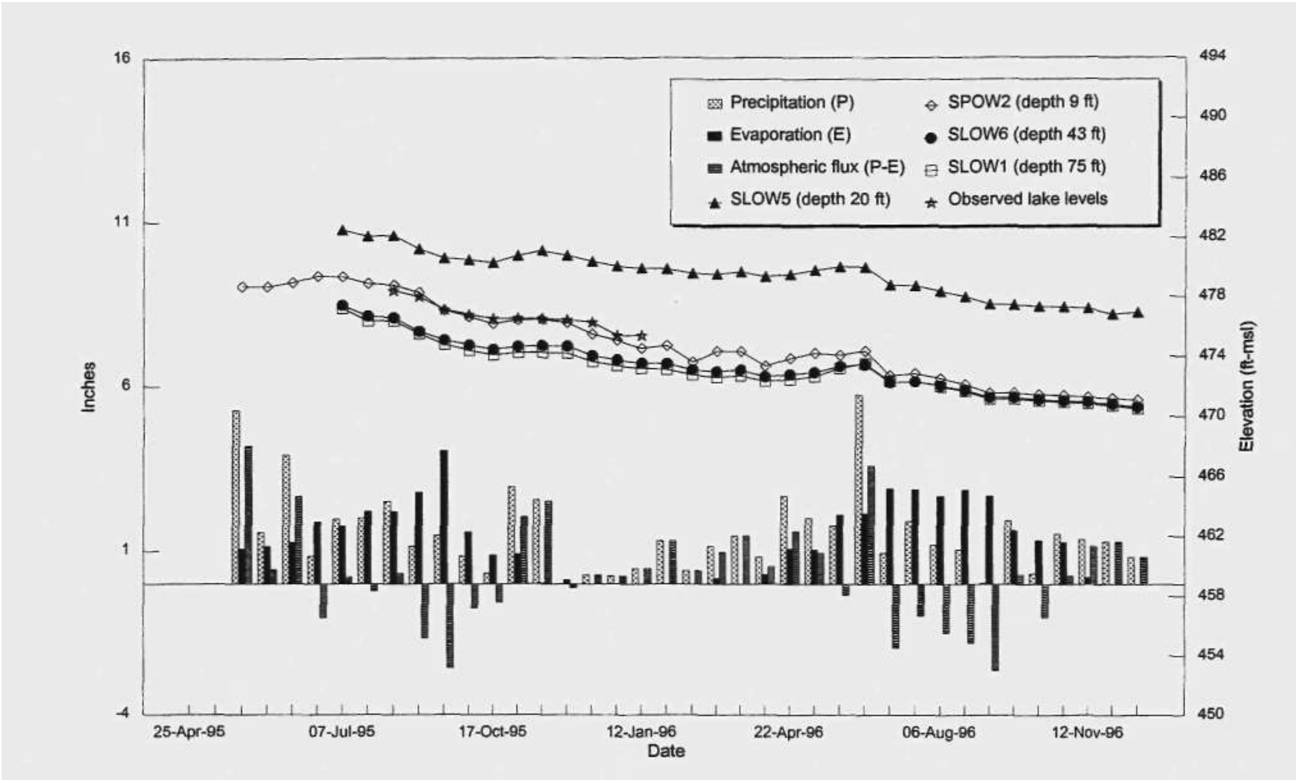


Figure 7. Ground-water elevations from wells of various depths

Table 9. The analysis indicates that all ground-water elevation variables are significantly correlated with one another and with the lake elevation, corroborating the regional flow influence and control at Sand Lake.

Ground-Water Flow Model

Steady State Simulation

Clark (1994) and Davies (1995) developed steady state MODFLOW models (McDonald and Harbaugh, 1988) that included the Sand Lake watershed area of Mason County. Clark (1994) also developed, as a part of his study, a two-dimensional, cross-sectional profile model for the Sand Lake system. Information from these modeling efforts, such as river and stream bed conductance values from Clark's (1994) previous work and general head boundary conductance values from Davies (1995) model, were used as input to develop the initial model runs and test model sensitivity prior to adjustments for final calibration. Model calibration runs were conducted to generate a simulated water table contour map that reasonably replicated the 1992 potentiometric contour map developed by the ISWS from mass measurements taken in the fall of 1992. The water table contour map for the fall of 1992 mass measurement was nearly identical to

Table 9. Pearson's Product-Moment Correlation Analysis for Ground-water Elevations

Variable	*Compared to*	*Correlation coefficient (r)*	*P-value*
SPOW2	Lake elevation	0.9530	O.001*
SPOW2	SLOW5	0.6665	0.035*
SPOW2	SLOW6	0.9269	<0.001*
SPOW2	SLOW1	0.9477	O.001*
SLOW5	Lake elevation	0.7954	0.006*
SPOW5	SPOW6	0.8601	0.001*
SLOW5	SLOW1	0.8252	0.003*
SLOW6	Lake elevation	0.9695	O.001*
SLOW6	SLOW1	0.9932	O.001*
SLOW1	Lake elevation	0.9795	O.001*

Notes: *Indicates significant relationship with 95 percent confidence ($P < 0.05$)
SLOW - Sand Lake Observation Well
SPOW - Sand Point Observation Well

the 1960 water table map by Walker et al. (1965) and, therefore, was assumed to be closely representative of historical steady state conditions.

A three-dimensional contour map of the 1992 mass measurement is shown for the modeled area in Figure 8. This map clearly shows that the Sand Lake wetland complex sits on what can be described as a ground-water ridge. This ridge was described by Clark (1994) as a significant anomaly for the potentiometric surface in the Mason County area. This bulge in the 480 to 490 ft-msl contours could only be replicated by Clark (1994) through model adjustments to areal recharge rates and hydraulic conductivity. Similar model adjustments were required for this study to simulate the ground-water ridge shown in Figure 8. This ridge is even more pronounced in Figures 9 and 10, which depict water table contours developed from the spring and fall of 1993 ISWS mass measurements, respectively. These graphics also show the formation of a significant water table mound located at the upgradient edge of the Sand Lake watershed. The field measurements of the observation well network created for this project corroborate this ridge throughout the project period.

The existence of this ground-water ridge shows that the water table in the area of the Sand Lake wetland complex is influenced significantly by local drainage features. Quiver Creek to the north exerts a significant drawdown affect to the water table in the vicinity of this drainage feature. White Oak Creek exerts a similar but somewhat less significant impact to the water table in its general area. The Illinois River also affects the water table for the portion of the aquifer nearest to the river.

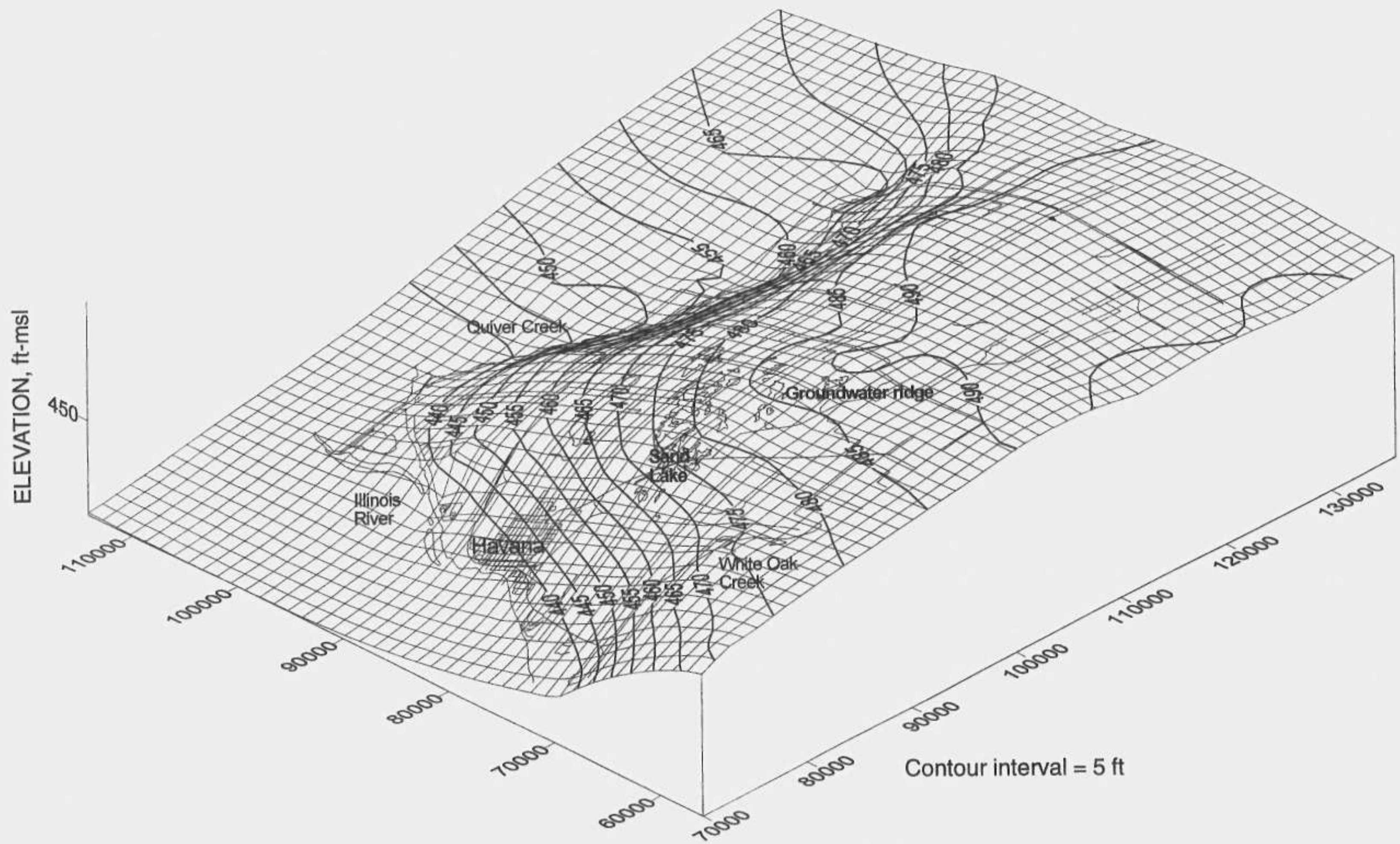


Figure 8. Potentiometric (water table) surface map for fall 1992 ISWS mass measurement
(Adapted from Sanderson and Buck, 1995)

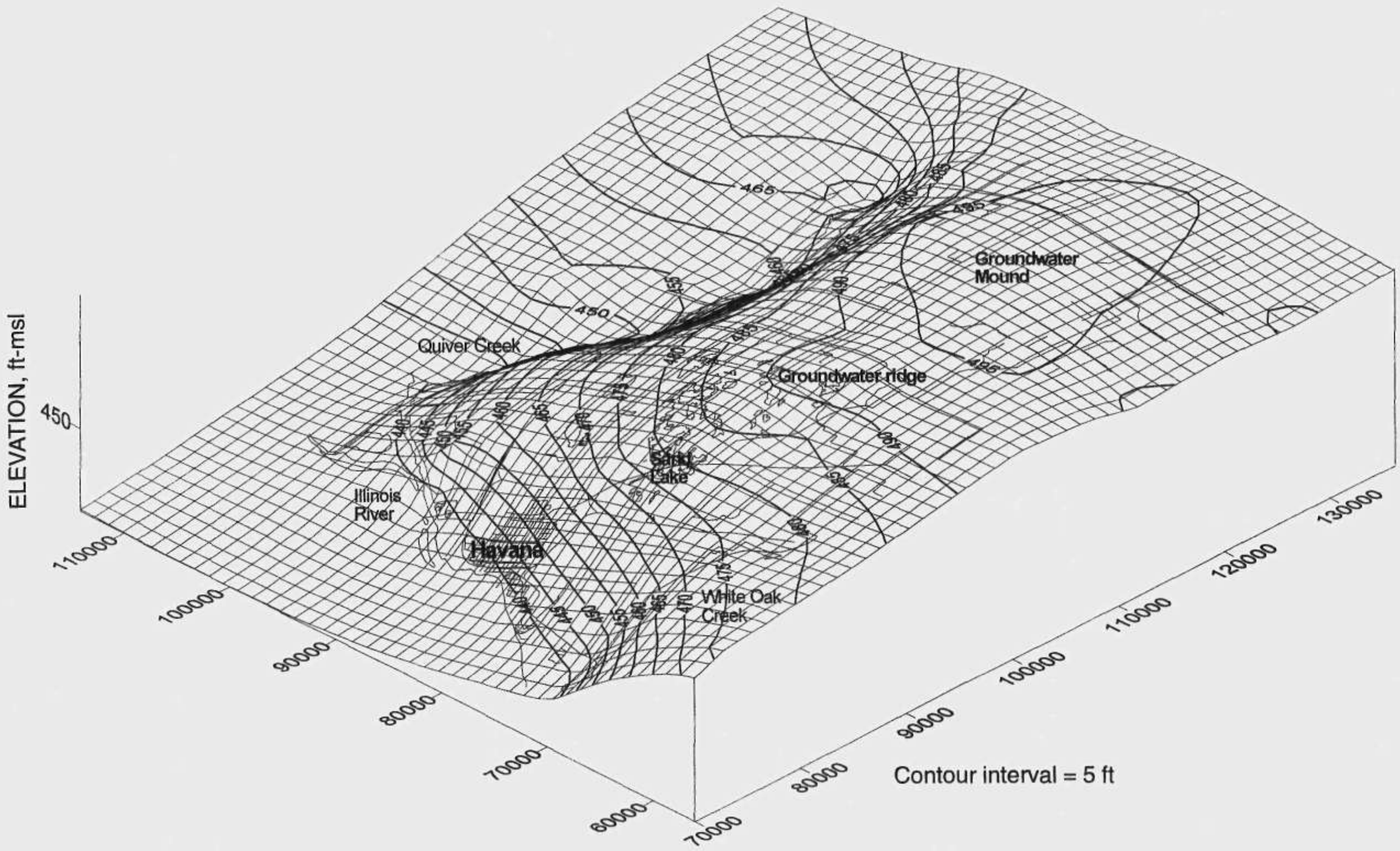


Figure 9. Potentiometric (water table) surface map for spring 1993 ISWS mass measurement
(Adapted from Sanderson and Buck, 1994)

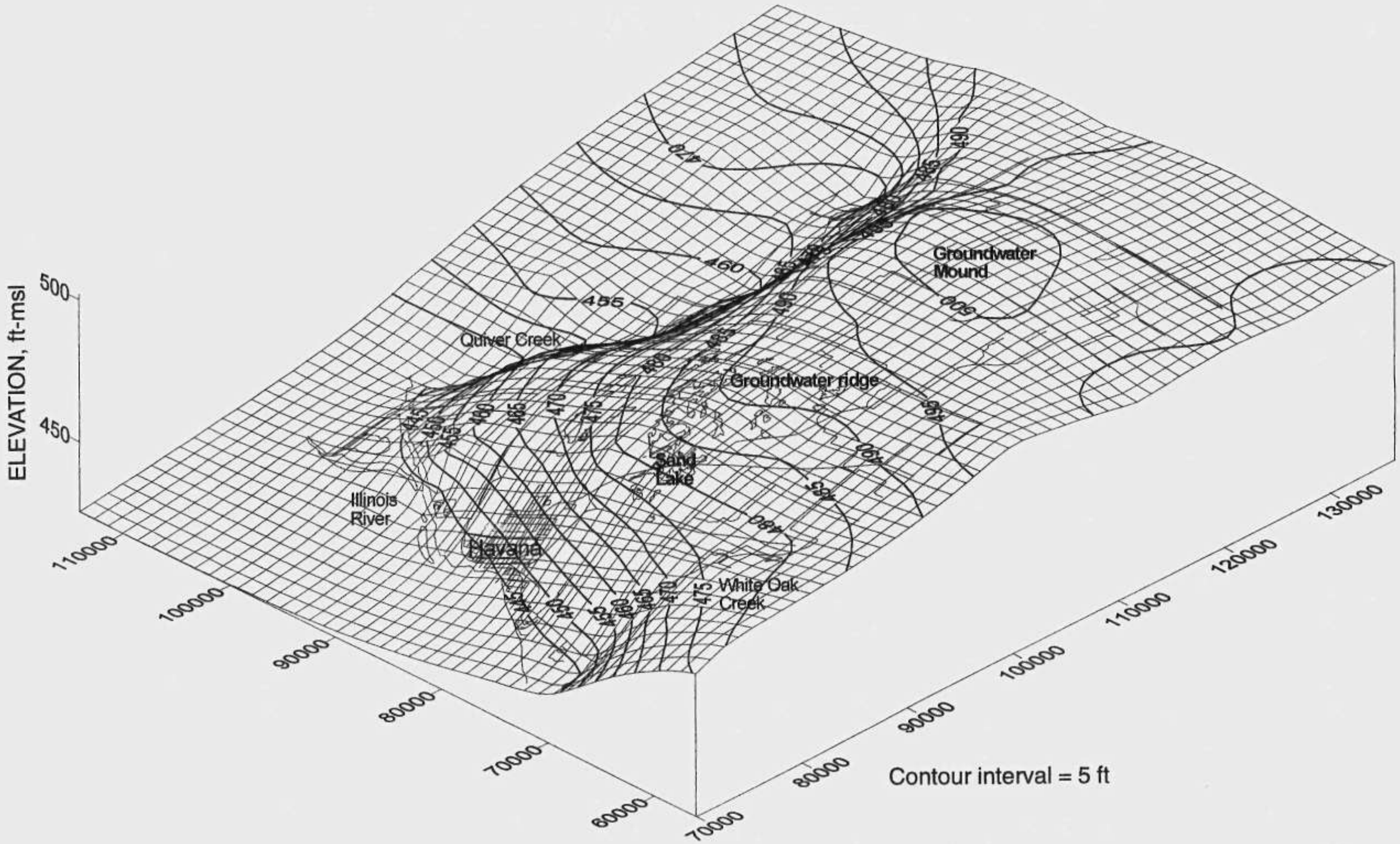


Figure 10. Potentiometric (water table) surface map for the fall (flood) of 1993 ISWS mass measurement (Adapted from Sanderson and Buck, 1994)

Transient Simulations

The transient model was developed by adding data to the basic steady state model for storage coefficients and monthly averaged values for recharge, river stage elevations, and general head boundary elevations. The summer of 1993 was a cool and wet period, so pumpage from irrigation wells in the vicinity of the Sand Lake watershed was assumed to be insignificant and not included in the transient model. Monthly average ground-water elevations developed from transient runs of the single layer model for various locations in the modeled area are listed in Table 10.

The impacts to ground-water elevations caused by the period high river stages that occurred during the flood of 1993 were evaluated by Clark (1994). He found in his regional model that increases in water-table elevations caused by prolonged flood stages in the Illinois River ranged from 2 to 5 ft in the Havana area and generally diminished to less than a few inches at a distance of 5 or more miles from the Illinois River. The single layer model for the Sand Lake watershed also was run in the transient mode for this study to evaluate the impact of the prolonged high river stages that occurred during the flood of 1993. For this comparison, the model was run using river stages that occurred over a period from the fall of 1991 through the fall of 1992. During this time the Illinois River experienced very little flooding, with river stages varying from a low of 429.9 ft-msl to a high of 436.4 ft-msl at the City of Havana. The results from this "low river" model were compared with the model elevations in Table 10. At cell (21,15), ground-water elevations were 1.5 ft lower, and changes in the area of Sand Lake were less than 0.01 ft. Therefore, prolonged high river stages had very little impact on the excessive ground-water flooding that occurred during 1993 in the area of Sand Lake, but high river stages did exacerbate flood problems in the area of Scarborough Estates by approximately 18 inches.

Model Results

The multiple-layered model was used to evaluate a water level management scheme for the Sand Lake complex. Questions were raised at numerous public meetings concerning what the effect high water levels in the area of Sand Lake were having on the flooded areas in the east side of the City of Havana such as Scarborough Estates. Many local citizens assumed that, if the water level of Sand Lake could be lowered by pumping or some other dewatering technique, many of the City of Havana's flood problems would be eliminated or significantly reduced.

To evaluate these concerns, a transient model was developed that incorporated a system of dewatering wells in the 17 cells that cover the main body of Sand Lake. The model was run for the 30-day period that simulated the month of September 1993. The capacity of the pumps was increased until the water level of Sand Lake was reduced to an approximate elevation of 479 ft-msl, which covers the main body of Sand Lake but does not inundate Sand Lake Road. The pumping capacity needed to maintain this lake level during the period of significant flooding required that all 17 pumps operate at a total capacity of 51,000 gallons per minute (gpm) (a rate

Table 10. Ground-Water Elevations from Transient Model Run

Stress period, month/year	*Scarborough Estates entrance (ft) (21,15)**	*Scarborough Lake (ft) (19,19)**	*Sand Lake (ft) (32,26)**
1 - steady state**	458.4	465.6	476.4
2 - Sept. 1992	457.6	464.8	475.5
3 - Oct. 1992	457.0	463.9	474.6
4 - Nov. 1992	459.9	466.7	477.4
5 - Dec. 1992	460.1	467.0	477.5
6 - Jan. 1993	460.9	467.7	478.0
7 - Feb. 1993	460.8	467.5	477.7
8 - Mar. 1993	463.7	470.5	480.3
9 - Apr. 1993	465.6	472.5	480.9
10-May 1993	464.2	471.2	480.2
11-June 1993	463.1	470.0	479.4
12-July 1993	465.2	471.9	480.7
13-Aug. 1993	464.9	471.6	480.4
14-Sept. 1993	467.3.	473.1	481.0
Difference from steady state (ft)	(8.9)	(7.5)	(4.6)

Notes: *model cell location (row, column)
**steady state = starting elevation for model run

of 3,000 gpm per pump). This is equivalent to the total pumping capacity of 48 average size center pivot irrigation systems. Note that the emergency pump acquired by the Soil Conservation Service for the City of Havana during the flood of 1993 had a rated capacity of 3,500 gpm.

With this transient model run, the level of Sand Lake was dropped approximately 3.5 ft at the end of the final stress period, yet the water surface elevation at the entrance to the Scarborough Estates Subdivision remained unchanged. Therefore, a water level management project for Sand Lake would have little or no impact to the other areas in the City of Havana that experienced ground-water flooding during 1993.

The multiple-layer model also was used in the transient mode to determine a local water budget for Sand Lake for the maximum period of flooding during 1993. The transient model for the month of September 1993 was developed and ran to include the zone budget output option from Visual MODFLOW (Guiguer and Franz, 1996). The cells surrounding and including the body of Sand Lake were zoned to allow for an evaluation of the daily inflows and outflows from the lake during September 1993. Figure 11 shows the results of this model. The model showed that the average total daily inflow to Sand Lake is 301,000 cubic ft per day (cfd) (1,564 gpm). Of this amount, daily inflow from precipitation amounted to 144,550 cfd (751 gpm) and daily

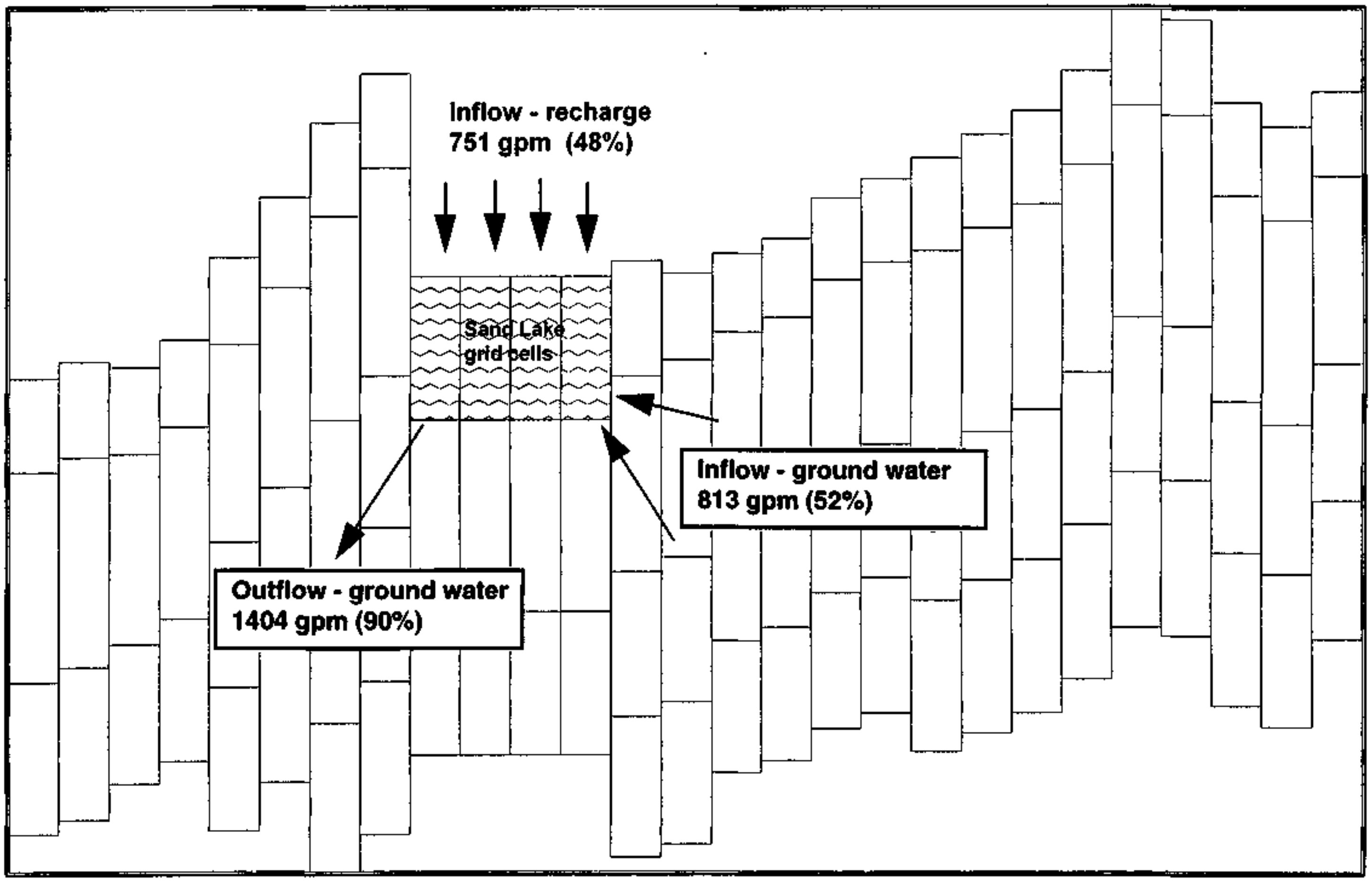


Figure 11. Average daily ground-water inflow and outflow for Sand Lake during September 1993

inflow from adjacent ground-water cells was 156,471 cfd (813 gpm). All ground-water inflow came from the first tier of cells at the upgradient side or littoral zone of the lake. All of the ground-water outflow occurred through the downgradient tier of cells, which indicates that very little, if any, ground-water inflow or outflow occurs through the actual bed of the lake.

The multiple-layer model also was used in simulations that included model runs of Visual MODFLOW (Guiguer and Franz, 1996) in conjunction with the MODPATH® (Guiguer and Franz, 1996) flow path modeling package. Output from the MODPATH® model is shown in Figures 12 and 13. Figure 12 shows output that depicts ground-water flow paths for a cross section through Sand Lake. This figure shows that the maximum extent of the recharge area or zone of capture for Sand Lake is 3.5 miles southeast of the lake. The travel time for ground-water particles to reach Sand Lake from this distance is over 30 years. It also takes approximately 11 years for ground-water particles to reach the Illinois River after leaving Sand Lake. Figure 13 depicts the surface view of ground-water flow paths for Sand Lake as well as Scarborough Estates Subdivision and the ground-water lake located just east of Scarborough Estates.

Sand Lake appears to occur in one of the deeper depressional areas and persists in part due to the fact that the local water table must decline over 6 ft for the lake system to recede. Sand Lake is located at an apparent change in the regional ground-water gradients. Gradients measured by ESE (1993), Sanderson and Buck (1995), and Clark (1994) show a clear break in ground-water gradients in the vicinity of Sand Lake. Gradients are clearly steeper on the downgradient side of Sand Lake than on the upgradient side (see Figures 10 and 12). The steeper gradients can be attributed to the change in aquifer properties near the Illinois River, such as reduced aquifer thickness and lower values of hydraulic conductivity, which together retard the flow of ground water to this outflow boundary. On the upgradient side of Sand Lake, Clark (1994) identified some of the highest regional values for hydraulic conductivity as well as the highest values for aquifer recharge rates. The combination of these factors should result in Sand Lake having a relatively greater ability to receive ground-water inflow on its upgradient side with a retarding effect on ground-water outflow on its downgradient side. The spacing of the flow lines generated with the Visual MODFLOW (Guiguer and Franz, 1996) model tend to represent this type of flow system.

Control Process II: Conclusions

The analyses of the hydrologic information that constitute the flow regime at Sand Lake as well as the results of the flow model indicate that both a local and regional flow system exist at the lake. Within the local flow system, the data indicate that conditions were not conducive for stagnation point development. The quantitative analysis of vertical movement (hydraulic gradient) did show movement in the downslope direction from the east and west toward Sand Lake; however, this movement can be attributed to the natural movement of water controlled by the local flow system forces of an elevational high. The "high" located to the east of the lake was

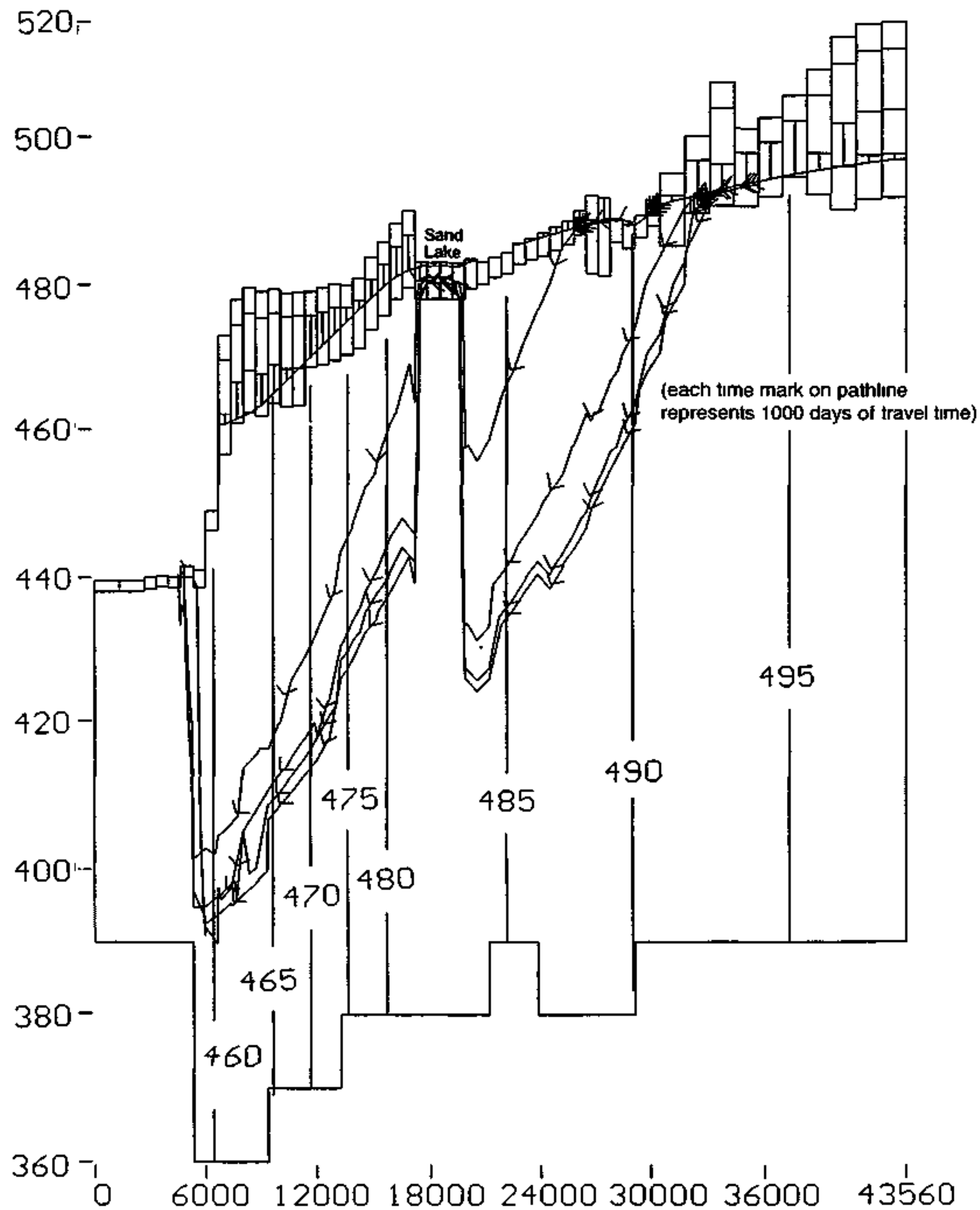


Figure 12. MODPATH® simulated ground-water flow paths for a cross section through Sand Lake

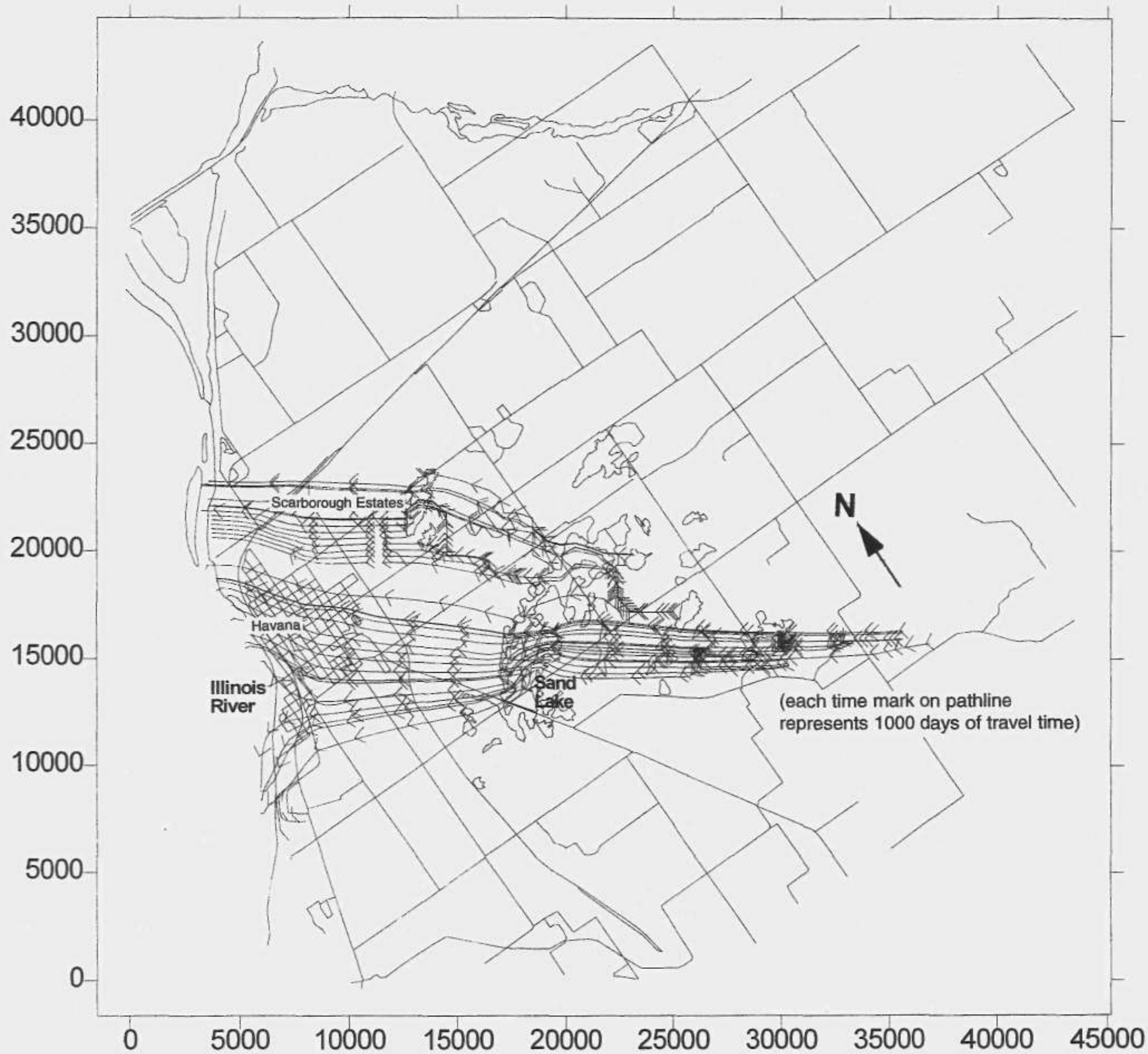


Figure 13. Surface view of MODPATH® simulated ground-water flow paths for Sand Lake as well as Scarborough Estates subdivision and ground-water lake located just east of Scarborough Estates

evident in the model simulations that used past mass-measurement water levels (Sanderson and Buck, 1995). The local flow system gradients attributed to these highs play only a minor role in the lake hydrology.

The time-series graph of ground-water elevations for wells of different depths shows similar fluctuations throughout the entire ground-water realm. Shallow and deep wells fluctuate similarly in response to precipitation events and only decline at slightly varying rates because of the different soil characteristics of the lakebed. The correlation analysis corroborates the significant relationship of ground-water levels at all depths in and around Sand Lake. A significant relationship between each well with the lake elevation also exists. This indicates that the regional system is the dominant influence on Sand Lake's existence, persistence, and recession.

The GPS elevational information collected for this study indicates that the bottom of Sand Lake is an elevational low point in this area. When regional ground-water elevations are high, ground water moves into the lake from its eastern edge where a minimum amount of silt is present and hydraulic conductivity values are high. This water fills the lower elevations and creates Sand Lake. The lake's persistence is partially due to the build up of silt and organic matter within the lakebed, but mostly due to the elevation of the ground water under the lake and its inability to move quickly toward the Illinois River. The reduced aquifer thickness and lower hydraulic conductivity values on the downgradient or outward flow boundary cause a damming effect of ground water on the western edge of the area toward the Illinois River. When regional ground-water levels decline below the bottom of the lake, surface water seepage begins and Sand Lake starts to recede. In fact, at the start of this project, ground-water levels were almost identical to the lake level. During the early part of the project, these levels fell below the lake bottom, and lake levels receded correspondingly. It is likely that, had ground-water measurements been taken around Sand Lake during 1994, they would have been above the bottom of the lakebed elevation. All the observation well information collected and the model results of the ground-water flow regime for Sand Lake corroborate a regional ground-water flow influence.

PROJECT CONCLUSIONS AND RECOMMENDATIONS

The following are conclusions of the analyses performed for this study. The conclusions are broken down into two components: conclusions concerning the existence, persistence, and recession of the lake, and recommendations to mitigate future catastrophic flooding events.

Sand Lake Existence, Persistence, and Recession

Sand Lake is a unique feature in the Havana region. Local residents indicate it exists less than half of the time and believe it is the cause of flooding problems for this area. In all of the folk-lore and news reports created about Sand Lake, one thing seems clear: it appears when there is substantial rainfall and subsequent flooding throughout the area. The analyses of the data for this study show a natural hydrologic situation at Sand Lake. Ground water forms a smoothed reflection of the land surface curvature under the major geologic structures (elevational highs), and the lake declines when ground-water elevations under it decline. This decline is slowed because of the accumulated silt and organic matter within the upper soil matrix at the lake; however, it also is very short-lived and is not responsible for the persistence of the lake. This lake, because of its low elevation in the area, is a barometer for regional ground-water elevations.

Many months of heavy precipitation during the summer and fall of 1993 throughout the entire Mississippi and Illinois River watersheds set up unusually high surface and ground-water levels in much of western Illinois. Sand Lake once again came to exist because of this influx of water. It persisted because regional ground-water elevations continued to be high, and it declined only when regional ground-water elevations were below its lakebed. There is evidence that this decline is slowed due to the soil make-up of the lake bottom sediments; however, the lag is short and does not constitute a major factor in the lake's existence.

The 1993 flood event was unprecedented in modern history. When compared to all other past floods, it differs by being larger in areal extent, larger in magnitude, longer in duration, greater in volume of floodwater, greater in amount of damage produced, and by occurring at a different time of year than normal flood events, i.e., summer rather than spring or fall (Changnon et al., 1996). Because of its enormity, Sand Lake's existence was inevitable. The lake persisted as long as ground-water elevations throughout the entire region were above the lakebed elevation. Other flooded areas near Sand Lake also maintained high surface water levels after the 1993 flood. Its recession was initiated when ground-water levels fell below the lakebed at the start of this study. Sand Lake finally disappeared in December 1995.

Most engineers and hydrologists who have studied the excessive flooding that occurred in Mason County during 1993 (ESE, 1993; Clark, 1994; Sanderson and Buck, 1995; Visocky, 1995) have postulated that the flood conditions occurred because the aquifer system simply received recharge exceeding its discharge capacity such that the water table rose above the ground surface in depressional areas that normally are dry. Furthermore, lack of a natural or artificial drainage system resulted in the formulation of numerous lakes that persisted for many months until the water table was able to decline to a level below the land surface. This postulation is corroborated by the field measurement program implemented at Sand Lake from 1995 through 1996.

Sand Lake Management

Because the flooding event in this region was catastrophic, the flooding at Sand Lake could not have been prevented. Currently, road levels around the lake are at an elevation that will, most likely, never be reached by another flood. However, although the likelihood of this type of event occurring again may be small, it always is possible. Steps in roadway elevation increases have already been taken in this area, which should ensure minimal disruption to transportation roadways by any future flooding events. Because Sand Lake is an elevational low in this area, future flooding is sure to occur. The most permanent measure that could be taken to lessen future flooding impacts would be to ensure that the overflow caused by excessive surface water ponding in the area has a mechanism for discharge into the Illinois River. In 1993, ground water rose above the land surface and became surface water. It flowed around the elevational high on the east end of Sand Lake. Water then moved north toward the City of Havana until it reached the railroad levee, approximately 1 mile northwest of the lake. Several discharge conduits were drilled through the levee to alleviate the ponded water. The development of a mechanism for movement of this overflow of water to the Illinois River prior to its emergence during the next major rainfall event would alleviate the enormity of the impact felt during 1993 through 1995 from this phenomenon and could potentially keep Sand Lake to a certain acceptable elevation.

The localized flooding problems caused by the high water levels of Sand Lake during the flood of 1993 could be ameliorated through the use of temporary pumping systems similar to those used during the flood of 1993. The flood of 1993 was estimated by Visocky (1995) as a 250-year event; therefore, flood problems of the magnitude experienced during 1993 are a rare occurrence. Events of this nature are usually best handled in consideration of effectiveness and economics through an emergency response program. A temporary pumping system set up along the railroad grade west of Sand Lake should be deployed as a means to pump accumulated overflow from the Sand Lake system. Local interests operated a system of this type for a number of weeks following the flood of 1993 and used the emergency pumping equipment acquired by the City of Havana. Flood water was pumped and diverted to the Illinois River through a temporary pipeline from an area referred to as Walker Lake by ESE (1993) in their engineering study conducted for the city and county to evaluate flood control options for Sand Lake. The area identified as Walker Lake is a low lying area that naturally collects high level overflow from the Sand Lake area watershed. Locating the temporary pumping system at the Walker Lake area allows the flood water storage capacity of this area to effectively reduce the pumping capacity needed to manage and reduce high lake levels in the area of Sand Lake. A system of two pumps with a capacity of 3,500 gpm per pump should be able to effectively manage the estimated quantities of ground-water inflow and resulting overflow from the Sand Lake system.

The transient ground-water model was applied to determine the capacity needed to lower Sand Lake by direct pumping over a 30-day period. The estimated pumping capacity required to directly lower Sand Lake 2 ft from its peak level of 1993 would require a pumping capacity of over 35,000 gpm over a 30-day period. Of this amount, over 20,000 gpm would be required over 30 days to directly pump an amount of water equal to the upper 2 ft of the lake volume. An additional pumping capacity of 14,000 gpm is required to handle direct and induced ground-water inflow to the lake system at its lowered elevation. This clearly indicates that a pumping system in or around Sand Lake will not effectively manage the volume of water that accumulates at this location during major rainfall events. The most cost-effective measure that could be taken to lessen future flooding impacts would be to ensure that the overflow of surface water from Sand Lake has a mechanism (pumping system, conduit, etc.) for discharge into the Illinois River.

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Appendix A. Sand Lake Monitoring Network: Raw Data and Water Level Hydrographs

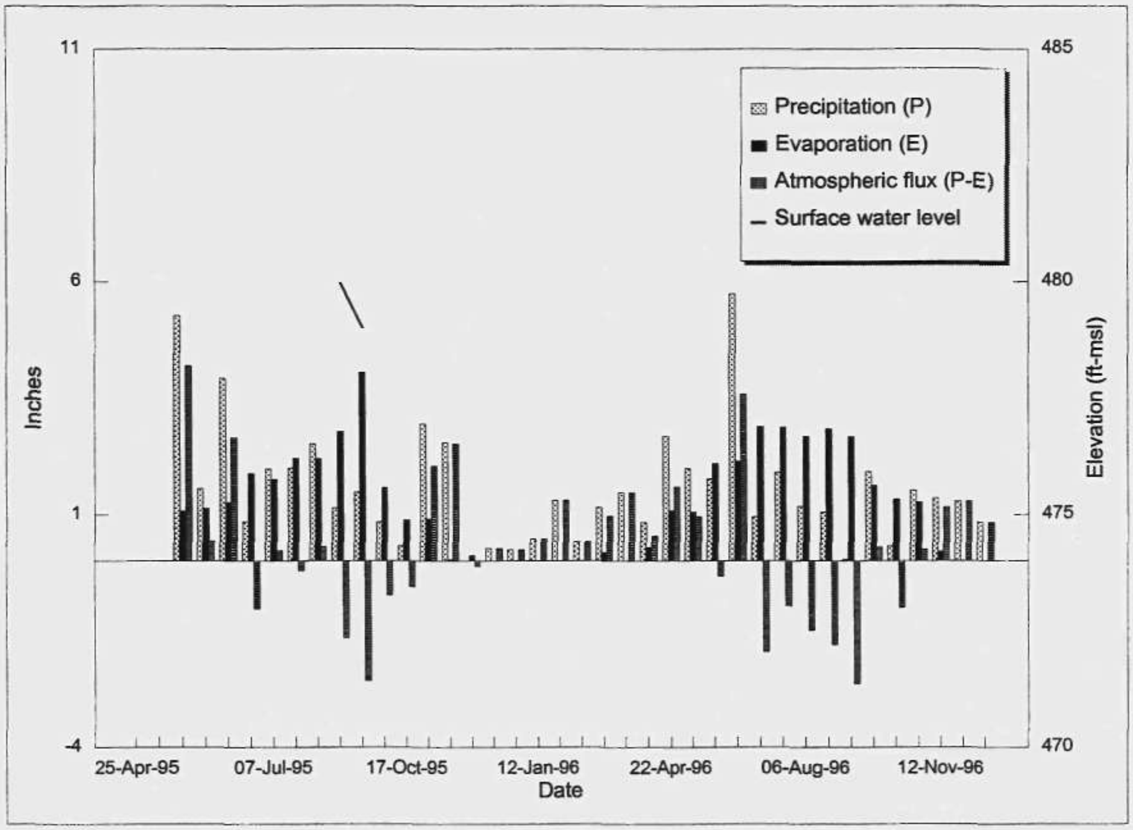
Appendix A.

Staff Gauge No. 1 (SG1) - Raw Data

Date	*Average precipitation (P) (in.)*	*Estimated evaporation (E) (in)*	*Atmospheric flux (P-E) (in.)*	*Surface water elevation (ft-msl)*
25-Apr-95				
0l-May-95				
17-May-95	5.27	1.07	4.20	
22-May-95	1.56	1.13	0.43	
0l-Jun-95	3.92	1.26	2.66	
26-Jun-95	0.85	1.88	-1.03	
07-Jul-95	1.98	1.76	0.22	
25-Jul-95	2.00	2.21	-0.21	
11-Aug-95	2.51	2.20	0.31	
24-Aug-95	1.14	2.79	-1.65	479.97
19-Sep-95	1.48	4.05	-2.57	479.00
06-Oct-95	0.84	1.58	-0.74	
17-Oct-95	0.32	0.88	-0.56	
0l-Nov-95	2.95	0.91	2.04	
14-Nov-95	2.55	0.03	2.52	
30-Nov-95	0.00	0.12	-0.12	
15-Dec-95	0.27	0.00	0.27	
29-Dec-95	0.24	0.00	0.24	
12-Jan-96	0.47	0.00	0.47	
25-Jan-96	1.31	0.00	1.31	
09-Feb-96	0.41	0.00	0.41	
29-Feb-96	1.15	0.18	0.97	
15-Mar-96	1.47	0.00	1.47	
10-Apr-96	0.83	0.29	0.54	
22-Apr-96	2.68	1.08	1.60	
08-May-96	2.00	1.05	0.95	
20-May-96	1.77	2 10	-0.33	
19-Jun-96	5.74	2.15	3.59	
12-Jul-96	0.95	2.90	-1.95	
22-Jul-96	1.91	2.88	-0.97	
06-Aug-96	1.18	2.68	-1.50	
21-Aug-96	1.05	2.85	-1.80	
12-Sep-96	0.04	2.68	-2.64	
0l-Oct-96	1.93	1.63	0.30	
15-Oct-96	0.32	1.33	-1.01	
30-Oct-96	1.52	1.27	0.25	
12-Nov-96	1.36	0.20	1.16	
03-Dec-96	1.29	0.00	1.29	
08-Jan-97	0.83	0.00	0.83	

Appendix A. Continued

Staff Gauge No. 1 (SG1)



Land surface elevation = 476.92 ft-msl
Top of gauge (21.5 ft), elevation 481.51 ft-msl

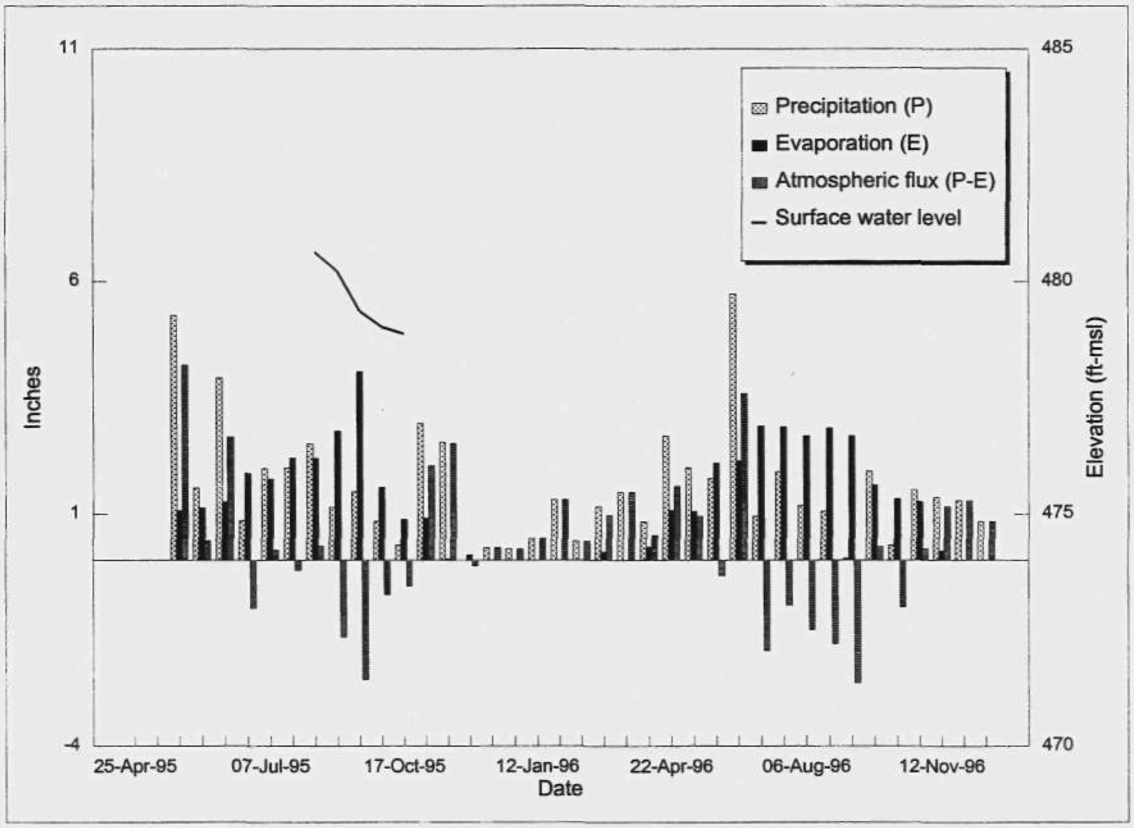
Appendix A. Continued

Staff Gauge No. 2 (SG2) - Raw Data

Date	*Average precipitation (P) (in)*	*Estimated evaporation (E) (in)*	*Atmospheric flux (P-E) (in)*	*Surface water elevation (ft-msl)*
25-Apr-95				
0l-May-95				
17-May-95	5.27	1.07	4.20	
22-May-95	1.56	1.13	0.43	
0l-Jun-95	3.92	1.26	2.66	
26-Jun-95	0.85	1.88	-1.03	
07-Jun-95	1.98	1.76	0.22	
25-Jul-95	2.00	2.21	-0.21	
11-Aug-95	2.51	2.20	0.31	480.63
24-Aug-95	1.14	2.79	-1.65	480.22
19-Sep-95	1.48	4.05	-2.57	479.36
06-Oct-95	0.84	1.58	-0.74	479.02
17-Oct-95	0.32	0.88	-0.56	478.87
0l-Nov-95	2.95	0.91	2.04	
14-Nov-95	2.55	0.03	2.52	
30-Nov-95	0.00	0.12	-0.12	
15-Dec-95	0.27	0.00	0.27	
29-Dec-95	0.24	0.00	0.24	
12-Jan-96	0.47	0.00	0.47	
25-Jan-96	1.31	0.00	1.31	
09-Feb-96	0.41	0.00	0.41	
29-Feb-96	1.15	0.18	0.97	
15-Mar-96	1.47	0.00	1.47	
10-Apr-96	0.83	0.29	0.54	
22-Apr-96	2.68	1.08	1.60	
08-May-96	2.00	1.05	0.95	
20-May-96	1.77	2.10	-0.33	
19-Jun-96	5.74	2.15	3.59	
12-Jul-96	0.95	2.90	-1.95	
22-Jul-96	1.91	2.88	-0.97	
06-Aug-96	1.18	2.68	-1.50	
21-Aug-96	1.05	2.85	-1.80	
12-Sep-96	0.04	2.68	-2.64	
0l-Oct-96	1.93	1.63	0.30	
15-Oct-96	0.32	1.33	-1.01	
30-Oct-96	1.52	1.27	0.25	
12-Nov-96	1.36	0.20	1.16	
03-Dec-96	1.29	0.00	1.29	
08-Jan-97	0.83	0.00	0.83	

Appendix A. Continued

Staff Gauge No. 2 (SG2)



Land surface elevation = 478.65 ft-msl
Top of gauge (25.0 ft), elevation 482.62 ft-msl

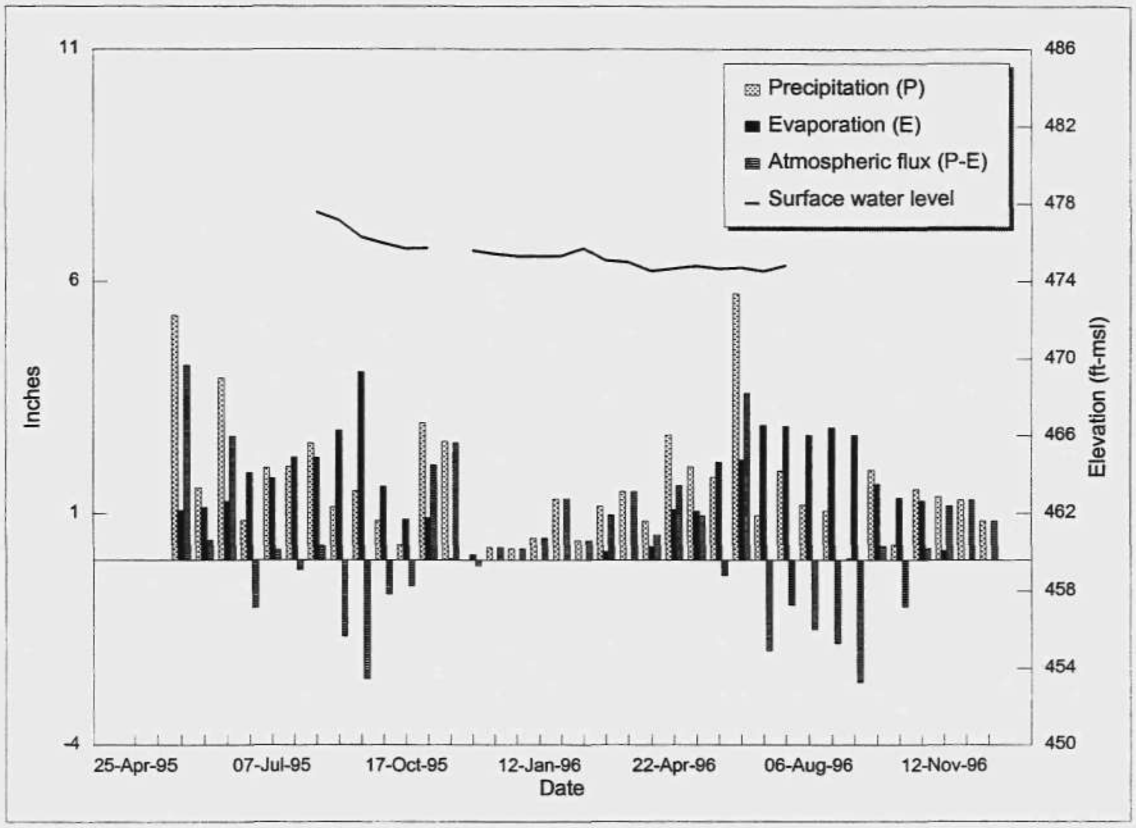
Appendix A. Continued

Staff Gauge No. 3 (SG3) - Raw Data

Date	*Average precipitation (P) (in.)*	*Estimated evaporation (E) (in.)*	*Atmospheric flux (P-E) (in.)*	*Surface water elevation (ft-msl)*
25-Apr-95				
0l-May-95				
17-May-95	5.27	1.07	4.20	
22-May-95	1.56	1.13	0.43	
01-Jun-95	3.92	1.26	2.66	
26-Jun-95	0.85	1.88	-1.03	
07-Jul-95	1.98	1.76	0.22	
25-Jul-95	2.00	2.21	-0.21	
11-Aug-95	2.51	2.20	0.31	477.58
24-Aug-95	1.14	2.79	-1.65	477.16
19-Sep-95	1.48	4.05	-2.57	476.29
06-Oct-95	0.84	1.58	-0.74	475.97
17-Oct-95	0.32	0.88	-0.56	475.69
0l-Nov-95	2.95	0.91	2.04	475.71
14-Nov-95	2.55	0.03	2.52	
30-Nov-95	0.00	0.12	-0.12	475.59
15-Dec-95	0.27	0.00	0.27	475.42
29-Dec-95	0.24	0.00	0.24	475.31
12-Jan-96	0.47	0.00	0.47	475.31
25-Jan-96	1.31	0.00	1.31	475.31
09-Feb-96	0.41	0.00	0.41	475.70
29-Feb-96	1.15	0 18	0.97	475.08
15-Mar-96	1.47	0.00	1.47	474.99
10-Apr-96	0.83	0.29	0.54	474.53
22-Apr-96	2.68	1.08	1.60	474.66
08-May-96	2.00	1.05	0.95	474.80
20-May-96	1.77	2.10	-0.33	474.65
19-Jun-96	5.74	2.15	3.59	474.72
12-Jul-96	0.95	2.90	-1.95	474.53
22-Jul-96	1.91	2.88	-0.97	474.83
06-Aug-96	1.18	2.68	-1.50	
21-Aug-96	1.05	2.85	-1.80	
12-Sep-96	0.04	2.68	-2.64	
0l-Oct-96	1.93	1.63	0.30	
15-Oct-96	0.32	1.33	-1.01	
30-Oct-96	1.52	1.27	0.25	
12-Nov-96	1.36	0.20	1.16	
03-Dec-96	1.29	0.00	1.29	
08-Jan-97	0.83	0.00	0.83	

Appendix A. Continued

Staff Gauge No.3 (SG3)



Land surface elevation = 474.53 ft-msl
Top of gauge (6.66 ft), elevation 479.37 ft-msl

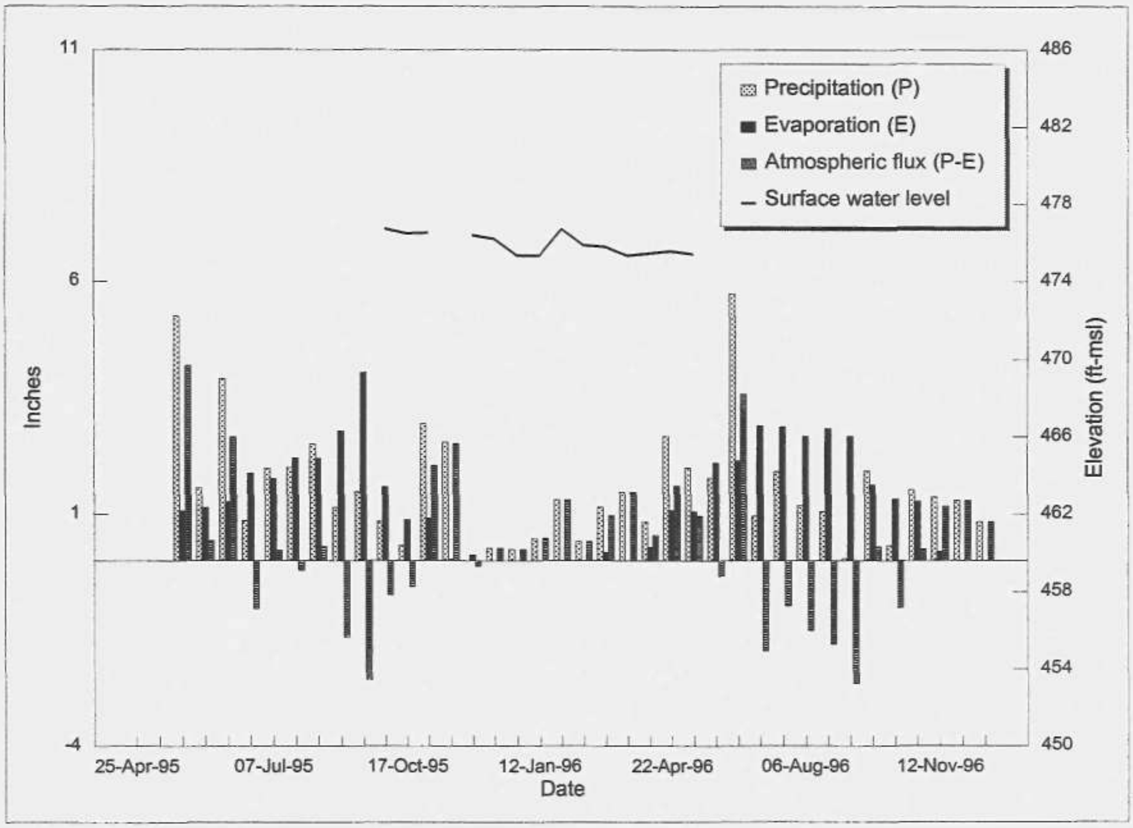
Appendix A. Continued

Staff Gauge No. 4 (SG4) - Raw Data

Date	*Average precipitation (P) (in.)*	*Estimated evaporation (E) (in)*	*Atmospheric flux (P-E) (in.)*	*Surface water elevation (ft-msl)*
25-Apr-95				
0l-May-95				
17-May-95	5.27	1.07	4.20	
22-May-95	1.56	1.13	0.43	
01-Jun-95	3.92	1.26	2.66	
26-Jun-95	0.85	1.88	-1.03	
07-Jul-95	1.98	1.76	0.22	
25-Jul-95	2.00	2.21	-0.21	
11-Aug-95	2.51	2.20	0.31	
24-Aug-95	1.14	2.79	-1.65	
19-Sep-95	1.48	4.05	-2.57	
06-Oct-95	0.84	1.58	-0.74	476.72
17-Oct-95	0.32	0.88	-0.56	476.48
0l-Nov-95	2.95	0.91	2.04	476.50
14-Nov-95	2 55	0.03	2.52	
30-Nov-95	0.00	0.12	-0.12	476.39
15-Dec-95	0.27	0.00	0.27	476.21
29-Dec-95	0.24	0.00	0.24	475.34
12-Jan-96	0.47	0.00	0.47	475.34
25-Jan-96	1.31	0.00	1.31	476.69
09-Feb-96	0.41	0.00	0.41	475.88
29-Feb-96	1.15	0.18	0.97	475.79
15-Mar-96	1.47	0 00	1.47	475.34
10-Apr-96	0.83	0.29	0.54	475.46
22-Apr-96	2.68	1.08	1.60	475.58
08-May-96	2.00	1.05	0.95	475.44
20-May-96	1.77	2.10	-0.33	
19-Jun-96	5.74	2.15	3.59	
12-Jul-96	0.95	2.90	-1.95	
22-Jul-96	1.91	2.88	-0.97	
06-Aug-96	1.18	2.68	-1.50	
21-Aug-96	1.05	2.85	-1.80	
12-Sep-96	0.04	2.68	-2.64	
01-Oct-96	1.93	1.63	0.30	
15-Oct-96	0.32	1.33	-1.01	
30-Oct-96	1.52	1.27	0.25	
12-Nov-96	1.36	0.20	1.16	
03-Dec-96	1.29	0.00	1.29	
08-Jan-97	0.83	0.00	0.83	

Appendix A. Continued

Staff Gauge No. 4 (SG4)



Land surface elevation = 475.34 ft-msl
Top of gauge (6.66 ft), elevation 477.36 ft-msl

Appendix A. Continued

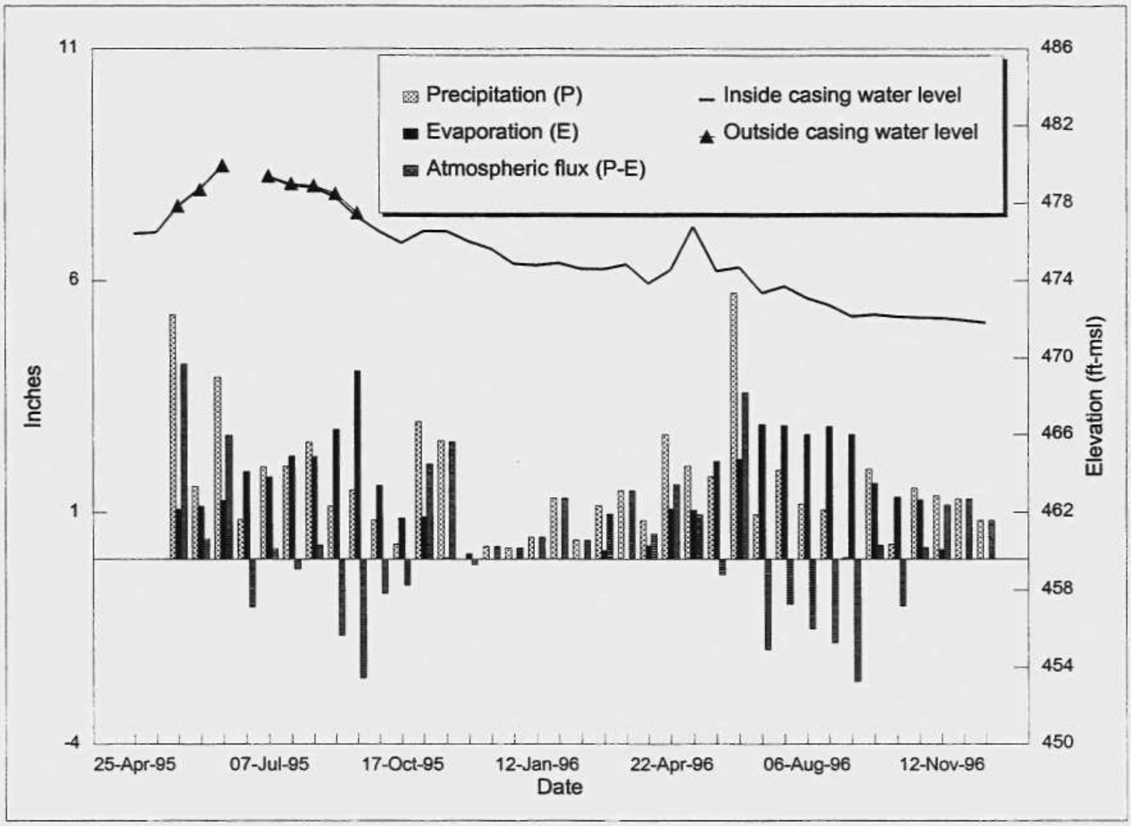
Sand Point Observation Well No. 1 (SPOW1) - Raw Data

Date	*Average precipitation (P) (in)*	*Estimated evaporation (E) (in.)*	*Atmospheric flux (P-E) (in.)*	*Ground-water elevation (inside) (ft-msl)*	*Ground-water elevation (outside) (ft-msl)*
25-Apr-95				476.43	
0l-May-95				476.49	
17-May-95	5.27	1.07	4.20	477.86	477.86
22-May-95	1.56	1.13	0.43	478.74	478.69
0l-Jun-95	3.92	1.26	2.66	479.93	479.93
26-Jun-95	0.85	1.88	-1.03		
07-Jul-95	1.98	1.76	0.22	479.35	479.38
25-Jul-95	2.00	2.21	-0.21	478.92	479.00
11-Aug-95	2.51	2.20	0.31	478.81	478.91
24-Aug-95	1.14	2.79	-1.65	478.30	478.48
19-Sep-95	1.48	4.05	-2.57	477.29	477.50
06-Oct-95	0.84	1.58	-0.74	476.54	
17-Oct-95	0.32	0.88	-0.56	475.94	
0l-Nov-95	2.95	0.91	2.04	476.55	
14-Nov-95	2.55	0.03	2.52	476.56	
30-Nov-95	0.00	0.12	-0.12	476.02	
15-Dec-95	0.27	0.00	0.27	475.64	
29-Dec-95	0.24	0.00	0.24	474.89	
12-Jan-96	0.47	0.00	0.47	474.80	
25-Jan-96	1.31	0.00	1.31	474.92	
09-Feb-96	0.41	0.00	0.41	474.61	
29-Feb-96	1.15	0.18	0.97	474.62	
15-Mar-96	1.47	0.00	1.47	474.85	
10-Apr-96	0.83	0.29	0.54	473.88	
22-Apr-96	2.68	1.08	1.60	474.56	
08-May-96	2.00	1.05	0.95	476.78	
20-May-96	1.77	2.10	-0.33	474.51	
19-Jun-96	5.74	2.15	3.59	474.69	
12-Jul-96	0.95	2.90	-1.95	473.38	
22-Jul-96	1.91	2.88	-0.97	473.73	
06-Aug-96	1.18	2.68	-1.50	473.11	
21-Aug-96	1.05	2.85	-1.80	472.75	
12-Sep-96	0.04	2.68	-2.64	472.16	
0l-Oct-96	1.93	1.63	0.30	472.26	
15-Oct-96	0.32	1.33	-1.01	472.15	
30-Oct-96	1.52	1.27	0.25	472.10	
12-Nov-96	1.36	0.20	1.16	472.09	
03-Dec-96	1.29	0.00	1.29	471.98	
08-Jan-97	0.83	0.00	0.83	471.84	

Note: Lambert X = 868894.6383, Lambert Y = 804298.7356

Appendix A. Continued

Sand Point Observation Well No. 1 (SPOW1)



Land surface elevation = 476.86 ft-msl
Measuring point elevation = 480.86 ft-msl

Appendix A. Continued

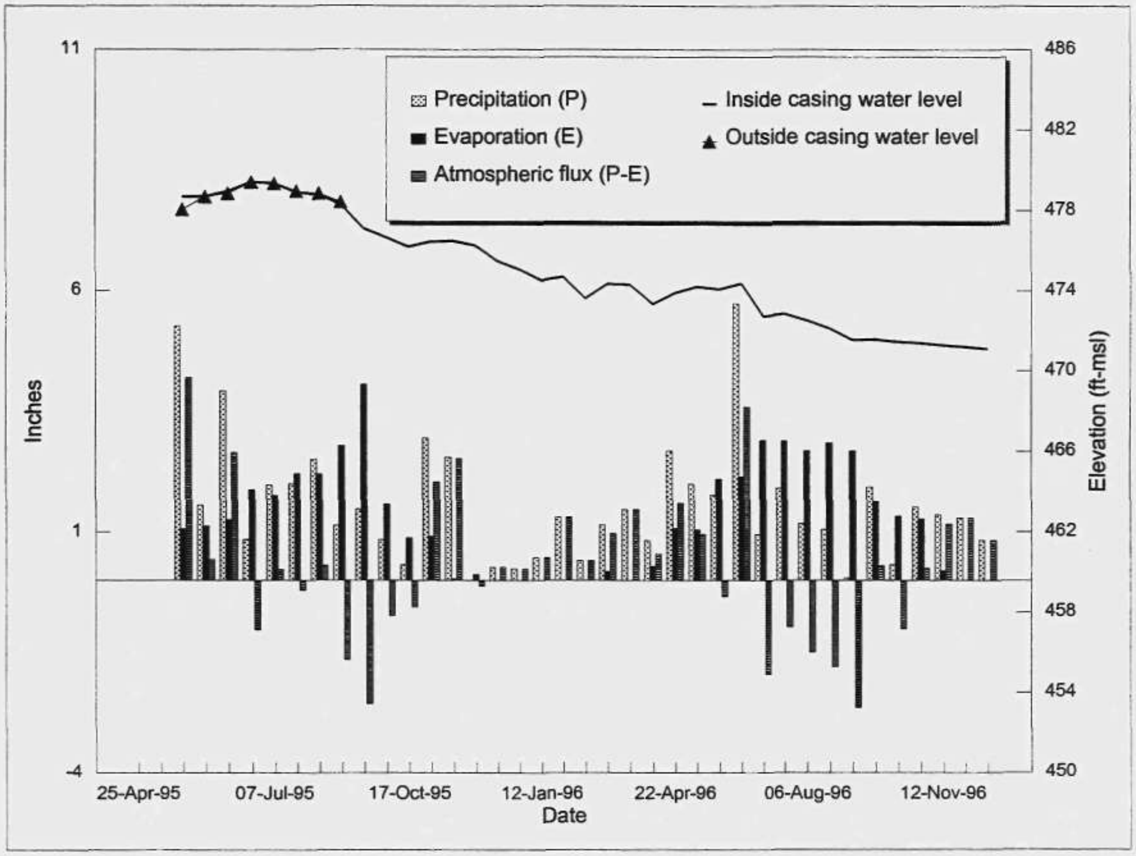
Sand Point Observation Well No. 2 (SPOW2) - Raw Data

Date	*Average precipitation (P) (in.)*	*Estimated evaporation (E) (in.)*	*Atmospheric flux (P-E) (in.)*	*Ground-water elevation inside (ft-msl)*	*Ground-water elevation outside (ft-msl)*
25-Apr-95					
0l-May-95					
17-May-95	5.27	1.07	4.20	478.70	478.07
22-May-95	1.56	1.13	0.43	478.70	478.70
01-Jun-95	3.92	1.26	2.66	478.97	478.87
26-Jun-95	0.85	1.88	-1.03	479.41	479.41
07-Jul-95	1.98	1.76	0.22	479.35	479.36
25-Jul-95	2.00	2.21	-0.21	478.92	478.98
11-Aug-95	2.51	2.20	0.31	478.81	478.86
24-Aug-95	1.14	2.79	-1.65	478.31	478.44
19-Sep-95	1.48	4.05	-2.57	477.11	
06-Oct-95	0.84	1.58	-0.74	476.66	
17-Oct-95	0.32	0.88	-0.56	476.20	
0l-Nov-95	2.95	0.91	2.04	476.46	
14-Nov-95	2.55	0.03	2.52	476.49	
30-Nov-95	0.00	0.12	-0.12	476.27	
15-Dec-95	0.27	0.00	0.27	475.50	
29-Dec-95	0.24	0.00	0.24	475.09	
12-Jan-96	0.47	0.00	0.47	474.54	
25-Jan-96	1.31	0.00	1.31	474.71	
09-Feb-96	0.41	0.00	0.41	473.63	
29-Feb-96	1.15	0.18	0.97	474.36	
15-Mar-96	1.47	0.00	1.47	474.32	
10-Apr-96	0.83	0.29	0.54	473.36	
22-Apr-96	2.68	1.08	1.60	473.89	
08-May-96	2.00	1.05	0.95	474.21	
20-May-96	1.77	2.10	-0.33	474.09	
19-Jun-96	5.74	2.15	3.59	474.37	
12-Jul-96	0.95	2.90	-1.95	472.74	
22-Jul-96	1.91	2.88	-0 97	472.87	
06-Aug-96	1.18	2.68	-1.50	472.54	
21-Aug-96	1.05	2.85	-1.80	472.13	
12-Sep-96	0.04	2.68	-2.64	471.56	
0l-Oct-96	1.93	1.63	0.30	471.58	
15-Oct-96	0.32	1.33	-1.01	471.46	
30-Oct-96	1.52	1.27	0.25	471.41	
12-Nov-96	1.36	0.20	1.16	471.30	
03-Dec-96	1.29	0.00	1.29	471.21	
08-Jan-97	0.83	0.00	0.83	471.11	

Note: Lambert X = 868952.4854, Lambert Y = 804690.2764

Appendix A. Continued

Sand Point Observation Well No. 2 (SPOW2)



Land surface elevation = 481.37 ft-msl
Measuring point elevation = 484.87 ft-msl

Appendix A. Continued

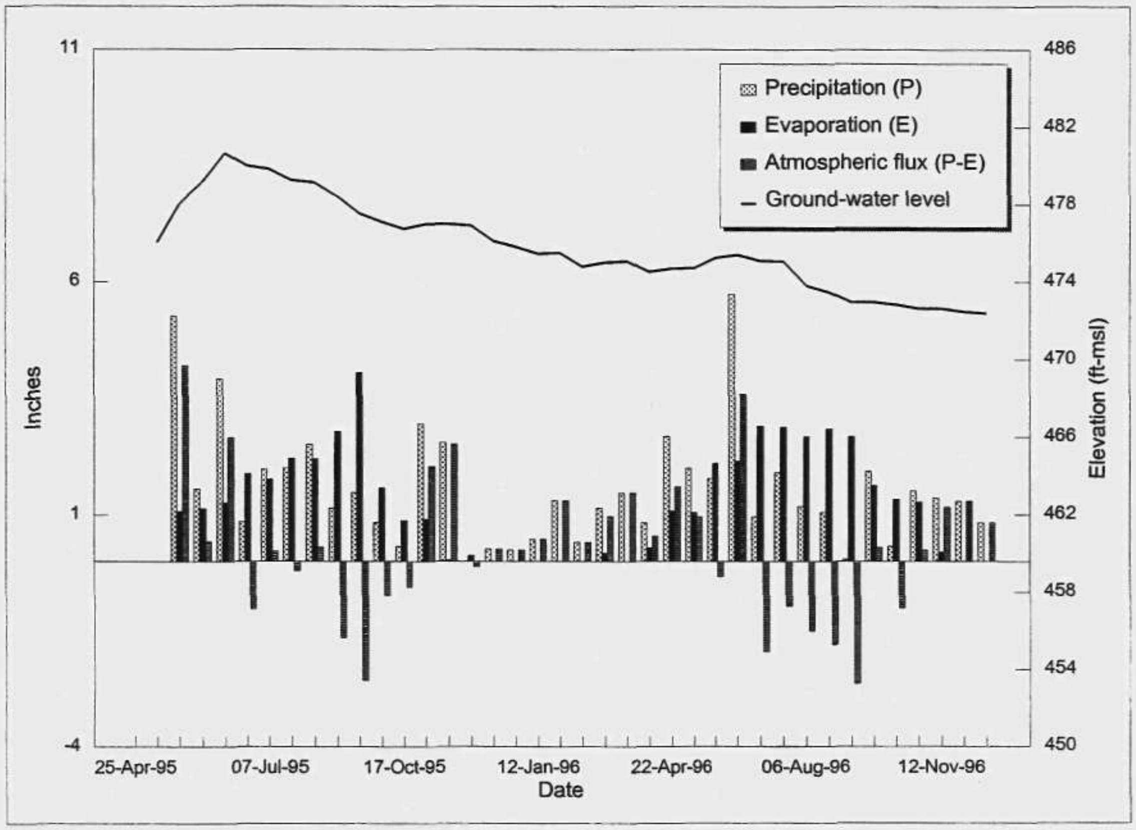
Sand Point Observation Well No. 3 (SPOW3) - Raw Data

Date	*Average precipitation (P) (in.)*	*Estimated evaporation (E) (in)*	*Atmospheric flux (P-E) (in.)*	*Ground-water elevation inside (ft-msl)*
25-Apr-95				
0l-May-95				476.06
17-May-95	5.27	1.07	4.20	478.05
22-May-95	1.56	1.13	0.43	479.15
0l-Jun-95	3.92	1.26	2.66	480.66
26-Jun-95	0.85	1.88	-1.03	480.01
07-Jul-95	1.98	1.76	0.22	479.84
25-Jul-95	2.00	2.21	-0.21	479.26
11-Aug-95	2.51	2.20	0.31	479.14
24-Aug-95	1.14	2.79	-1.65	478.43
19-Sep-95	1.48	4.05	-2.57	477.54
06-Oct-95	0.84	1.58	-0.74	477.10
17-Oct-95	0.32	0.88	-0.56	476.74
0l-Nov-95	2.95	0.91	2.04	477.00
14-Nov-95	2.55	0.03	2.52	476.99
30-Nov-95	0.00	0.12	-0.12	476.92
15-Dec-95	0.27	0.00	0.27	476.13
29-Dec-95	0.24	0.00	0.24	475.83
12-Jan-96	0.47	0.00	0.47	475.47
25-Jan-96	1.31	0.00	1.31	475.52
09-Feb-96	0.41	0.00	0.41	474.81
29-Feb-96	1.15	0.18	0.97	475.01
15-Mar-96	1.47	0.00	1.47	475.08
10-Apr-96	0.83	0.29	0.54	474.53
22-Apr-96	2.68	1.08	1.60	474.71
08-May-96	2.00	1.05	0.95	474.72
20-May-96	1.77	2.10	-0.33	475.25
19-Jun-96	5.74	2.15	3.59	475.42
12-Jul-96	0.95	2.90	-1.95	475.10
22-Jul-96	1.91	2.88	-0.97	475.09
06-Aug-96	1.18	2.68	-1.50	473.82
21-Aug-96	1.05	2.85	-1.80	473.48
12-Sep-96	0.04	2.68	-2.64	472.96
0l-Oct-96	1.93	1.63	0.30	472.96
15-Oct-96	0.32	1.33	-1.01	472.84
30-Oct-96	1.52	1.27	0.25	472.65
12-Nov-96	1.36	0.20	1.16	472.64
03-Dec-96	1.29	0.00	1.29	472.47
08-Jan-97	0.83	0.00	0.83	472.40

Note: Lambert X = 868902.3753, Lambert Y = 804671.5390

Appendix A. Continued

Sand Point Observation Well No. 3 (SPOW3)



Land surface elevation = 490.00 ft-msl
Measuring point elevation = 487.70 ft-msl

Appendix A. Continued

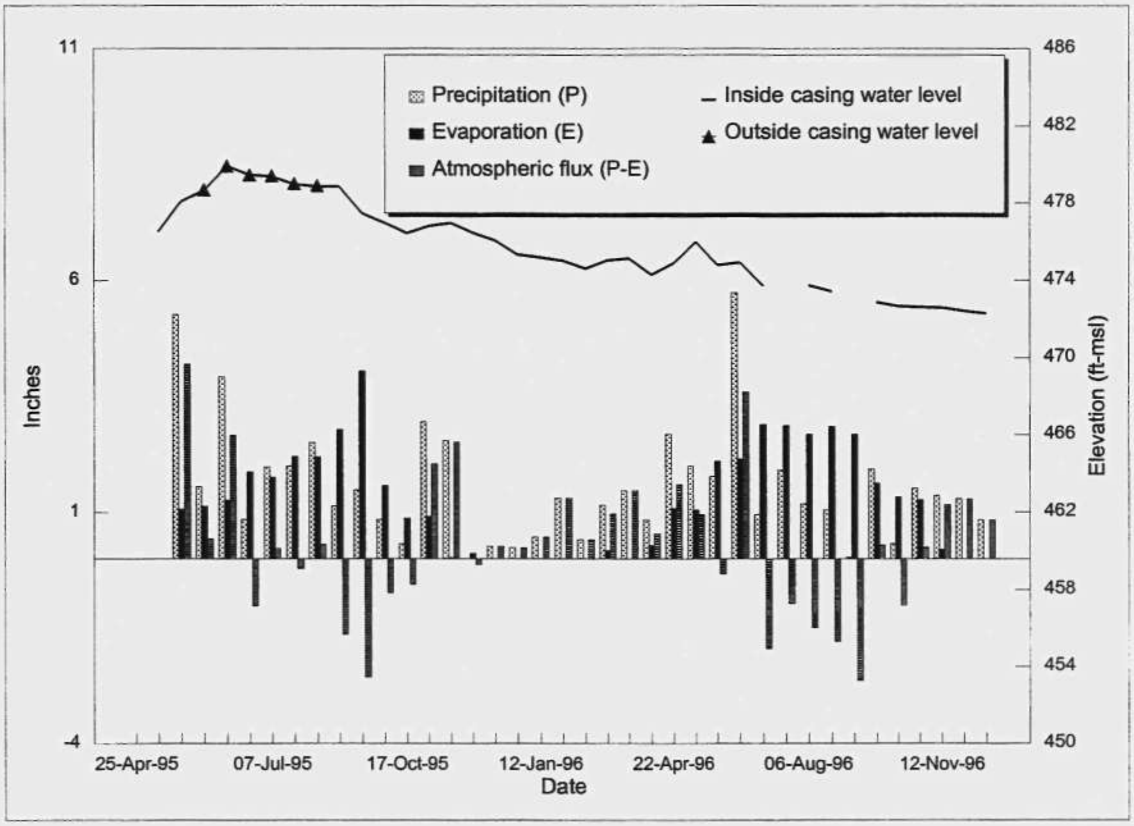
Sand Point Observation Well No. 4 (SPOW4) - Raw Data

Date	*Average precipitation (P) (in.)*	*Estimated evaporation (E) (in.)*	*Atmospheric flux (P-E) (in.)*	*Ground-water elevation inside (ft-msl)*	*Ground-water elevation outside (ft-msl)*
25-Apr-95					
0l-May-95				476.54	
17-May-95	5.27	1.07	4.20	478.09	
22-May-95	1.56	1.13	0.43	478.65	478.68
0l-Jun-95	3.92	1.26	2.66	479.91	479.91
26-Jun-95	0.85	1.88	-1.03	479.45	479.45
07-Jul-95	1.98	1.76	0.22	479.37	479.39
25-Jul-95	2.00	2.21	-0.21	478.96	479.00
11-Aug-95	2.51	2.20	0.31	478.85	478.91
24-Aug-95	1.14	2.79	-1.65	478.84	
19-Sep-95	1.48	4.05	-2.57	477.46	
06-Oct-95	0.84	1.58	-0.74	476.97	
17-Oct-95	0.32	0.88	-0.56	476.44	
0l-Nov-95	2.95	0.91	2.04	476.80	
14-Nov-95	2.55	0.03	2.52	476.96	
30-Nov-95	0.00	0.12	-0.12	476.47	
15-Dec-95	0.27	0.00	0.27	476.06	
29-Dec-95	0.24	0.00	0.24	475.34	
12-Jan-96	0.47	0.00	0.47	475.19	
25-Jan-96	1.31	0.00	1.31	475.02	
09-Feb-96	0.41	0.00	0.41	474.61	
29-Feb-96	1.15	0.18	0.97	475.04	
15-Mar-96	1.47	0.00	1.47	475.14	
10-Apr-96	0.83	0.29	0.54	474.30	
22-Apr-96	2.68	1.08	1.60	474.90	
08-May-96	2.00	1.05	0.95	476.00	
20-May-96	1.77	2.10	-0.33	474.79	
19-Jun-96	5.74	2.15	3.59	474.93	
12-Jul-96	0.95	2.90	-1.95	473.72	
22-Jul-96	1.91	2.88	-0.97		
06-Aug-96	1.18	2.68	-1.50	473.75	
21-Aug-96	1.05	2.85	-1.80	473.44	
12-Sep-96	0.04	2.68	-2.64		
0l-Oct-96	1.93	1.63	0.30	472.88	
15-Oct-96	0.32	1.33	-1.01	472.68	
30-Oct-96	1.52	1.27	0.25	472.62	
12-Nov-96	1.36	0.20	1.16	472.59	
03-Dec-96	1.29	0.00	1.29	472.43	
08-Jan-97	0.83	0.00	0.83	472.30	

Note: Lambert X = 869333.1559, Lambert Y = 804999.8529

Appendix A. Continued

Sand Point Observation Well No. 4 (SPOW4)



Land surface elevation = 478.61 ft-msl
Measuring point elevation = 480.91 ft-msl

Appendix A. Continued

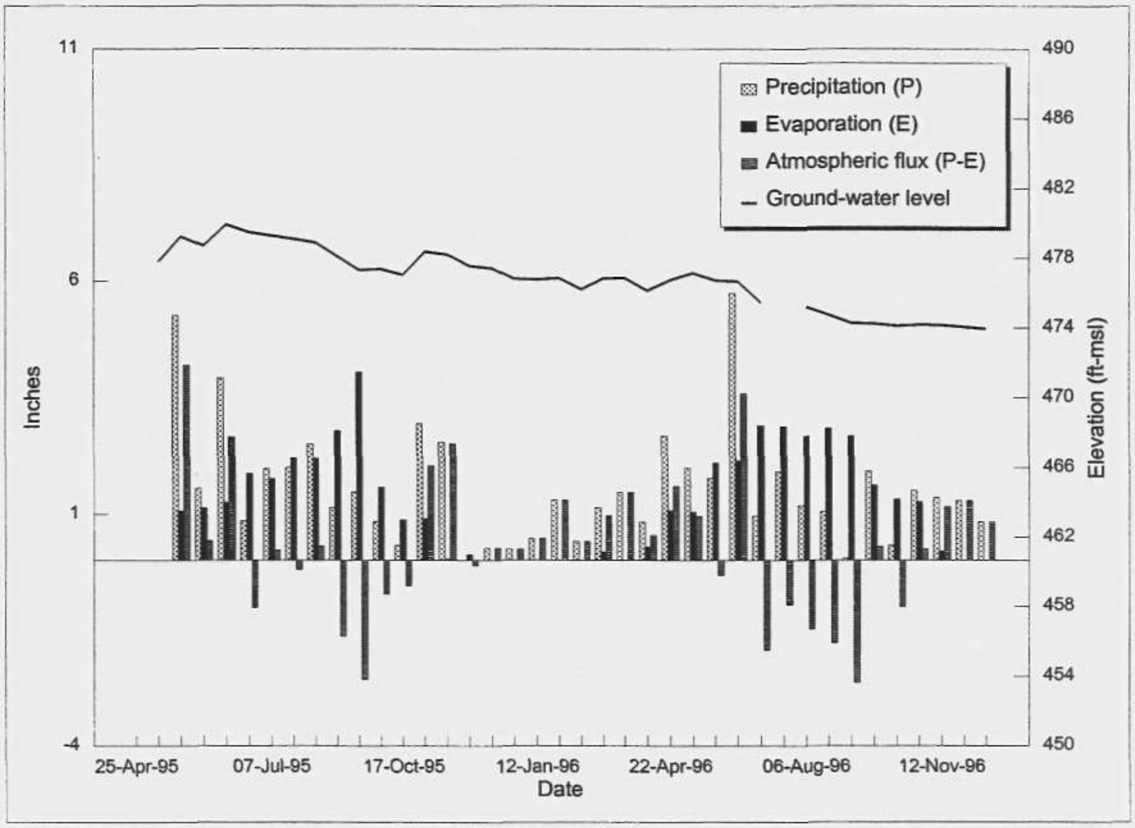
Sand Point Observation Well No. 5 (SPOW5) - Raw Data

Date	*Average precipitation (P) (in.)*	*Estimated evaporation (E) (in.)*	*Atmospheric flux (P-E) (in.)*	*Ground-water elevation inside (ft-msl)*
25-Apr-95				
0l-May-95				477.81
17-May-95	5.27	1.07	4.20	479.25
22-May-95	1.56	1.13	0.43	478.71
01-Jun-95	3.92	1.26	2.66	479.92
26-Jun-95	0.85	1.88	-1.03	479.49
07-Jul-95	1.98	1.76	0.22	479.28
25-Jul-95	2.00	2.21	-0.21	479.10
11-Aug-95	2.51	2.20	0.31	478.90
24-Aug-95	1.14	2.79	-1.65	478.10
19-Sep-95	1.48	4.05	-2.57	477.31
06-Oct-95	0.84	1.58	-0.74	477.38
17-Oct-95	0.32	0.88	-0.56	477.04
0l-Nov-95	2.95	0.91	2.04	478.39
14-Nov-95	2.55	0.03	2.52	478.22
30-Nov-95	0.00	0.12	-0.12	477.57
15-Dec-95	0.27	0.00	0.27	477.43
29-Dec-95	0.24	0.00	0.24	476.82
12-Jan-96	0.47	0.00	0.47	476.76
25-Jan-96	1.31	0.00	1.31	476.87
09-Feb-96	0.41	0.00	0.41	476.21
29-Feb-96	1.15	0.18	0.97	476.84
15-Mar-96	1.47	0.00	1.47	476.87
10-Apr-96	0.83	0.29	0.54	476.14
22-Apr-96	2.68	1.08	1.60	476.74
08-May-96	2.00	1.05	0.95	477.15
20-May-96	1.77	2.10	-0.33	476 73
19-Jun-96	5.74	2.15	3.59	476.68
12-Jul-96	0.95	2.90	-1.95	475.45
22-M-96	1.91	2.88	-0.97	
06-Aug-96	1.18	2.68	-1.50	475.18
21-Aug-96	1.05	2.85	-1.80	474.75
12-Sep-96	0.04	2.68	-2.64	474.28
01-Oct-96	1.93	1.63	0.30	474.26
15-Oct-96	0.32	1.33	-1.01	474.13
30-Oct-96	1.52	1.27	0.25	474.18
12-Nov-96	1.36	0.20	1.16	474.15
03-Dec-96	1.29	0.00	1.29	474.05
08-Jan-97	0.83	0.00	0.83	473.95

Note: Lambert X = 869517.5912, Lambert Y = 804694.8154

Appendix A. Continued

Sand Point Observation Well No. 5 (SPOW5)



Land surface elevation = 481.31 ft-msl
Measuring point elevation = 483.51 ft-msl

Appendix A. Continued

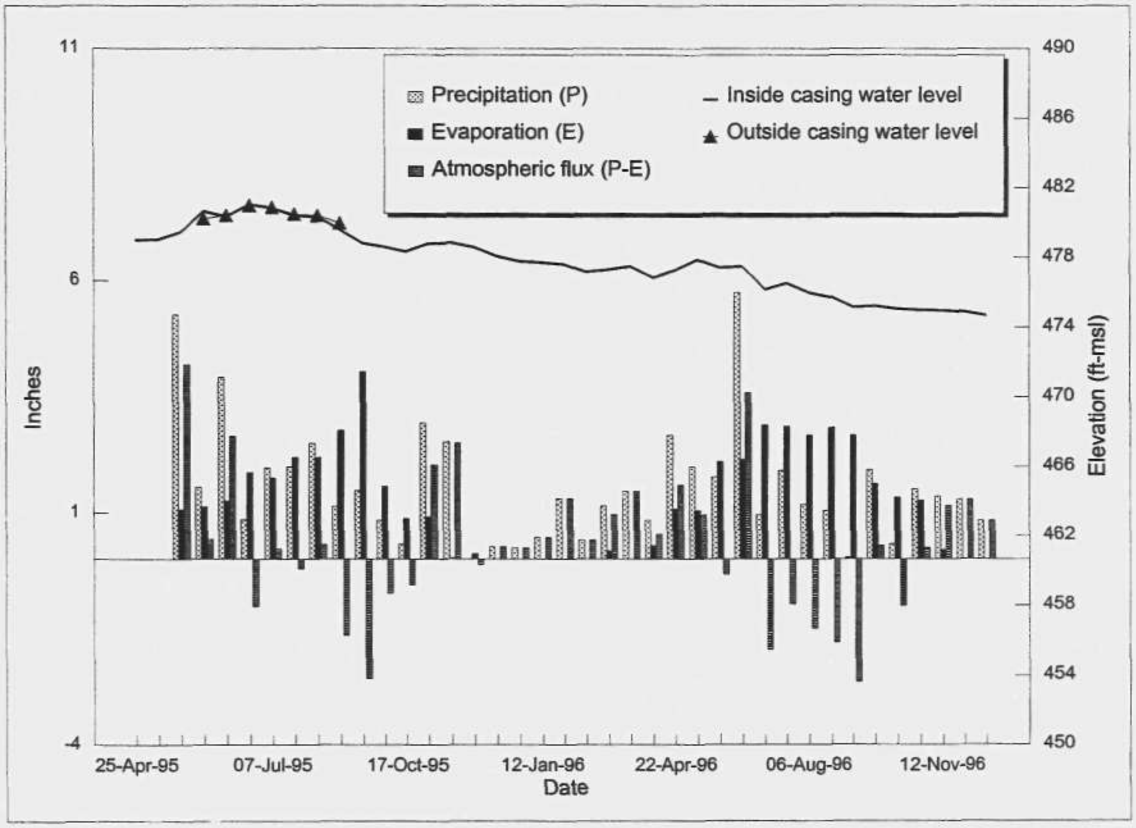
Sand Point Observation Well No. 6 (SPOW6) - Raw Data

Date	*Average precipitation (P) (in.)*	*Estimated evaporation (E) (in.)*	*Atmospheric flux (P-E) (in)*	*Ground-water elevation inside (ft-msl)*	*Ground-water elevation outside (ft-msl)*
25-Apr-95				479.00	
0l-May-95				479.02	
17-May-95	5.27	1.07	4.20	479.44	
22-May-95	1.56	1.13	0.43	480.63	480.22
01-Jun-95	3.92	1.26	2.66	480.32	480.40
26-Jun-95	0.85	1.88	-1.03	481.02	480.97
07-Jul-95	1.98	1.76	0.22	480.85	480.88
25-Jul-95	2.00	2.21	-0.21	480.39	480.49
11-Aug-95	2.51	2.20	0.31	480.33	480.39
24-Aug-95	1.14	2.79	-1.65	479.57	479.96
19-Sep-95	1.48	4.05	-2.57	478.80	
06-Oct-95	0.84	1.58	-0.74	478.60	
17-Oct-95	0.32	0.88	-0.56	478.32	
0l-Nov-95	2.95	0.91	2.04	478.79	
14-Nov-95	2.55	0.03	2.52	478.84	
30-Nov-95	0.00	0.12	-0.12	478.58	
15-Dec-95	0.27	0.00	0.27	478.07	
29-Dec-95	0.24	0.00	0.24	477.77	
12-Jan-96	0.47	0.00	0.47	477.69	
25-Jan-96	1.31	0.00	1.31	477.60	
09-Feb-96	0.41	0.00	0.41	477.16	
29-Feb-96	1.15	0.18	0.97	477.29	
15-Mar-96	1.47	0.00	1.47	477.47	
10-Apr-96	0.83	0.29	0.54	476.83	
22-Apr-96	2.68	1.08	1.60	477.25	
08-May-96	2.00	1.05	0.95	477.86	
20-May-96	1.77	2.10	-0.33	477.40	
19-Jun-96	5.74	2.15	3.59	477.47	
12-Jul-96	0.95	2.90	-1.95	476.15	
22-Jul-96	1.91	2.88	-0.97	476.51	
06-Aug-96	1.18	2.68	-1.50	475.97	
21-Aug-96	1.05	2.85	-1.80	475.71	
12-Sep-96	0.04	2.68	-2.64	475.15	
01-Oct-96	1.93	1.63	0.30	475.21	
15-Oct-96	0.32	1.33	-1.01	475.05	
30-Oct-96	1.52	1.27	0.25	474.99	
12-Nov-96	1.36	0.20	1.16	474.96	
03-Dec-96	1.29	0.00	1.29	474.88	
08-Jan-97	0.83	0.00	0.83	474.68	

Note: Lambert X = 869347.8699, Lambert Y = 804595.7097

Appendix A. Continued

Sand Point Observation Well No. 6 (SPOW6)



Land surface elevation = 479.14 ft-msl
Measuring point elevation = 482.14 ft-msl

Appendix A. Continued

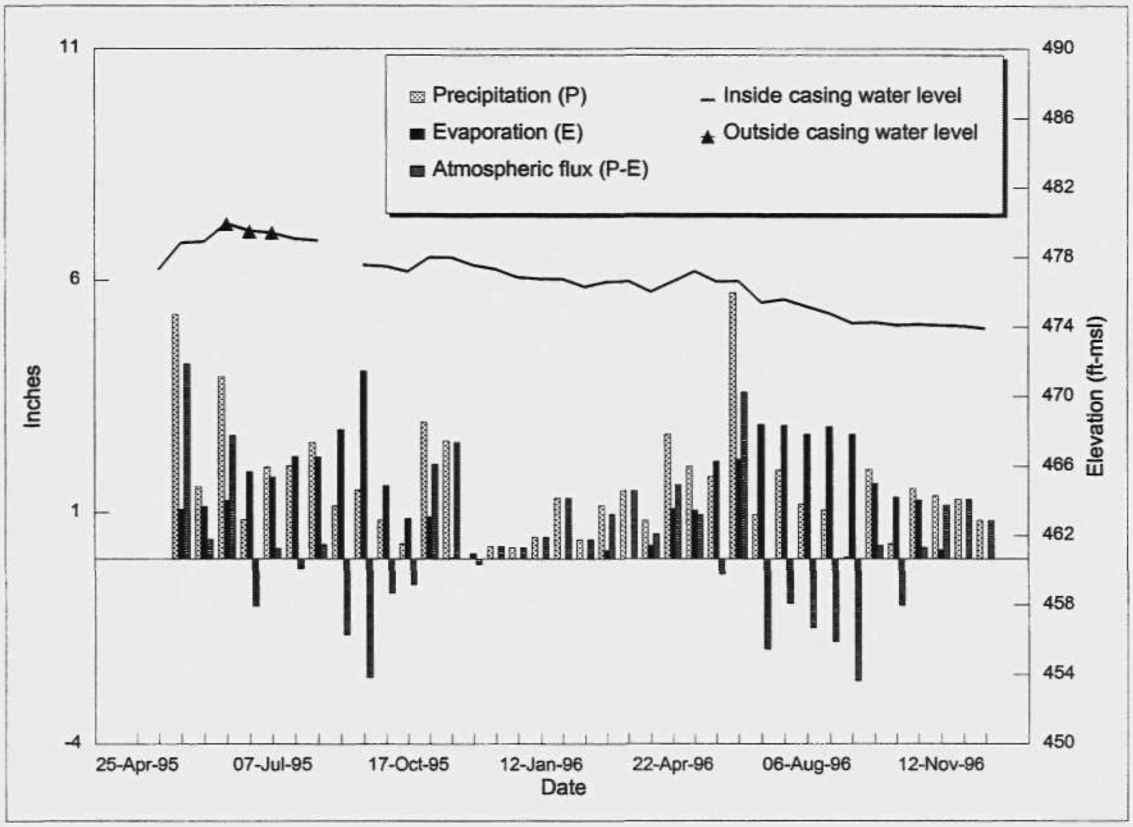
Sand Point Observation Well No. 7 (SPOW7) - Raw Data

Date	*Average precipitation (P) (in)*	*Estimated evaporation (E) (in.)*	*Atmospheric flux (P-E) (in.)*	*Ground-water elevation inside (ft-msl)*	*Ground-water elevation outside (ft-msl)*
25-Apr-95					
0l-May-95				477.29	
17-May-95	5.27	1.07	4.20	478.84	
22-May-95	1.56	1.13	0.43	478.90	
01-Jun-95	3.92	1.26	2.66	479.95	479.90
26-Jun-95	0.85	1.88	-1.03	479.53	479.45
07-M-95	1.98	1.76	0.22	479.40	479.40
25-Jul-95	2.00	2.21	-0.21	479.08	
11-Aug-95	2.51	2.20	0.31	478.96	
24-Aug-95	1.14	2.79	-1.65		
19-Sep-95	1.48	4.05	-2.57	477.55	
06-Oct-95	0.84	1.58	-0.74	477.48	
17-Oct-95	0.32	0.88	-0.56	477.18	
0l-Nov-95	2.95	0.91	2.04	478.00	
14-Nov-95	2.55	0.03	2.52	477.99	
30-Nov-95	0.00	0.12	-0.12	477.55	
15-Dec-95	0.27	0.00	0.27	477.30	
29-Dec-95	0.24	0.00	0.24	476.85	
12-Jan-96	0.47	0.00	0.47	476.76	
25-Jan-96	1.31	0.00	1.31	476.76	
09-Feb-96	0.41	0.00	0.41	476.29	
29-Feb-96	1.15	0.18	0.97	476.59	
15-Mar-96	1.47	0.00	1.47	476.64	
10-Apr-96	0.83	0.29	0.54	476.02	
22-Apr-96	2.68	1.08	1.60	476.60	
08-May-96	2.00	1.05	0.95	477.20	
20-May-96	1.77	2.10	-0.33	476.60	
19-Jun-96	5.74	2.15	3.59	476.64	
12-Jul-96	0.95	2.90	-1.95	475.40	
22-Jul-96	1.91	2.88	-0.97	475.59	
06-Aug-96	1.18	2.68	-1.50	475.16	
21-Aug-96	1.05	2.85	-1.80	474.77	
12-Sep-96	0.04	2.68	-2.64	474.21	
0l-Oct-96	1.93	1.63	0.30	474.26	
15-Oct-96	0.32	1.33	-1.01	474.11	
30-Oct-96	1.52	1.27	0.25	474.15	
12-Nov-96	1.36	0.20	1.16	474.10	
03-Dec-96	1.29	0.00	1.29	474.06	
08-Jan-97	0.83	0.00	0.83	473.91	

Note: Lambert X = 869411.4285, Lambert Y = 804516.0486

Appendix A. Continued

Sand Point Observation Well No. 7 (SPOW7)



Land surface elevation = 479.18 ft-msl
Measuring point elevation = 481.38 ft-msl

Appendix A. Continued

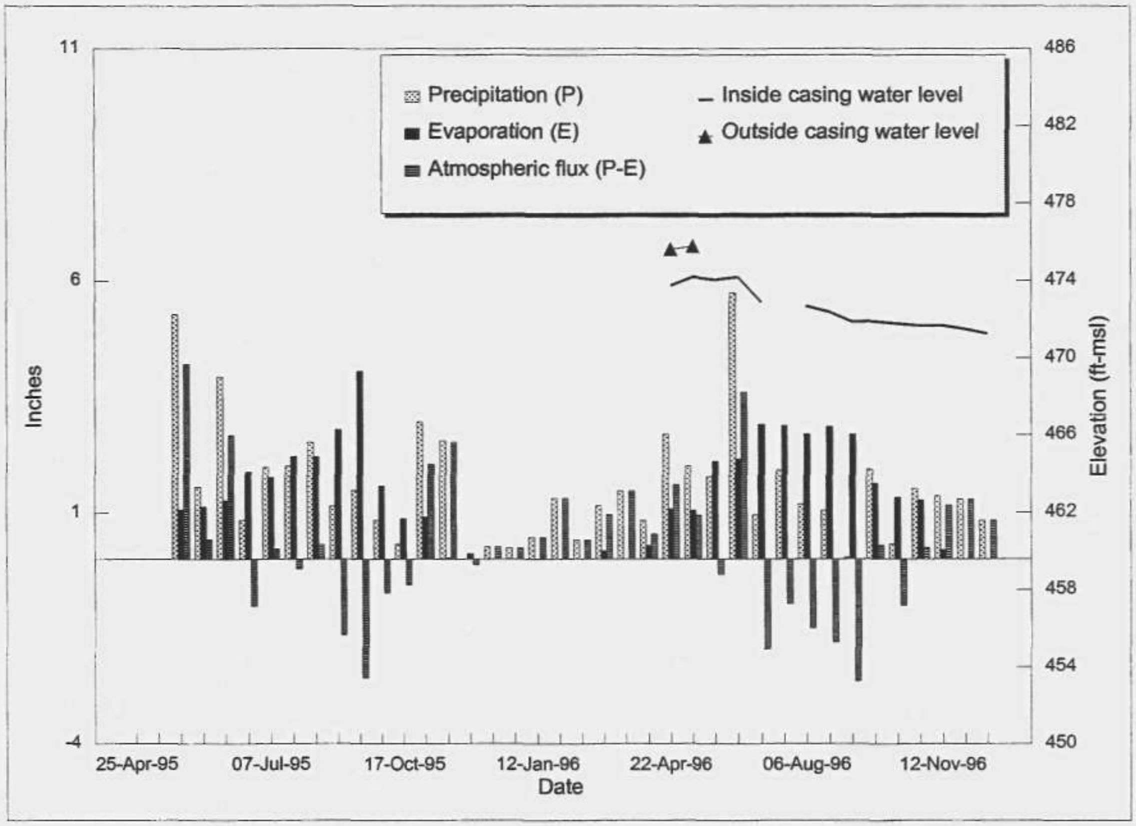
Sand Point Observation Well No. 8 (SPOW8) - Raw Data

Date	*Average precipitation (P) (in)*	*Estimated evaporation (E) (in.)*	*Atmospheric flux (P-E) (in.)*	*Ground-water elevation inside (ft-msl)*	*Ground-water elevation outside (ft-msl)*
25-Apr-95					
0l-May-95					
17-May-95	5.27	1.07	4.20		
22-May-95	1.56	1.13	0.43		
0l-Jun-95	3.92	1.26	2.66		
26-Jun-95	0.85	1.88	-1.03		
07-Jul-95	1.98	1.76	0.22		
25-Jul-95	2.00	2.21	-0.21		
11-Aug-95	2.51	2.20	0.31		
24-Aug-95	1.14	2.79	-1.65		
19-Sep-95	1.48	4.05	-2.57		
06-Oct-95	0.84	1.58	-0.74		
17-Oct-95	0.32	0.88	-0.56		
0l-Nov-95	2.95	0.91	2.04		
14-Nov-95	2.55	0.03	2.52		
30-Nov-95	0.00	0.12	-0.12		
15-Dec-95	0.27	0.00	0.27		
29-Dec-95	0.24	0.00	0.24		
12-Jan-96	0.47	0.00	0.47		
25-Jan-96	1.31	0.00	1.31		
09-Feb-96	0.41	0.00	0.41		
29-Feb-96	1.15	0.18	0.97		
15-Mar-96	1.47	0.00	1.47		
10-Apr-96	0.83	0.29	0.54		
22-Apr-96	2.68	1.08	1.60	473.76	475.62
08-May-96	2.00	1.05	0.95	474.19	475.78
20-May-96	1.77	2.10	-0.33	474.06	
19-Jun-96	5.74	2.15	3.59	474.19	
12-Jul-96	0.95	2.90	-1.95	472.88	
22-Jul-96	1.91	2.88	-0.97		
06-Aug-96	1.18	2.68	-1.50	472.69	
21-Aug-96	1.05	2.85	-1.80	472.40	
12-Sep-96	0.04	2.68	-2.64	471.88	
01-Oct-96	1.93	1.63	0.30	471.89	
15-Oct-96	0.32	1.33	-1.01	471.78	
30-Oct-96	1.52	1.27	0.25	471.69	
12-Nov-96	1.36	0.20	1.16	471.69	
03-Dec-96	1.29	0.00	1.29	471.50	
08-Jan-97	0.83	0.00	0.83	471.27	

Note: Lambert X = 869106.2062, Lambert Y = 804712.0927

Appendix A. Continued

Sand Point Observation Well No. 8 (SPOW8)



Land surface elevation = 475.39 ft-msl
Measuring point elevation = 478.39 ft-msl

Appendix A. Continued

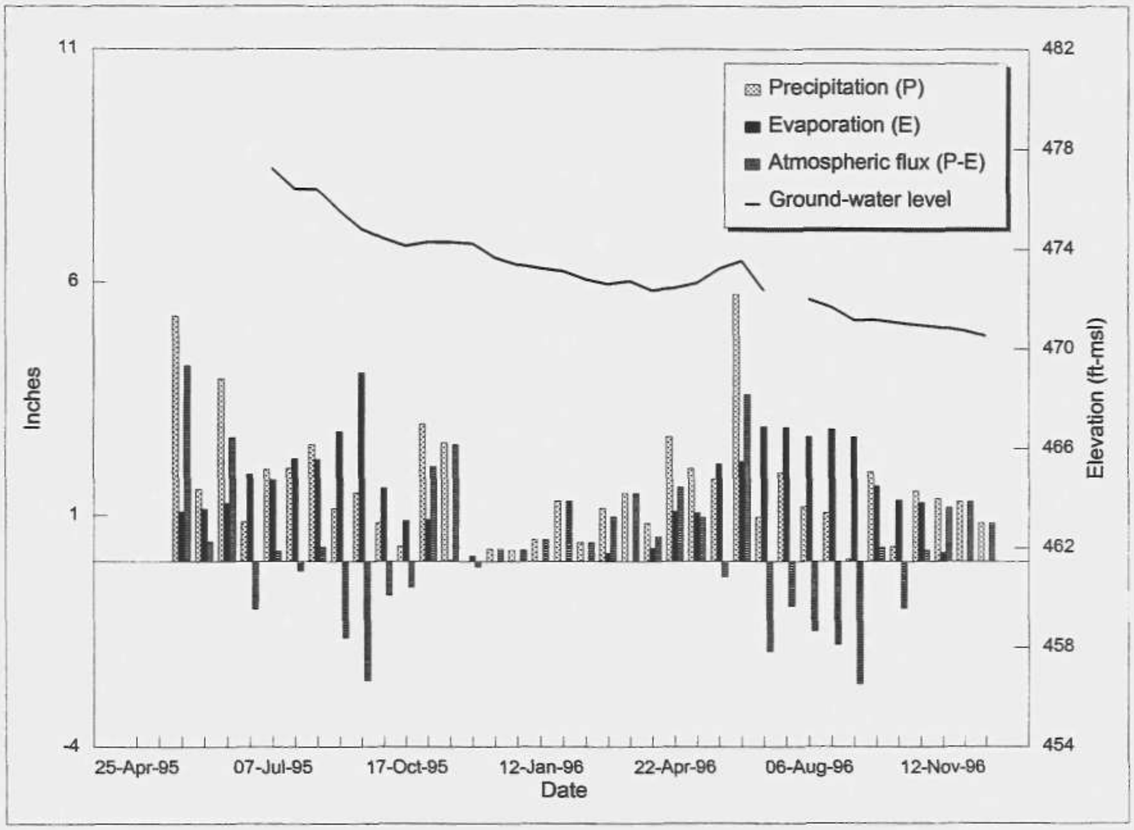
Sand Lake Observation Well No. 1 (SLOW1) - Raw Data

Date	*Average precipitation (P) (in)*	*Estimated evaporation (E) (in.)*	*Atmospheric flux (P-E) (in.)*	*Ground-water elevation inside (ft-msl)*
25-Apr-95				
0l-May-95				
17-May-95	5.27	1.07	4.20	
22-May-95	1.56	1.13	0.43	
0l-Jun-95	3.92	1.26	2.66	
26-Jun-95	0.85	1.88	-1.03	
07-Jul-95	1.98	1.76	0.22	477.22
25-Jul-95	2.00	2.21	-0.21	476.40
11-Aug-95	2.51	2.20	0.31	476.40
24-Aug-95	1.14	2.79	-1.65	475.55
19-Sep-95	1.48	4.05	-2.57	474.81
06-Oct-95	0.84	1.58	-0.74	474.42
17-Oct-95	0.32	0.88	-0.56	474.13
0l-Nov-95	2.95	0.91	2.04	474.28
14-Nov-95	2.55	0.03	2.52	474.27
30-Nov-95	0.00	0.12	-0.12	474.23
15-Dec-95	0.27	0.00	0.27	473.66
29-Dec-95	0.24	0.00	0.24	473.38
12-Jan-96	0.47	0.00	0.47	473.22
25-Jan-96	1.31	0.00	1.31	473.13
09-Feb-96	0.41	0.00	0.41	472.78
29-Feb-96	1.15	0.18	0.97	472.60
15-Mar-96	1.47	0.00	1.47	472.72
10-Apr-96	0.83	0.29	0.54	472.36
22-Apr-96	2.68	1.08	1.60	472.45
08-May-96	2.00	1.05	0.95	472.64
20-May-96	1.77	2.10	-0.33	473.21
19-Jun-96	5.74	2.15	3.59	473.53
12-Jul-96	0.95	2.90	-1.95	472.34
22-Jul-96	1.91	2.88	-0.97	
06-Aug-96	1.18	2.68	-1.50	472.00
21-Aug-96	1.05	2.85	-1.80	471.68
12-Sep-96	0.04	2.68	-2.64	471.16
01-Oct-96	1.93	1.63	0.30	471.17
15-Oct-96	0.32	1.33	-1.01	471.06
30-Oct-96	1.52	1.27	0.25	470.95
12-Nov-96	1.36	0.20	1.16	470.86
03-Dec-96	1.29	0.00	1.29	470.73
08-Jan-97	0.83	0.00	0.83	470.53

Note: Lambert X = 868635.6522, Lambert Y = 804329.1983

Appendix A. Continued

Sand Lake Observation Well No. 1 (SLOW1)



Land surface elevation = 483.87 ft-msl
Measuring point elevation = 485.07 ft-msl

Appendix A. Continued

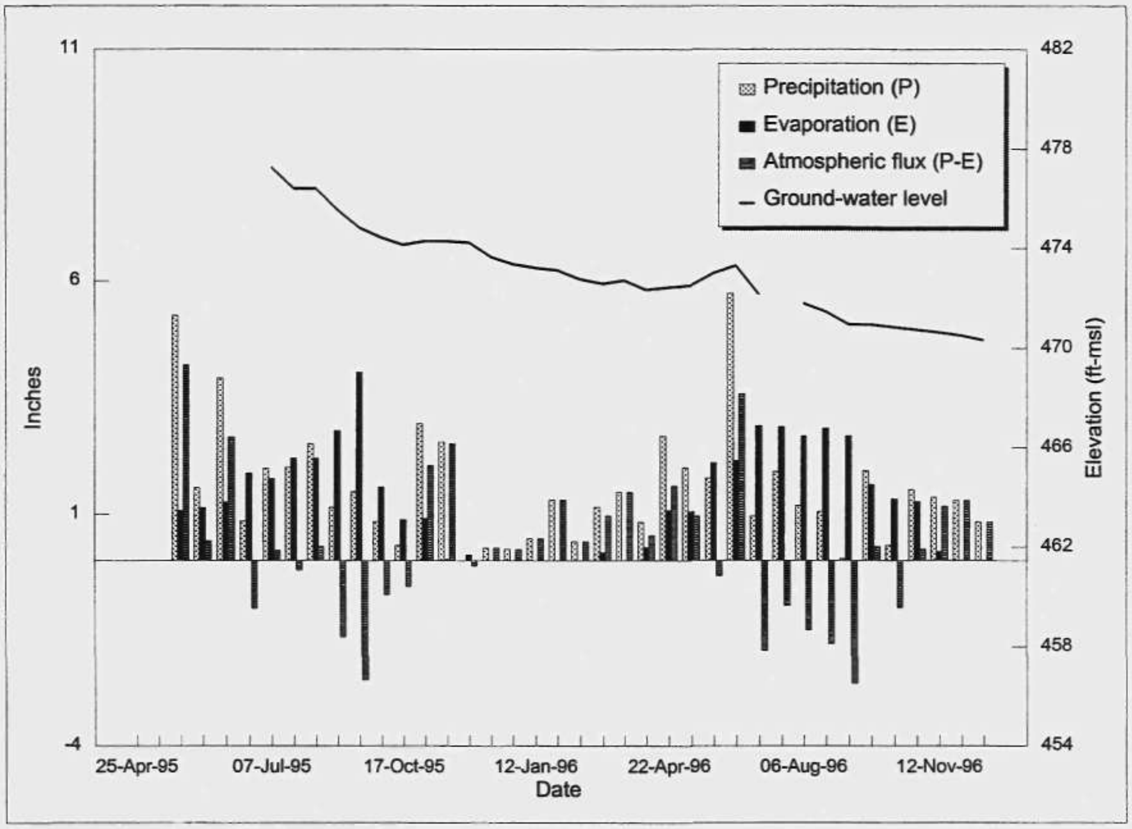
Sand Lake Observation Well No. 2 (SLOW2) - Raw Data

Date	*Average precipitation (P) (in)*	*Estimated evaporation (E) (in)*	*Atmospheric flux (P-E) (in)*	*Ground-water elevation inside (ft-msl)*
25-Apr-95				
0l-May-95				
17-May-95	5.27	1.07	4.20	
22-May-95	1.56	1.13	0.43	
0l-Jun-95	3.92	1.26	2.66	
26-Jun-95	0.85	1.88	-1.03	
07-Jul-95	1.98	1.76	0.22	477.24
25-Jul-95	2.00	2.21	-0.21	476.40
11-Aug-95	2.51	2.20	0.31	476.40
24-Aug-95	1.14	2.79	-1.65	475.55
19-Sep-95	1.48	4.05	-2.57	474.82
06-Oct-95	0.84	1.58	-0.74	474.42
17-Oct-95	0.32	0.88	-0.56	474.12
0l-Nov-95	2.95	0.91	2.04	474.27
14-Nov-95	2.55	0.03	2.52	474.27
30-Nov-95	0.00	0.12	-0.12	474.23
15-Dec-95	0.27	0.00	0.27	473.65
29-Dec-95	0.24	0.00	0.24	473.37
12-Jan-96	0.47	0.00	0.47	473.21
25-Jan-96	1.31	0 00	1.31	473.12
09-Feb-96	0.41	0.00	0.41	472.76
29-Feb-96	1.15	0.18	0.97	472.58
15-Mar-96	1.47	0.00	1.47	472.71
10-Apr-96	0.83	0.29	0.54	472.34
22-Apr-96	2.68	1.08	1.60	472.43
08-May-96	2.00	1.05	0.95	472.51
20-May-96	1.77	2.10	-0.33	473.01
19-Jun-96	5.74	2.15	3.59	473.30
12-Jul-96	0.95	2.90	-1.95	472.15
22-Jul-96	1.91	2.88	-0.97	
06-Aug-96	1.18	2.68	-1.50	471.79
21-Aug-96	1.05	2.85	-1.80	471.47
12-Sep-96	0.04	2.68	-2.64	470.95
0l-Oct-96	1.93	1.63	0.30	470.94
15-Oct-96	0.32	1.33	-1.01	470.84
30-Oct-96	1.52	1.27	0.25	470.73
12-Nov-96	1.36	0.20	1.16	470.64
03-Dec-96	1.29	0.00	1.29	470.51
08-Jan-97	0.83	0.00	0.83	470.32

Note: Lambert X = 868634.7955, Lambert Y = 804327.8115

Appendix A. Continued

Sand Lake Observation Well No. 2 (SLOW2)



Land surface elevation = 484.00 ft-msl
Measuring point elevation = 486.11 ft-msl

Appendix A. Continued

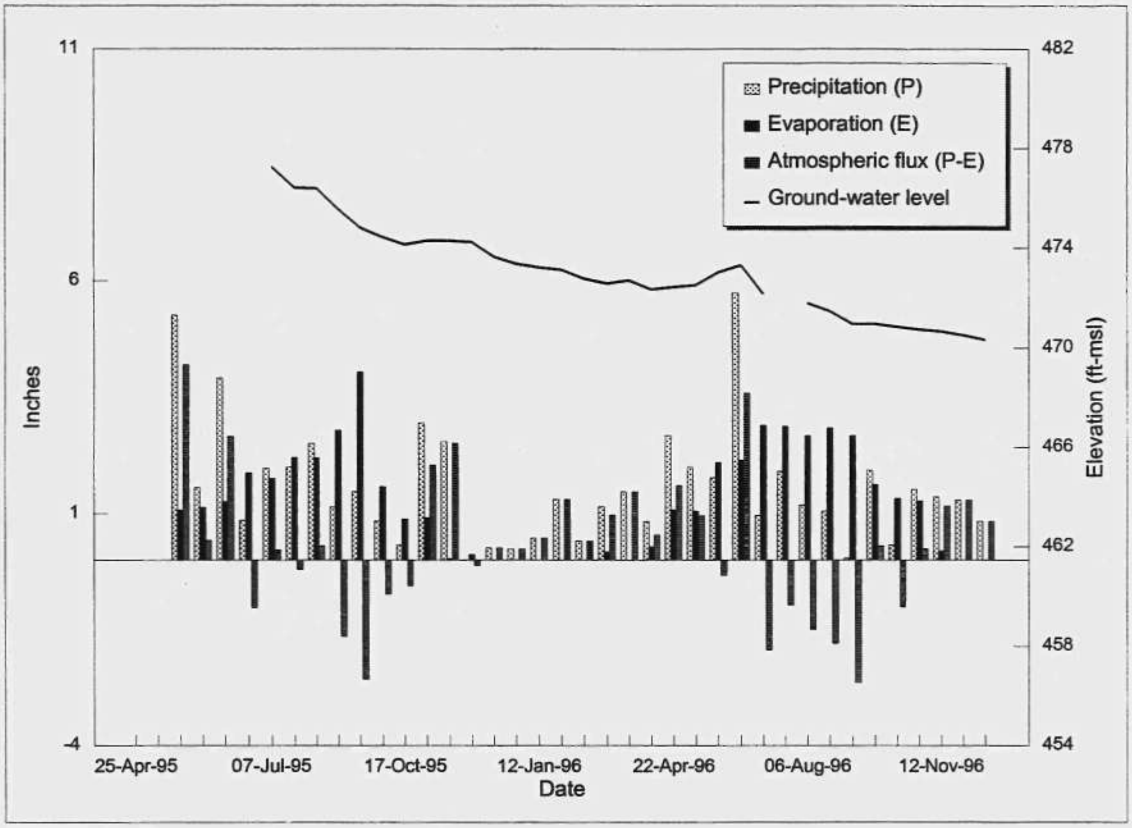
Sand Lake Observation Well No. 3 (SLOW3) - Raw Data

Date	*Average precipitation (P) (in.)*	*Estimated evaporation (E) (in)*	*Atmospheric flux (P-E) (in.)*	*Ground-water elevation inside (ft-msl)*
25-Apr-95				
0l-May-95				
17-May-95	5.27	1.07	4.20	
22-May-95	1.56	1.13	0.43	
0l-Jun-95	3.92	1.26	2.66	
26-Jun-95	0.85	1.88	-1.03	
07-Jul-95	1.98	1.76	0.22	477.23
25-Jul-95	2.00	2.21	-0.21	476.40
11-Aug-95	2.51	2.20	0.31	476.39
24-Aug-95	1.14	2.79	-1.65	475.55
19-Sep-95	1.48	4.05	-2.57	474.80
06-Oct-95	0.84	1.58	-0.74	474.42
17-Oct-95	0.32	0.88	-0.56	474.13
0l-Nov-95	2.95	0.91	2.04	474.28
14-Nov-95	2.55	0.03	2.52	474.27
30-Nov-95	0.00	0.12	-0.12	474.23
15-Dec-95	0.27	0.00	0.27	473.65
29-Dec-95	0.24	0.00	0.24	473.37
12-Jan-96	0.47	0.00	0.47	473.21
25-Jan-96	1.31	0.00	1.31	473.12
09-Feb-96	0.41	0.00	0.41	472.76
29-Feb-96	1.15	0.18	0.97	472.57
15-Mar-96	1.47	0.00	1.47	472.70
10-Apr-96	0.83	0.29	0.54	472.34
22-Apr-96	2.68	1.08	1.60	472.43
08-May-96	2.00	1.05	0.95	472.51
20-May-96	1.77	2.10	-0.33	473.02
19-Jun-96	5.74	2.15	3.59	473.30
12-Jul-96	0.95	2.90	-1.95	472.14
22-Jul-96	1.91	2.88	-0.97	
06-Aug-96	1.18	2.68	-1.50	471.79
21-Aug-96	1.05	2.85	-1.80	471.47
12-Sep-96	0.04	2.68	-2.64	470.96
01-Oct-96	1.93	1.63	0.30	470.95
15-Oct-96	0.32	1.33	-1.01	470.84
30-Oct-96	1.52	1.27	0.25	470.74
12-Nov-96	1.36	0.20	1.16	470.65
03-Dec-96	1.29	0.00	1.29	470.51
08-Jan-97	0.83	0.00	0.83	470.32

Note: Lambert X = 868636.2278, Lambert Y = 804327.8327

Appendix A. Continued

Sand Lake Observation Well No. 3 (SLOW3)



Land surface elevation = 484.04 ft-msl
Measuring point elevation = 485.44 ft-msl

Appendix A. Continued

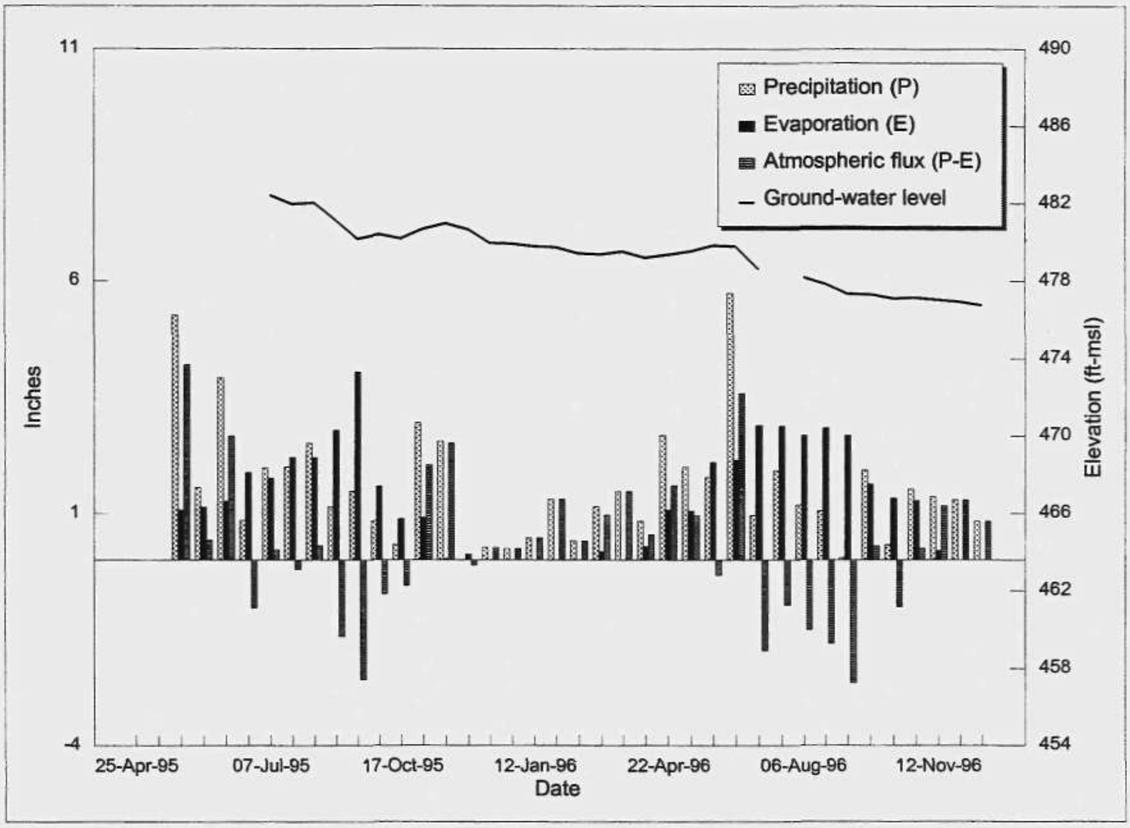
Sand Lake Observation Well No. 4 (SLOW4) - Raw Data

Date	*Average precipitation (P) (in.)*	*Estimated evaporation (E) (in)*	*Atmospheric flux (P-E) (in.)*	*Ground-water elevation inside (ft-msl)*
25-Apr-95				
01-May-95				
17-May-95	5.27	1.07	4.20	
22-May-95	1.56	1.13	0.43	
01-Jun-95	3.92	1.26	2.66	
26-Jun-95	0.85	1.88	-1.03	
07-Jul-95	1.98	1.76	0.22	482.40
25-Jul-95	2.00	2.21	-0.21	481.96
11-Aug-95	2.51	2.20	0.31	482.02
24-Aug-95	1.14	2.79	-1.65	481.12
19-Sep-95	1.48	4.05	-2.57	480.18
06-Oct-95	0.84	1.58	-0.74	480.38
17-Oct-95	0.32	0.88	-0.56	480.18
01-Nov-95	2.95	0.91	2.04	480.66
14-Nov-95	2.55	0.03	2.52	480.97
30-Nov-95	0.00	0.12	-0.12	480.65
15-Dec-95	0.27	0.00	0.27	479.95
29-Dec-95	0.24	0.00	0.24	479.92
12-Jan-96	0.47	0.00	0.47	479.80
25-Jan-96	1.31	0.00	1.31	479.75
09-Feb-96	0.41	0.00	0.41	479.43
29-Feb-96	1.15	0.18	0.97	479.39
15-Mar-96	1.47	0.00	1.47	479.53
10-Apr-96	0.83	0.29	0.54	479.22
22-Apr-96	2.68	1.08	1.60	479.37
08-May-96	2.00	1.05	0.95	479.55
20-May-96	1.77	2.10	-0.33	479.84
19-Jun-96	5.74	2.15	3.59	479.81
12-Jul-96	0.95	2.90	-1.95	478.62
22-Jul-96	1.91	2.88	-0.97	
06-Aug-96	1.18	2.68	-1.50	478.20
21-Aug-96	1.05	2.85	-1.80	477.88
12-Sep-96	0.04	2.68	-2.64	477.35
01-Oct-96	1.93	1.63	0.30	477.32
15-Oct-96	0.32	1.33	-1.01	477.11
30-Oct-96	1.52	1.27	0.25	477 15
12-Nov-96	1.36	0.20	1.16	477.06
03-Dec-96	1.29	0.00	1.29	476.95
08-Jan-97	0.83	0.00	0.83	476.77

Note: Lambert X = 869756.7842, Lambert Y = 804362.2049

Appendix A. Continued

Sand Lake Observation Well No. 4 (SLOW4)



Land surface elevation = 485.77 ft-msl
Measuring point elevation = 488.57 ft-msl

Appendix A. Continued

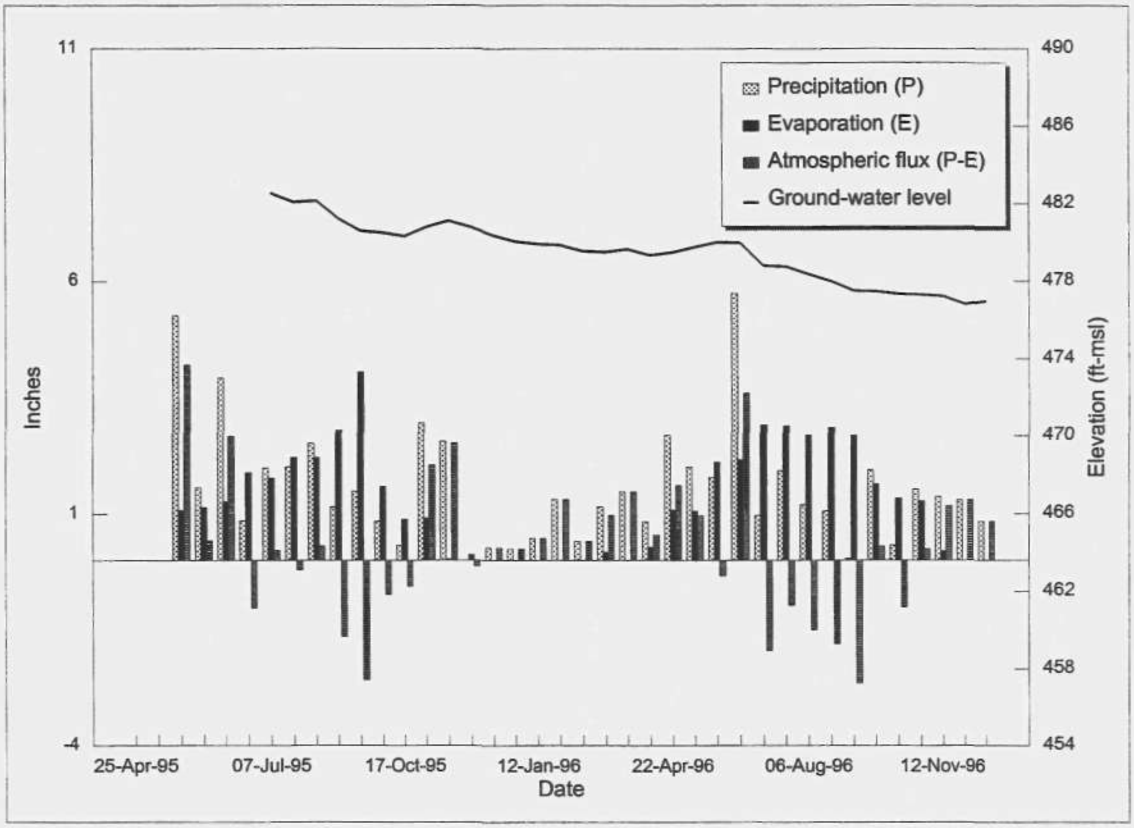
Sand Lake Observation Well No. 5 (SLOW5) - Raw Data

Date	*Average precipitation (P) (in.)*	*Estimated evaporation (E) (in)*	*Atmospheric flux (P-E) (in.)*	*Ground-water elevation inside (ft-msl)*
25-Apr-95				
0l-May-95				
17-May-95	5.27	1.07	4.20	
22-May-95	1.56	1.13	0.43	
0l-Jun-95	3.92	1.26	2.66	
26-Jun-95	0.85	1.88	-1.03	
07-Jul-95	1.98	1.76	0.22	482.53
25-Jul-95	2.00	2.21	-0.21	482.09
11-Aug-95	2.51	2.20	0.31	482.14
24-Aug-95	1.14	2.79	-1.65	481.24
19-Sep-95	1.48	4.05	-2.57	480.60
06-Oct-95	0.84	1.58	-0.74	480.50
17-Oct-95	0.32	0.88	-0.56	480.31
0l-Nov-95	2.95	0.91	2.04	480 77
14-Nov-95	2.55	0.03	2.52	481.11
30-Nov-95	0.00	0.12	-0.12	480.78
15-Dec-95	0.27	0.00	0.27	480.37
29-Dec-95	0.24	0.00	0.24	480.05
12-Jan-96	0.47	0.00	0.47	479.93
25-Jan-96	1.31	0.00	1.31	479 87
09-Feb-96	0.41	0.00	0.41	479.56
29-Feb-96	1.15	0.18	0.97	479.52
15-Mar-96	1.47	0.00	1.47	479.65
10-Apr-96	0.83	0.29	0.54	479.34
22-Apr-96	2.68	1.08	1.60	479.49
08-May-96	2.00	1.05	0.95	479.77
20-May-96	1.77	2.10	-0.33	480.00
19-Jun-96	5.74	2.15	3.59	479.99
12-Jul-96	0.95	2.90	-1.95	478.80
22-Jul-96	1.91	2.88	-0.97	478.75
06-Aug-96	1.18	2.68	-1.50	478.37
21-Aug-96	1.05	2.85	-1.80	478.01
12-Sep-96	0.04	2.68	-2.64	477.51
01-Oct-96	1.93	1.63	0.30	477.48
15-Oct-96	0.32	1.33	-1.01	477.36
30-Oct-96	1.52	1.27	0.25	477.31
12-Nov-96	1.36	0.20	1.16	477.23
03-Dec-96	1.29	0.00	1.29	476.82
08-Jan-97	0.83	0.00	0.83	476.96

Note: Lambert X = 869756.2752, Lambert Y = 804361.3242

Appendix A. Continued

Sand Lake Observation Well No. 5 (SLOWS)



Land surface elevation = 485.60 ft-msl
Measuring point elevation = 488.10 ft-msl

Appendix A. Continued

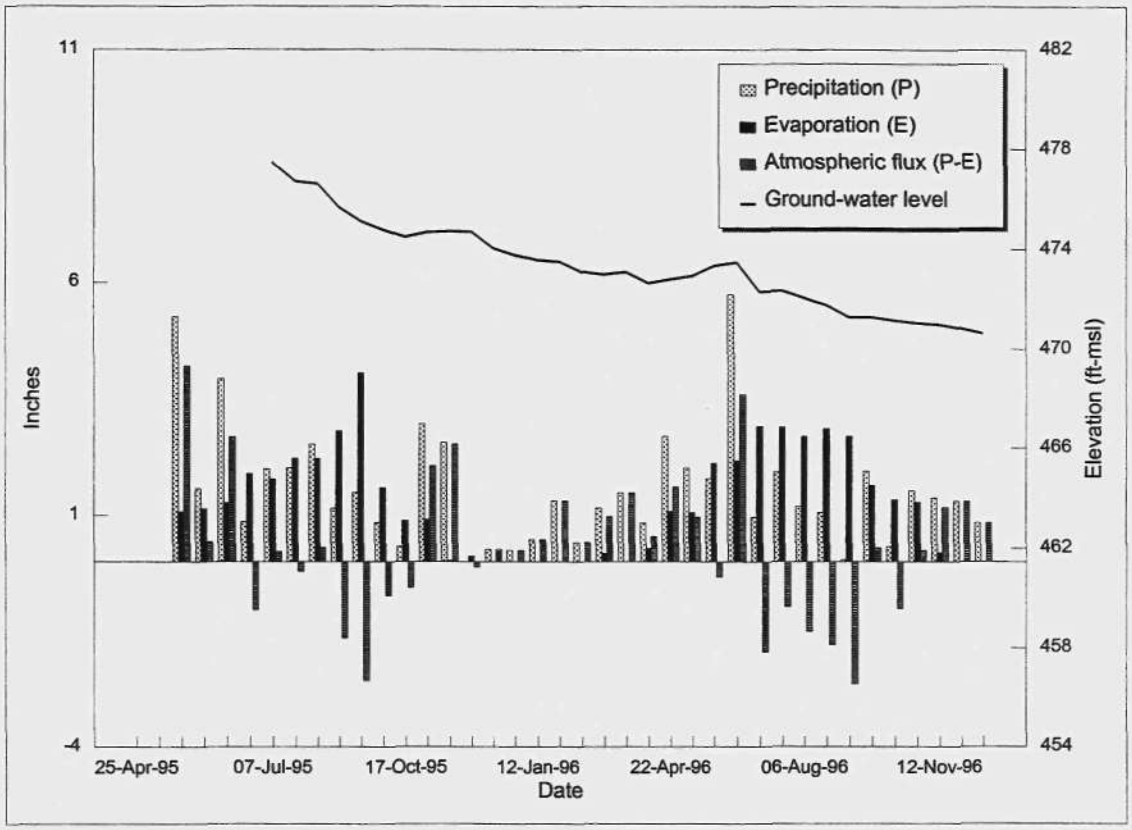
Sand Lake Observation Well No. 6 (SLOW6) - Raw Data

Date	*Average precipitation (P) (in.)*	*Estimated evaporation (E) (in.)*	*Atmospheric flux (P-E) (in.)*	*Ground-water elevation inside (ft-msl)*
25-Apr-95				
0l-May-95				
17-May-95	5.27	1.07	4.20	
22-May-95	1.56	1.13	0.43	
0l-Jun-95	3.92	1.26	2.66	
26-Jun-95	0.85	1.88	-1.03	
07-Jul-95	1.98	1.76	0.22	477.45
25-Jul-95	2.00	2.21	-0.21	476.71
11-Aug-95	2.51	2.20	0.31	476.61
24-Aug-95	1.14	2.79	-1.65	475.68
19-Sep-95	1.48	4.05	-2.57	475.11
06-Oct-95	0.84	1.58	-0.74	474.78
17-Oct-95	0.32	0.88	-0.56	474.48
0l-Nov-95	2.95	0.91	2.04	474.67
14-Nov-95	2.55	0.03	2.52	474.72
30-Nov-95	0.00	0.12	-0.12	474.70
15-Dec-95	0.27	0.00	0.27	474.05
29-Dec-95	0.24	0.00	0.24	473.77
12-Jan-96	0.47	0.00	0.47	473.57
25-Jan-96	1.31	0.00	1.31	473.50
09-Feb-96	0.41	0.00	0.41	473.10
29-Feb-96	1.15	0.18	0.97	472.99
15-Mar-96	1.47	0.00	1.47	473.10
10-Apr-96	0.83	0.29	0.54	472.65
22-Apr-96	2.68	1.08	1.60	472.80
08-May-96	2.00	1.05	0.95	472.93
20-May-96	1.77	2.10	-0.33	473.34
19-Jun-96	5.74	2.15	3.59	473.48
12-M-96	0.95	2.90	-1.95	472.30
22-Jul-96	1.91	2.88	-0.97	472.33
06-Aug-96	1.18	2.68	-1.50	472.05
21-Aug-96	1.05	2.85	-1.80	471.76
12-Sep-96	0.04	2.68	-2.64	471.27
0l-Oct-96	1.93	1.63	0.30	471.28
15-Oct-96	0.32	1.33	-1.01	471.14
30-Oct-96	1.52	1.27	0.25	471.04
12-Nov-96	1.36	0.20	1.16	470.97
03-Dec-96	1.29	0.00	1.29	470.83
08-Jan-97	0.83	0.00	0.83	470.64

Note: Lambert X = 868921.8592, Lambert Y = 804750.6128

Appendix A. Continued

Sand Lake Observation Well No. 6 (SLOW6)



Land surface elevation = 484.54 ft-msl
Measuring point elevation = 486.74 ft-msl

Appendix A. Continued

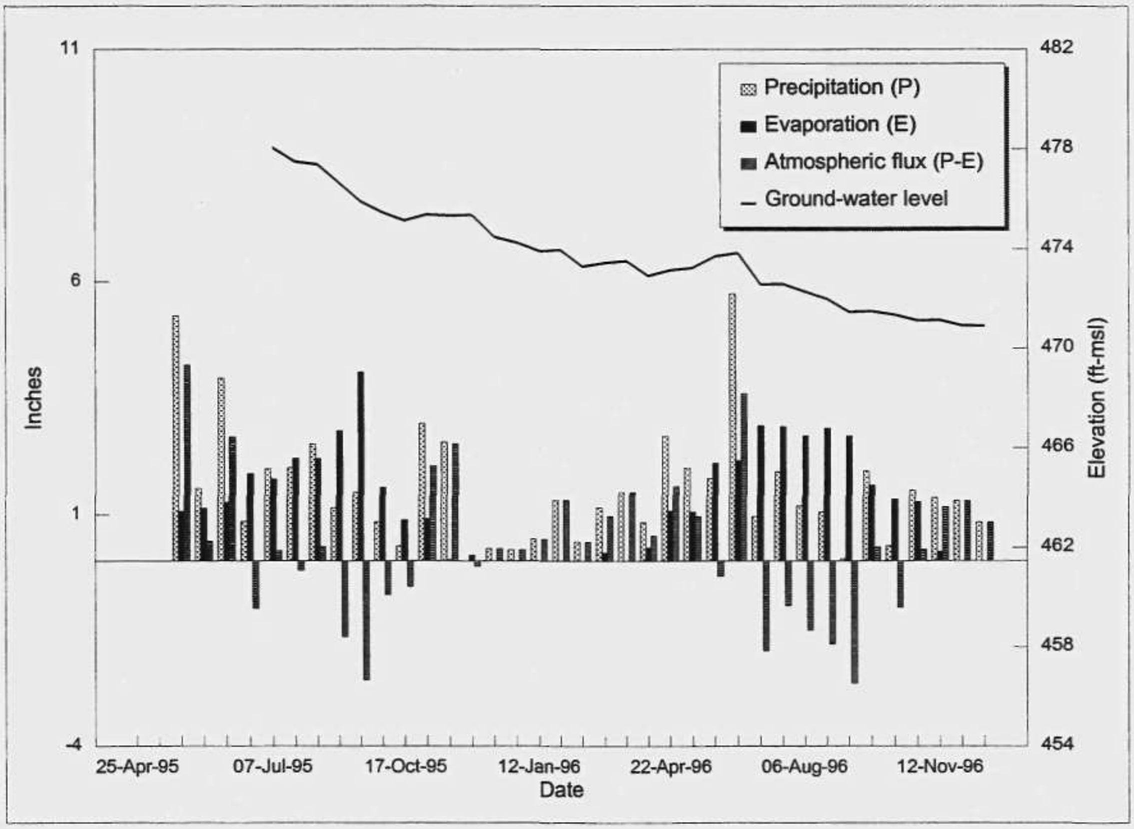
Sand Lake Observation Well No. 7 (SLOW7) - Raw Data

Date	*Average precipitation (P) (in)*	*Estimated evaporation (E) (in.)*	*Atmospheric flux (P-E) (in.)*	*Ground-water elevation inside (ft-msl)*
25-Apr-95				
0l-May-95				
17-May-95	5.27	1.07	4.20	
22-May-95	1.56	1.13	0.43	
0l-Jun-95	3.92	1.26	2.66	
26-Jun-95	0.85	1.88	-1.03	
07-Jul-95	1.98	1.76	0.22	478.04
25-Jul-95	2.00	2.21	-0.21	477.49
11-Aug-95	2.51	2.20	0.31	477.39
24-Aug-95	1.14	2.79	-1.65	476.66
19-Sep-95	1.48	4.05	-2.57	475.90
06-Oct-95	0.84	1.58	-0.74	475.46
17-Oct-95	0.32	0.88	-0.56	475.12
0l-Nov-95	2.95	0.91	2.04	475.37
14-Nov-95	2.55	0.03	2.52	475.34
30-Nov-95	0.00	0.12	-0.12	475.36
15-Dec-95	0.27	0.00	0.27	474.48
29-Dec-95	0.24	0.00	0.24	474.25
12-Jan-96	0.47	0.00	0.47	473.90
25-Jan-96	1.31	0.00	1.31	473.96
09-Feb-96	0.41	0.00	0.41	473.29
29-Feb-96	1.15	0.18	0.97	473.44
15-Mar-96	1.47	0.00	1.47	473.52
10-Apr-96	0.83	0.29	0.54	472.92
22-Apr-96	2.68	1.08	1.60	473.15
08-May-96	2.00	1.05	0.95	473.22
20-May-96	1.77	2.10	-0.33	473.70
19-Jun-96	5.74	2.15	3.59	473.83
12-Jul-96	0.95	2.90	-1.95	472.57
22-Jul-96	1.91	2.88	-0.97	472.58
06-Aug-96	1.18	2.68	-1.50	472.28
21-Aug-96	1.05	2.85	-1.80	471.97
12-Sep-96	0.04	2.68	-2.64	471.45
01-Oct-96	1.93	1.63	0.30	471.48
15-Oct-96	0.32	1.33	-1.01	471.33
30-Oct-96	1.52	1.27	0.25	471.11
12-Nov-96	1.36	0.20	1.16	471.12
03-Dec-96	1.29	0.00	1.29	470.90
08-Jan-97	0.83	0.00	0.83	470.89

Note: Lambert X = 868921.8592, Lambert Y = 804751.6130

Appendix A. Continued

Sand Lake Observation Well No. 7 (SLOW7)



Land surface elevation = 484.69 ft-msl
Measuring point elevation = 485.79 ft-msl

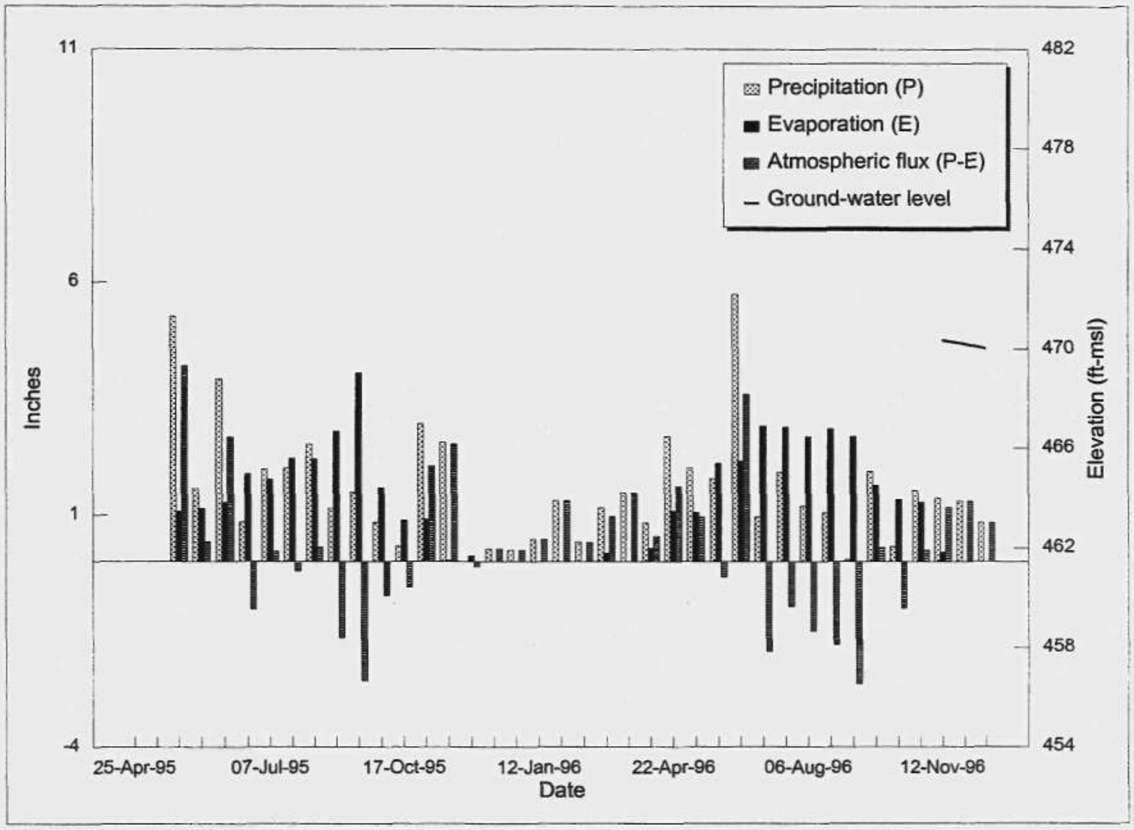
Appendix A. Continued

Sand Lake Observation Well No. 8 (SLOW8) - Raw Data

Date	*Average precipitation (P) (in)*	*Estimated evaporation (E) (in.)*	*Atmospheric flux (P-E) (in.)*	*Ground-water elevation inside (ft-msl)*
25-Apr-95				
0l-May-95				
17-May-95	5.27	1.07	4.20	
22-May-95	1.56	1.13	0.43	
01-Jun-95	3.92	1.26	2.66	
26-Jun-95	0.85	1.88	-1.03	
07-Jul-95	1.98	1.76	0.22	
25-Jul-95	2.00	2.21	-0.21	
11-Aug-95	2.51	2.20	0.31	
24-Aug-95	1.14	2.79	-1.65	
19-Sep-95	1.48	4.05	-2.57	
06-Oct-95	0.84	1.58	-0.74	
17-Oct-95	0.32	0.88	-0.56	
0l-Nov-95	2.95	0.91	2.04	
14-Nov-95	2.55	0.03	2.52	
30-Nov-95	0.00	0.12	-0.12	
15-Dec-95	0.27	0.00	0.27	
29-Dec-95	0.24	0.00	0.24	
12-Jan-96	0.47	0.00	0.47	
25-Jan-96	1.31	0.00	1.31	
09-Feb-96	0.41	0.00	0.41	
29-Feb-96	1.15	0.18	0.97	
15-Mar-96	1.47	0.00	1.47	
10-Apr-96	0.83	0.29	0.54	
22-Apr-96	2.68	1.08	1.60	
08-May-96	2.00	1.05	0.95	
20-May-96	1.77	2.10	-0.33	
19-Jun-96	5.74	2.15	3.59	
12-Jul-96	0.95	2.90	-1.95	
22-Jul-96	1.91	2.88	-0.97	
06-Aug-96	1.18	2.68	-1.50	
21-Aug-96	1.05	2.85	-1.80	
12-Sep-96	0.04	2.68	-2.64	
01-Oct-96	1.93	1.63	0.30	
15-Oct-96	0.32	1.33	-1.01	
30-Oct-96	1.52	1.27	0.25	
12-Nov-96	1.36	0.20	1.16	470.35
03-Dec-96	1.29	0.00	1.29	470.21
08-Jan-97	0.83	0.00	0.83	470.01

Appendix A. Concluded

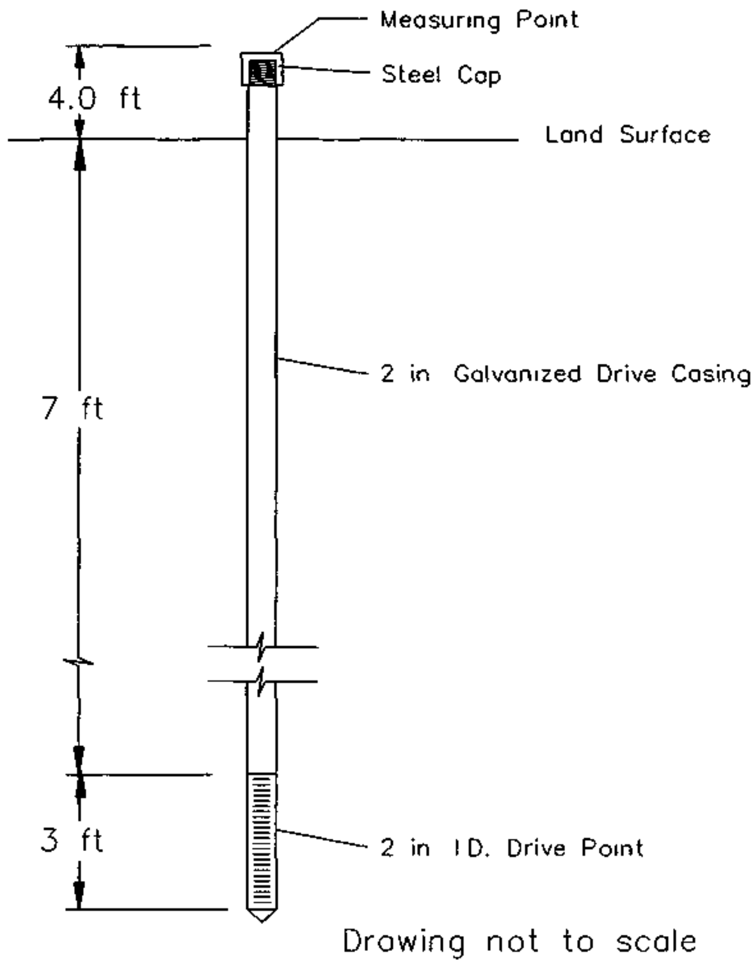
Sand Lake Observation Well No. 8 (SLOW8)



Land surface elevation = 499.54 ft-msl
Measuring point elevation = 498.19 ft-msl

Appendix B. Observation Wells: General Descriptions and Construction Reports

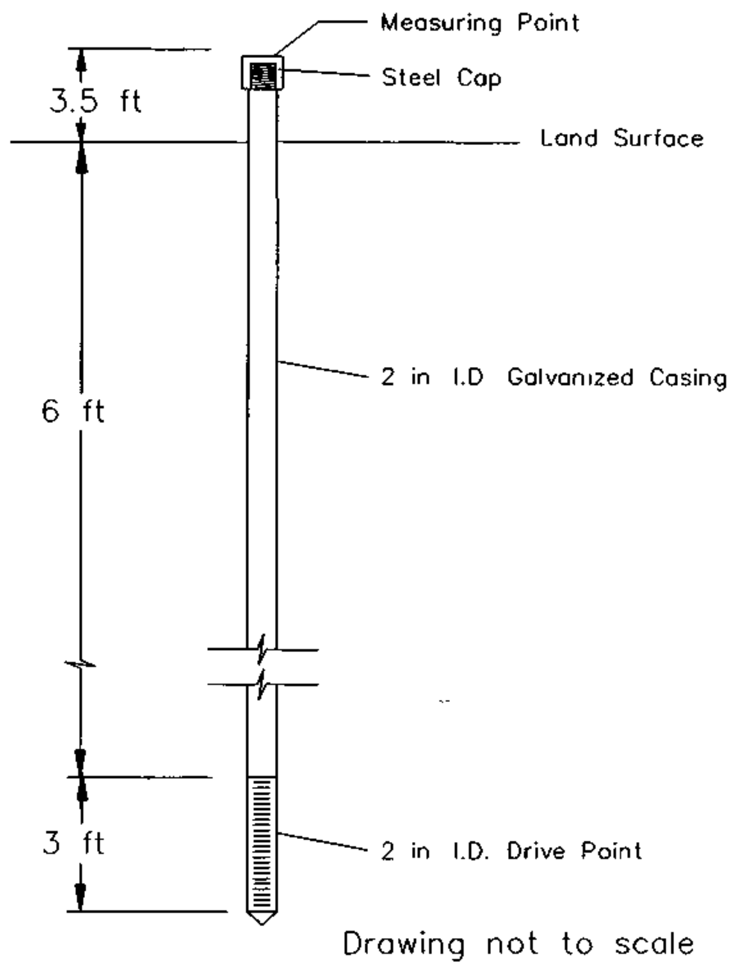
Appendix B.



Illinois State Water Survey Drillers Log
Section 8.8a, T 21N., R.8W., Mason County
SWS Hole # N/A

Depth (feet)	Description of Materials
	Log Not Available

Sand Point Observation Well 1

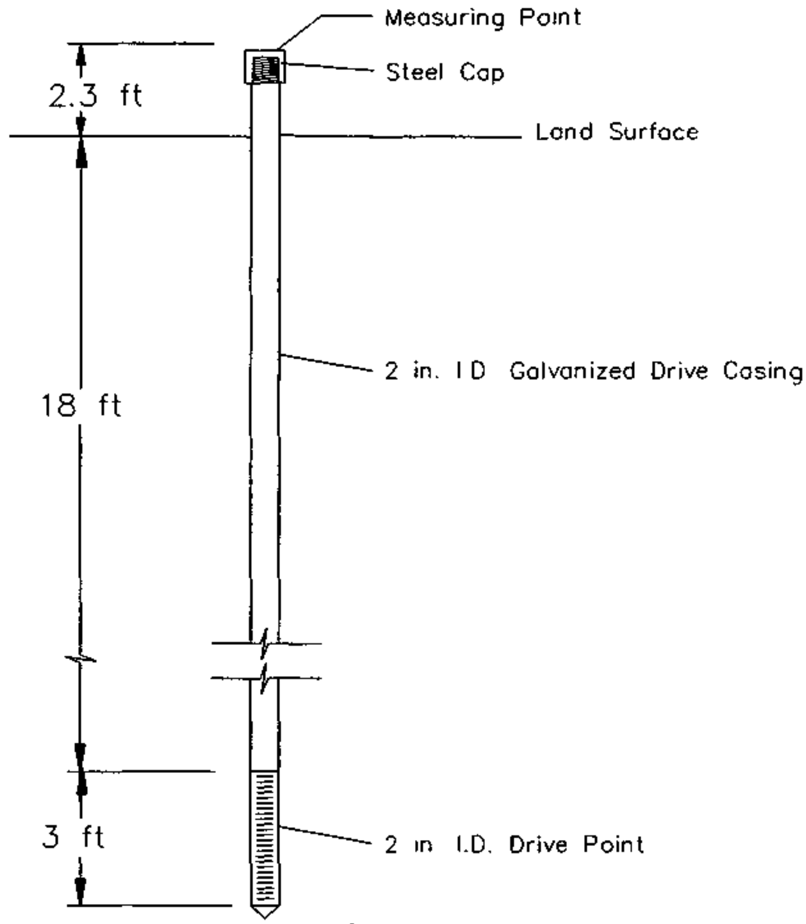


Illinois State Water Survey Drillers Log
Section 8.8c, T 21N., R.8W, Mason County
SWS Hole # N/A

Depth (feet)	Description of Materials
	Log Not Available

Sand Point Observation Well 2

Appendix B. Continued



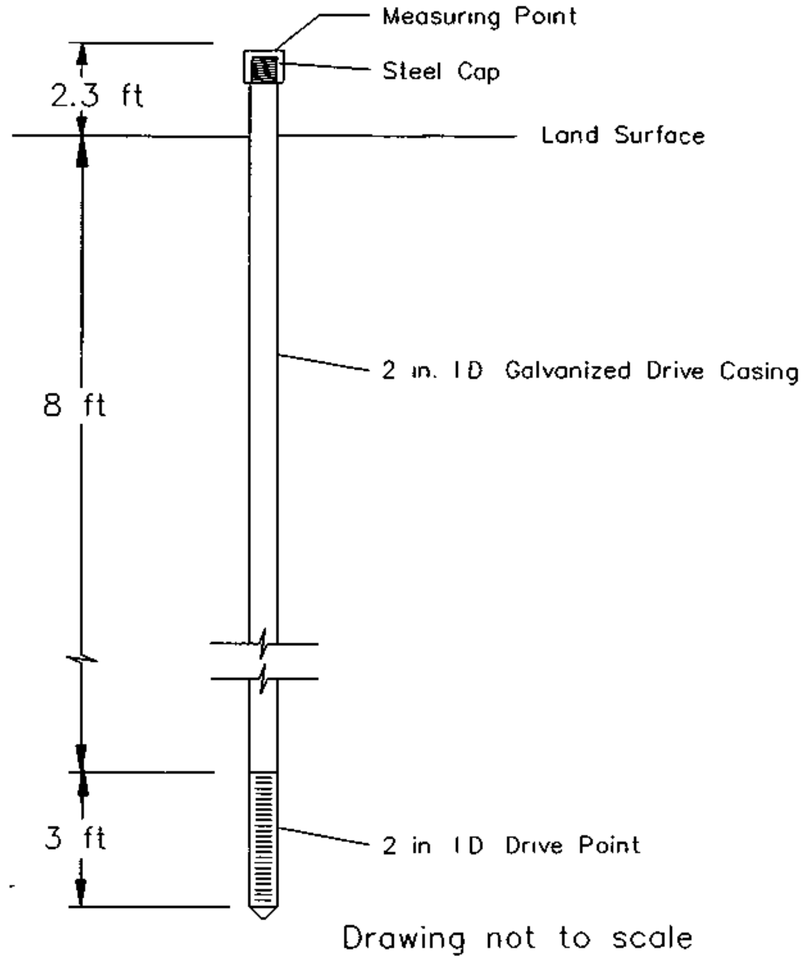
Drawing not to scale

Illinois State Water Survey Drillers Log
Section 7.1c, T 21N , R.8W., Mason County
SWS Hole # N/A

Depth (feet)	Description of Materials
	Log Not Available

Sand Point Observation Well 3

Appendix B. Continued

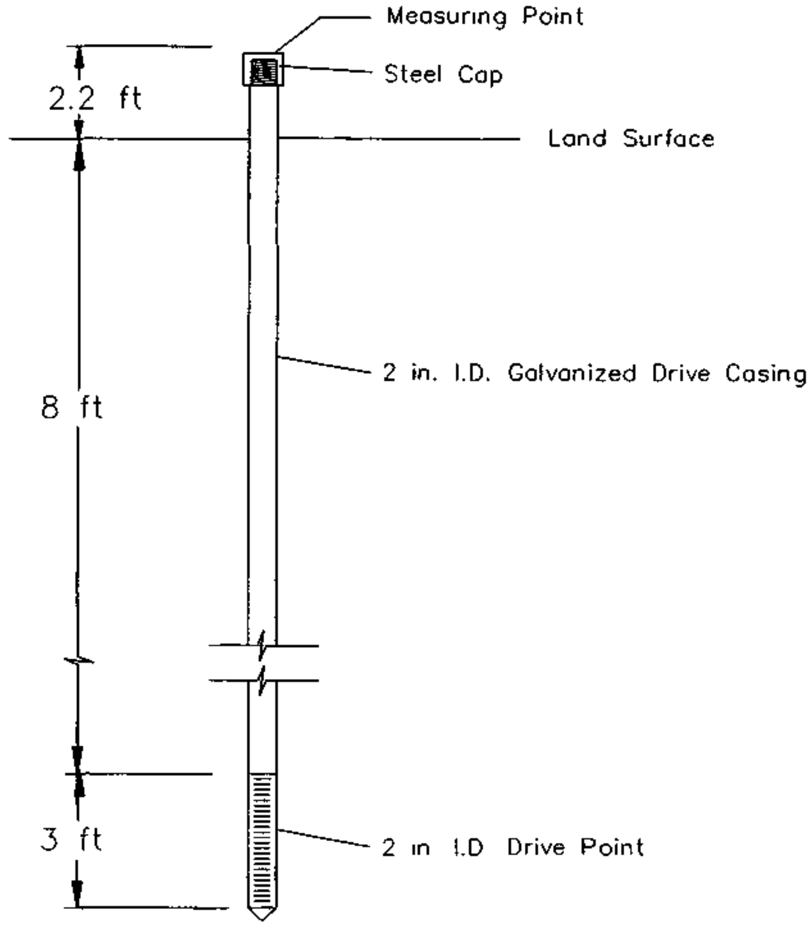


Illinois State Water Survey Drillers Log
Section 8.6d, T.21N , R 8W., Mason County
SWS Hole # N/A

Depth (feet)	Description of Materials
	Log Not Available

Sand Point Observation Well 4

Appendix B. Continued



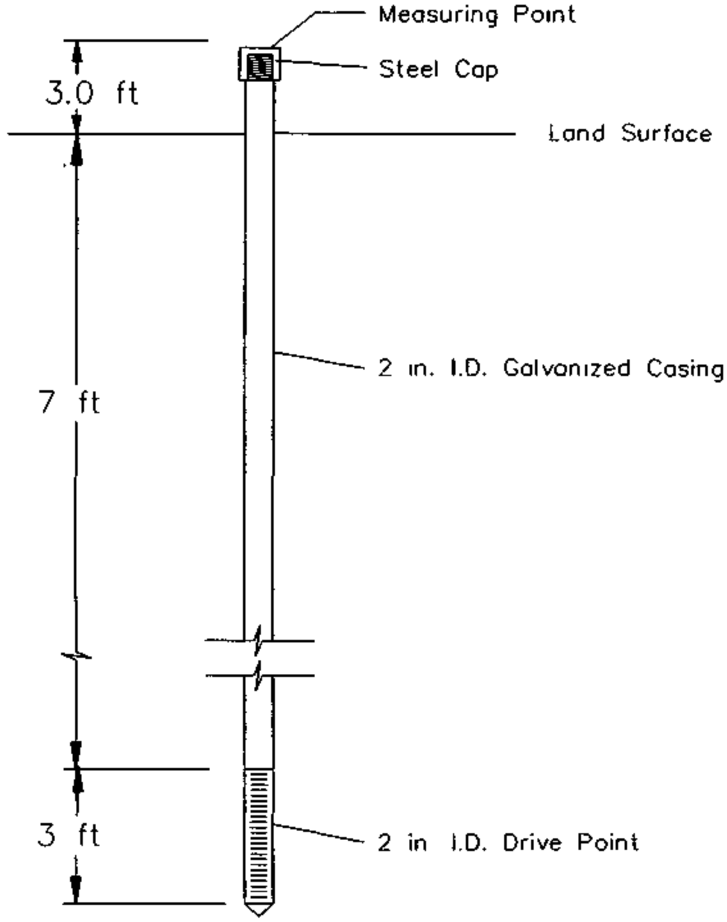
Drawing not to scale

Illinois State Water Survey Drillers Log
Section 7.5a, T.21N., R.8W., Mason County
SWS Hole # N/A

Depth (feet)	Description of Materials
	Log Not Available

Sand Point Observation Well 5

Appendix B. Continued

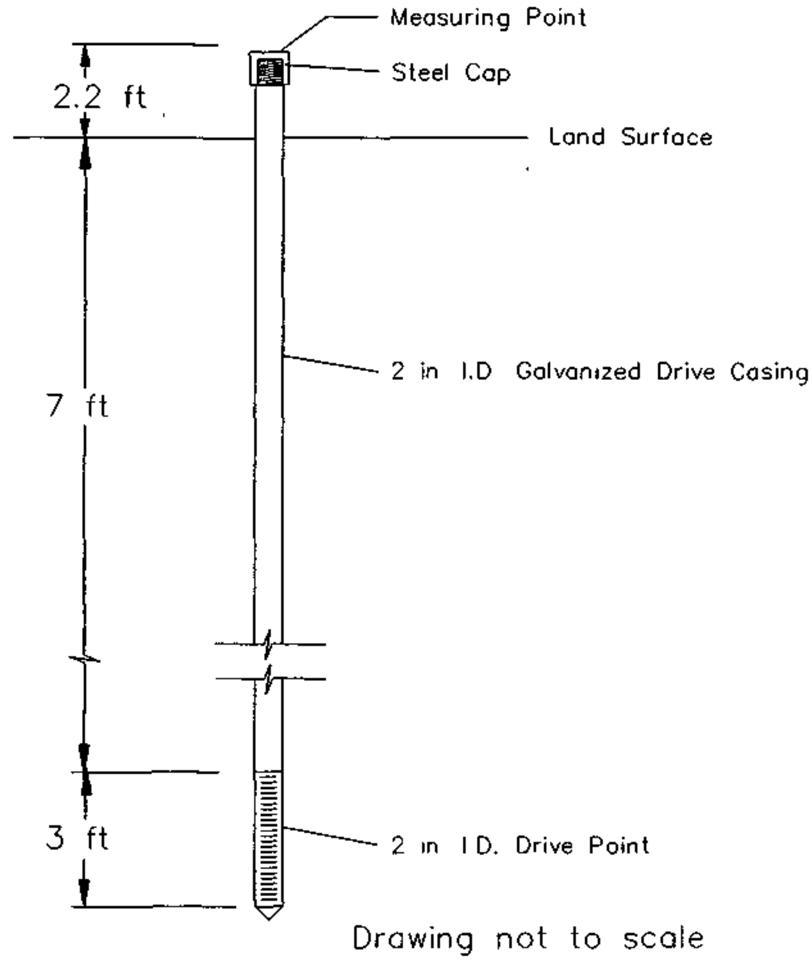


Drawing not to scale

Illinois State Water Survey Drillers Log
Section 8.6b, T 21N., R.8W., Mason County
SWS Hole # N/A

Depth (feet)	Description of Materials
	Log Not Available

Sand Point Observation Well 6

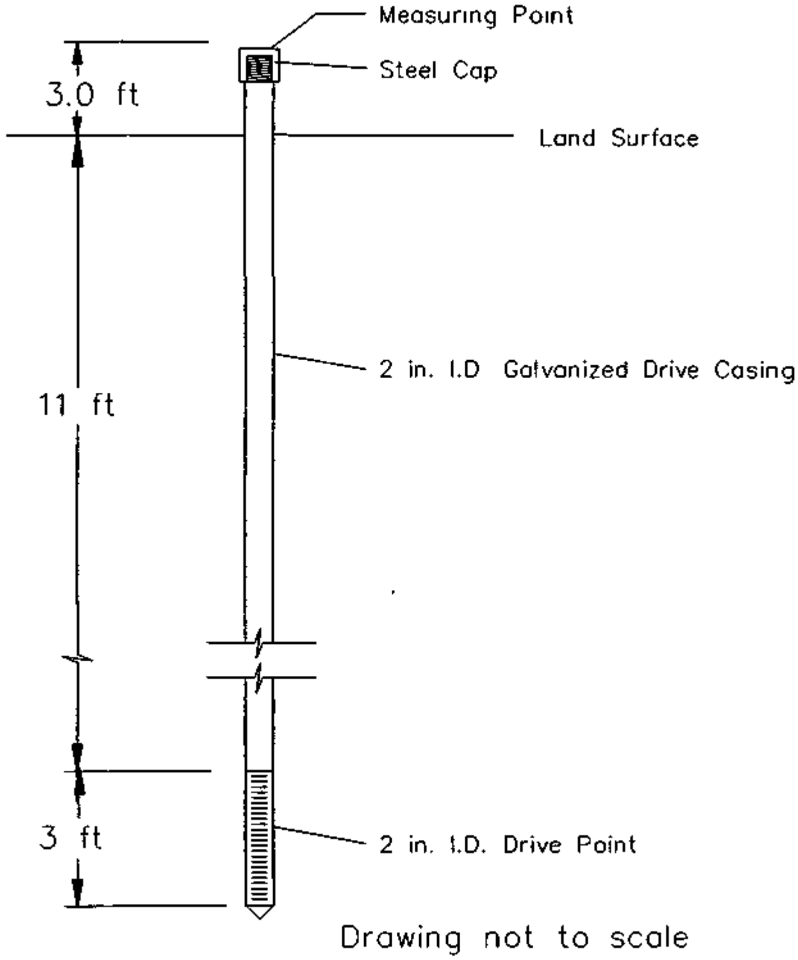


Illinois State Water Survey Drillers Log
Section 8.6a, T.21N., R.8W., Mason County
SWS Hole # N/A

Depth (feet)	Description of Materials
	Log Not Available

Sand Point Observation Well 7

Appendix B. Continued

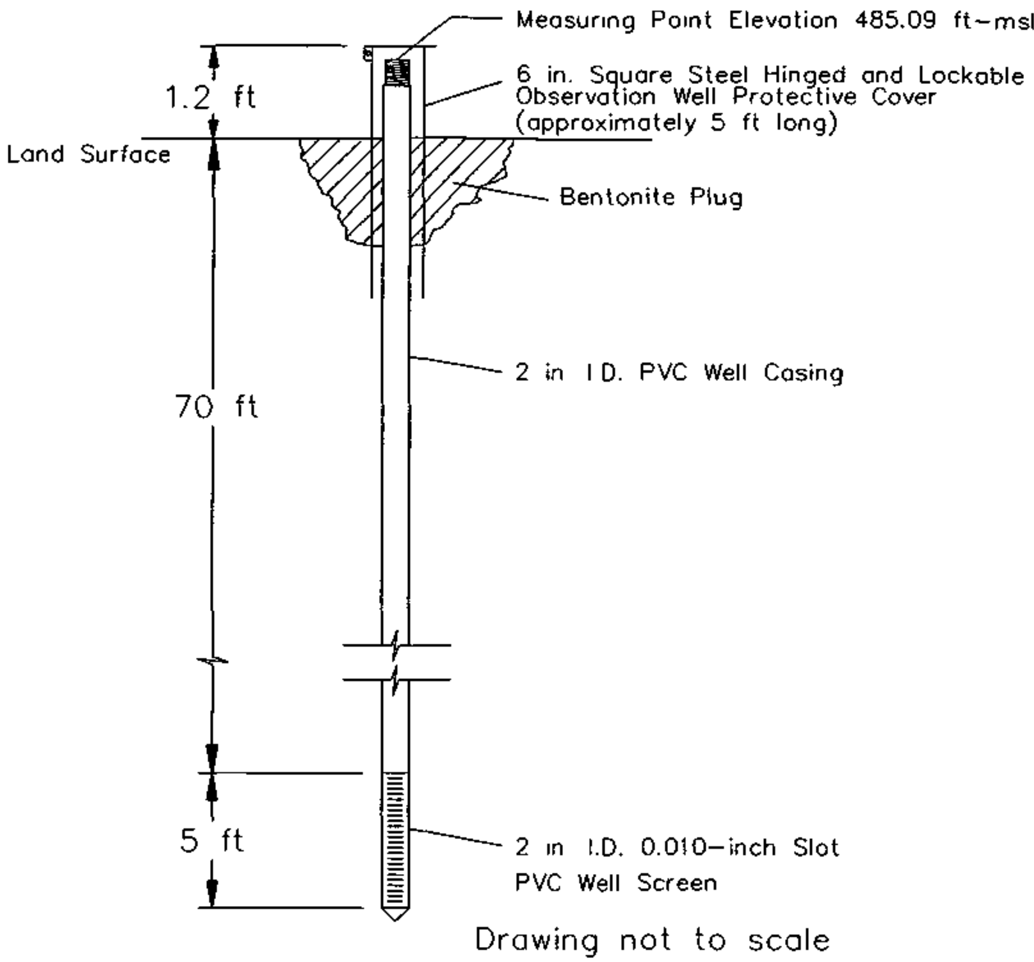


Illinois State Water Survey Drillers Log
Section 8 8c, T.21N., R.8W., Mason County
SWS Hole # N/A

Depth (feet)	Description of Materials
	Log Not Available

Sand Point Observation Well 8

Appendix B. Continued



Illinois State Water Survey Drillers Log
Section 7.2a, T.21N., R.8W., Mason County
SWS Hole # R-280

Depth (feet)	Description of Materials
0-4.0	Dark brown organic medium sand
4.0-6.0	Brown medium sand
6.0-10.0	Brown medium clayey sand
10.0-16.0	Brown fine to medium sand, dirty
16.0-34.0	Light brown fine to medium sand
34.0-49.0	Light brown medium to coarse sand
49.0-75.0	Gray coarse sand, some gravel

Sand Lake Observation Well 1

Appendix B. Continued

ILLINOIS STATE WATER SURVEY WELL CONSTRUCTION REPORT

Sand Lake Observation Well: SL0W1

ISWS Hole Number: R-280	Location: Section 7.2a, T.21N., R.8W.
Date Drilled: June 5, 1995	County: Mason
Driller: Coulson	Static Water Level: 6.65 ft below land surface
Hydrogeologist: Buck	Casing Top Elevation: 485.09 ft-msl

Located west of Route 97, about 200 ft north of farmer's field access road off of Sand Lake Road near large growth of trees, or approximately 4400 east and 250 ft north of the southwest corner of Section 7.

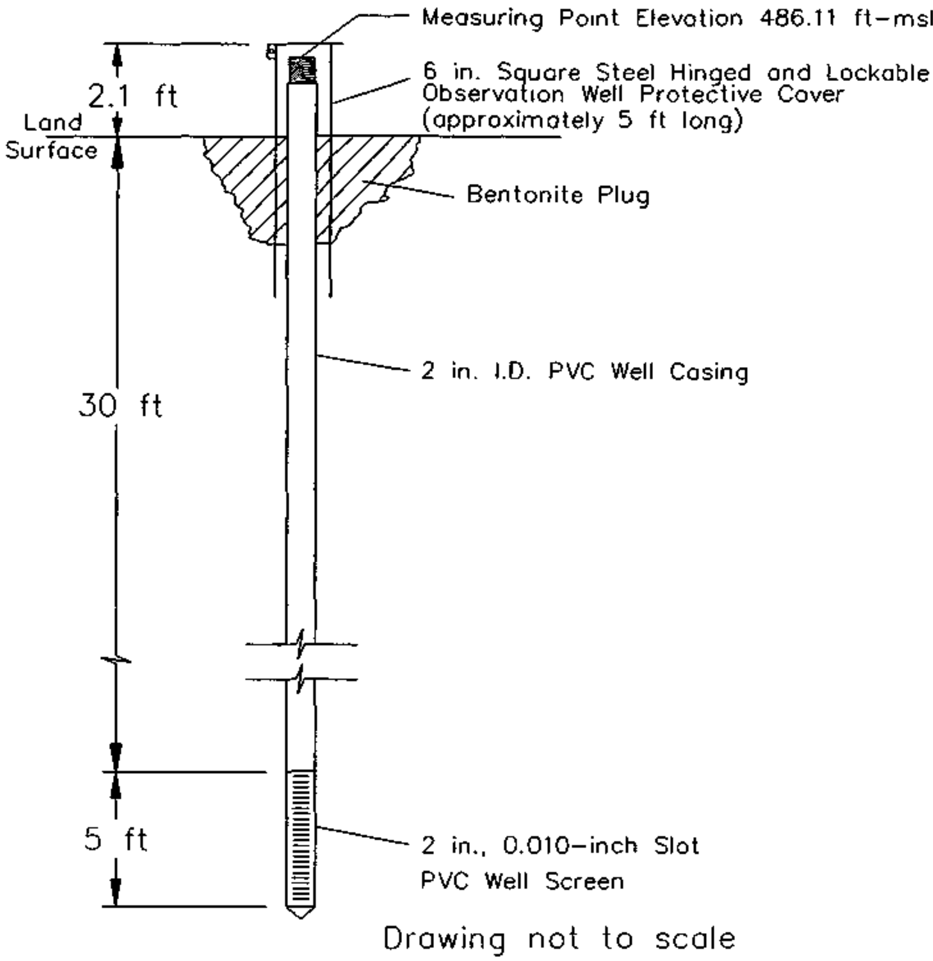
Geology:

Depth (ft)	*Description of materials*
0-4	Dark brown organic medium sand
4-6	Brown medium sand
6-10	Brown medium clayey sand
10-16	Brown fine to medium sand, dirty
16-34	Light brown fine to medium sand
34-49	Light brown medium to coarse sand
49-75	Gray coarse sand some gravel

Well Construction Features:

Seven 10-ft lengths of 2-in. diameter schedule 40 PVC threaded pipe set from 0 to 70 ft.
One 5-ft length of 2-in. diameter schedule 40 0.010 in. (40 slot) PVC screen set from 65 to 70 ft.
One 2.5-ft length of 2-in. diameter schedule 40 PVC pipe set from +2.5 to 0 ft.
Bentonite plug from 0 to 1 ft below land surface.
6-in. square metal well protector.

Appendix B. Continued



Illinois State Water Survey Drillers Log
Section 7 2a, T.21N., R.8W., Mason County
SWS Hole # R-281

Depth (feet)	Description of Materials
0-4 0	Dark brown organic medium sand
4.0-6.0	Brown medium sand
6 0-9.0	Brown medium clayey sand
9 0-15.0	Brown fine to medium sand
15 0-35 0	Light brown fine to medium sand

Sand Lake Observation Well 2

ILLINOIS STATE WATER SURVEY WELL CONSTRUCTION REPORT

Sand Lake Observation Well: SLOW2

ISWS Hole Number: R-281
Date Drilled: June 5, 1995

Location: Section 7.2a, T.21N., R.8W.
County: Mason

Driller: Coulson
Hydrogeologist: Buck

Static Water Level: 6.77 ft below land surface
Casing Top Elevation: 486.11 ft-msl

Located west of Route 97, about 200 ft north of farmer's field access road off of Sand Lake Road near large growth of trees, or approximately 4400 east and 250 ft north of the southwest corner of Section 7.

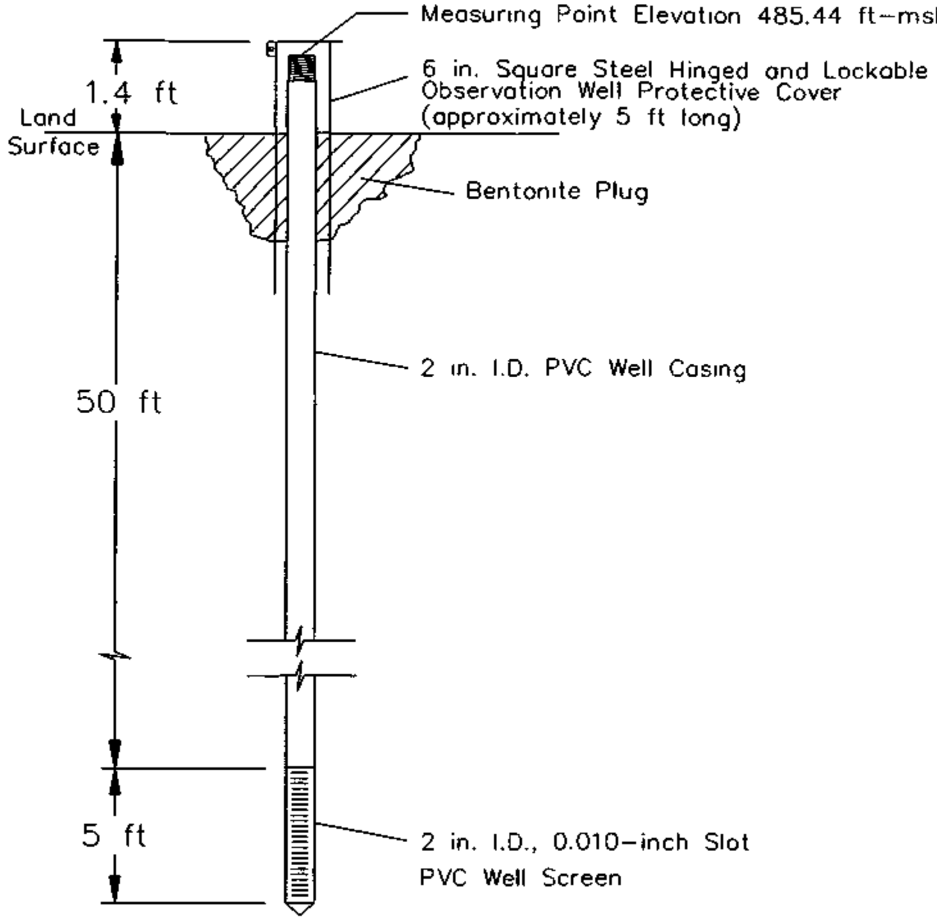
Geology:

Depth (ft)	*Description of materials*
0-4	Dark brown organic medium sand
4-6	Brown medium sand
6-9	Brown medium clayey sand (hard drilling at 9 ft)
9-15	Brown fine to medium sand
16-35	Light brown fine to medium sand

Well Construction Features:

Three 10-ft lengths of 2-in. diameter schedule 40 PVC threaded pipe set from 0 to 30 ft.
One 5-ft length of 2-in. diameter schedule 40 0.010 in. (10 slot) PVC screen set from 30 to 35 ft.
One 2.5-ft length of 2-in. diameter schedule 40 PVC pipe set from +2.5 to 0 ft.
Bentonite plug from 0 to 1 ft below land surface.
6-in. square metal well protector.

Appendix B. Continued



Drawing not to scale

Illinois State Water Survey Drillers Log
Section 7.2a, T.21N., R.8W, Mason County
SWS Hole # R-282

Depth (feet)	Description of Materials
0-4 0	Dark brown organic medium sand
4.0-6.0	Brown medium sand
6 0-10.0	Brown medium clayey sand
10 0-16 0	Brown fine to medium sand, dirty
16.0-34.0	Light brown fine to medium sand
34.0-49.0	Light brown medium to coarse sand
49 0-113.0	Gray coarse sand, some gravel
113.0	Gray shale

Sand Lake Observation Well 3

Appendix B. Continued

ILLINOIS STATE WATER SURVEY WELL CONSTRUCTION REPORT

Sand Lake Observation Well: SLOW3

ISWS Hole Number: R-282
Date Drilled: June 6, 1995

Location: Section 7.2a, T.21N., R.8W.
County: Mason

Driller: Coulson
Hydrogeologist: Buck

Static Water Level: 6.81 ft below land surface
Casing Top Elevation: 485.44 ft-msl

Located west of Route 97, about 200 ft north of farmer's field access road off of Sand Lake Road near large growth of trees, or approximately 4400 east and 250 ft north of the southwest corner of Section 7.

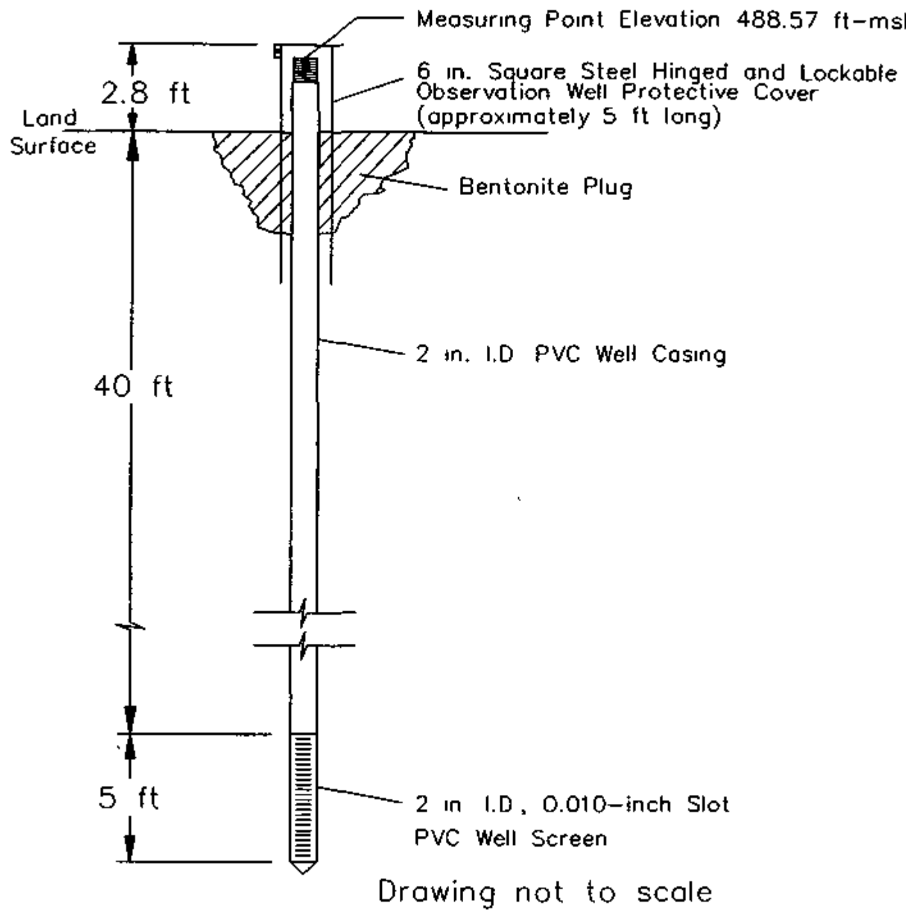
Geology:

Depth (ft)	*Description of materials*
0-4	Dark brown organic medium sand
4-6	Brown medium sand
6-10	Brown medium clayey sand
10-16	Brown fine to medium sand, dirty
16-34	Light brown fine to medium sand
34-49	Light brown medium to coarse sand
49-113	Gray coarse sand some gravel
113	Gray shale

Well Construction Features:

Five 10-ft lengths of 2-in. diameter schedule 40 PVC threaded pipe set from 0 to 50 ft.
One 5-ft length of 2-in. diameter schedule 40 0.010 in. (10 slot) PVC screen set from 50 to 55 ft.
One 2.5-ft length of 2-in. diameter schedule 40 PVC pipe set from +2.5 to 0 ft.
Bentonite plug from 0 to 1 ft below land surface.
6-in. square metal well protector.

Appendix B. Continued



Illinois State Water Survey Drillers Log
Section 8.5a, T.21N, R.8W, Mason County
SWS Hole # R-283

Depth (feet)	Description of Materials
0-3 0	Black sandy clay loam
3.0-12.0	Brown fine to medium sand
12.0-30.0	Brown fine sand, dirty
30 0-38.0	Brown fine to medium sand
38 0-45 0	Brown medium to coarse sand

Sand Lake Observation Well 4

ILLINOIS STATE WATER SURVEY WELL CONSTRUCTION REPORT

Sand Lake Observation Well: SL0W4

ISWS Hole Number: R-283
Date Drilled: June 7, 1995

Location: Section 8.5a, T.21N., R.8W.
County: Mason

Driller: Coulson
Hydrogeologist: Buck

Static Water Level: 3.37 ft below land surface
Casing Top Elevation: 488.57 ft-msl

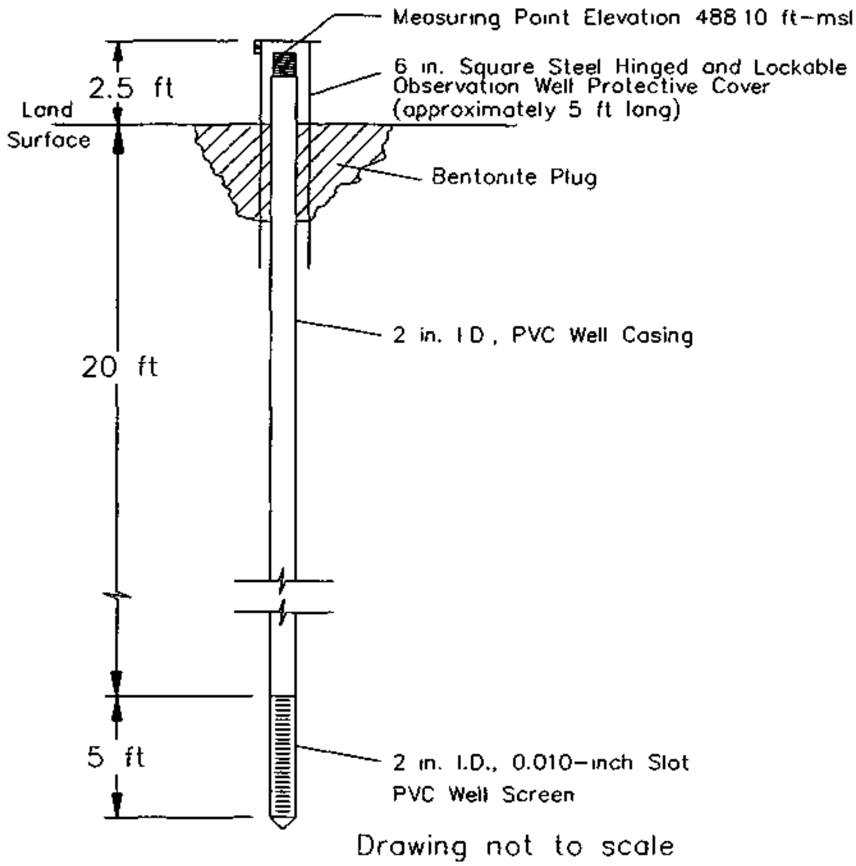
Located near intersection of old Illinois Central railroad grade and north/south fence line through Section 8, or approximately 2650 east and 300 ft north of the southwest corner of Section 8.

Geology:

Depth (ft)	*Description of materials*
0-3	Black sandy clay loam
3-12	Brown fine to medium sand
12-30	Brown fine sand dirty
30-38	Brown fine to medium sand
38-45	Brown medium to coarse sand

Weil Construction Features:

Four 10-ft lengths of 2-in. diameter schedule 40 PVC threaded pipe set from 0 to 40 ft.
One 5-ft length of 2-in. diameter schedule 40 0.010 in. (40 slot) PVC screen set from 35 to 40 ft.
One 2.5-ft length of 2-in. diameter schedule 40 PVC pipe set from +2.5 to 0 ft.
Bentonite plug from 0 to 1 ft below land surface.
6-in. square metal well protector.



Illinois State Water Survey Drillers Log
Section 8 5a, T.21N , R 8W , Mason County
SWS Hole # R-284

Depth (feet)	Description of Materials
0-3 0	Black sandy clay loam
3 0-12.0	Brown fine to medium sand
12.0-25.0	Brown fine sand, dirty

Sand Lake Observation Well 5

Appendix B. Continued

ILLINOIS STATE WATER SURVEY WELL CONSTRUCTION REPORT

Sand Lake Observation Well: SLOW5

ISWS Hole Number: R-284
Date Drilled: June 7, 1995

Location: Section 8.5a, T.21N., R.8W.
County: Mason

Driller: Coulson
Hydrogeologist: Buck

Static Water Level: 3.07 ft below land surface
Casing Top Elevation: 488.10 ft-msl

Located near intsection of old Illinois Central railroad grade and north/south fence line through Section 8, or approximately 2650 east and 300 ft north of the southwest corner of Section 8.

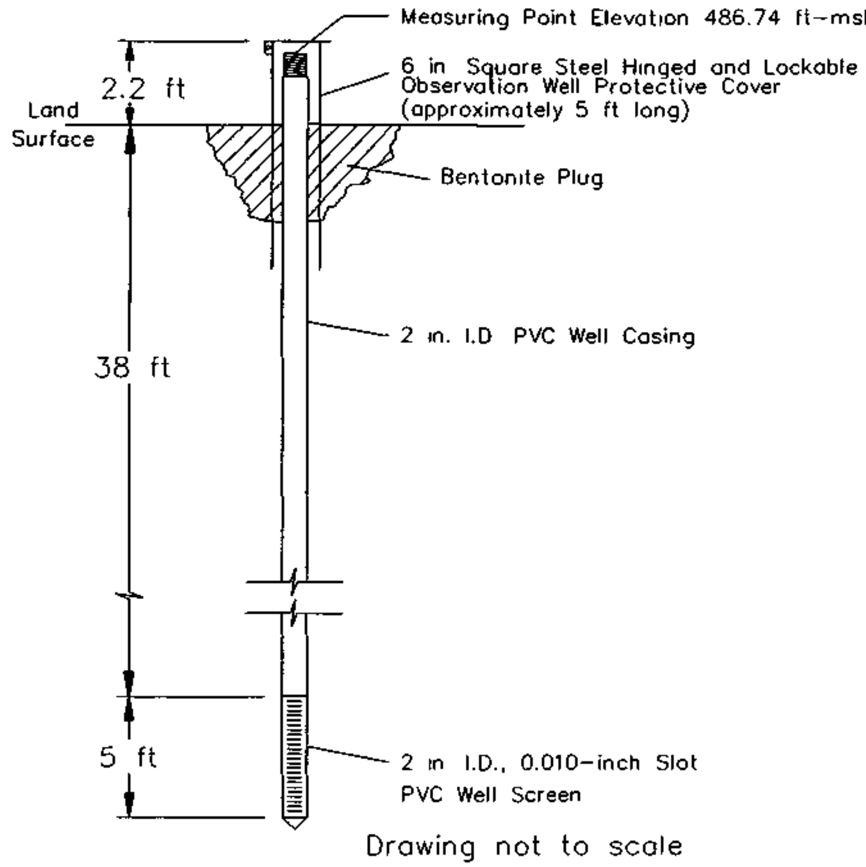
Geology:

Depth (ft)	*Description of materials*
0-3	Black sandy clay loam
3-12	Brown fine to medium sand
12-25	Brown fine sand dirty

Well Construction Features:

Two 10-ft lengths of 2-in. diameter schedule 40 PVC threaded pipe set from 0 to 20 ft.
One 5-ft length of 2-in. diameter schedule 40 0.010 in. (40 slot) PVC screen set from 15 to 20 ft.
One 2.5-ft length of 2-in. diameter schedule 40 PVC pipe set from +2.5 to 0 ft.
Bentonite plug from 0 to 1 ft below land surface.
6-in. square metal well protector.

Appendix B. Continued



Illinois State Water Survey Drillers Log
Section 7.1c, T 21N , R.8W , Mason County
SWS Hole # R–285

Depth (feet)	Description of Materials
0–4 0	Brown medium sand, some organics
4.0–5 0	Brown fine to medium sand
5 0–6 0	Brown clayey sand
6 0–43.0	Light brown fine to medium sand

Sand Lake Observation Well 6

Appendix B. Continued

ILLINOIS STATE WATER SURVEY WELL CONSTRUCTION REPORT

Sand Lake Observation Well: SLOW6

ISWS Hole Number: R-285	Location: Section 7.lc, T.21N., R.8W.
Date Drilled: June 8, 1995	County: Mason
Driller: Coulson	Static Water Level: 7.09 ft below land surface
Hydrogeologist: Buck	Casing Top Elevation: 486.74 ft-msl

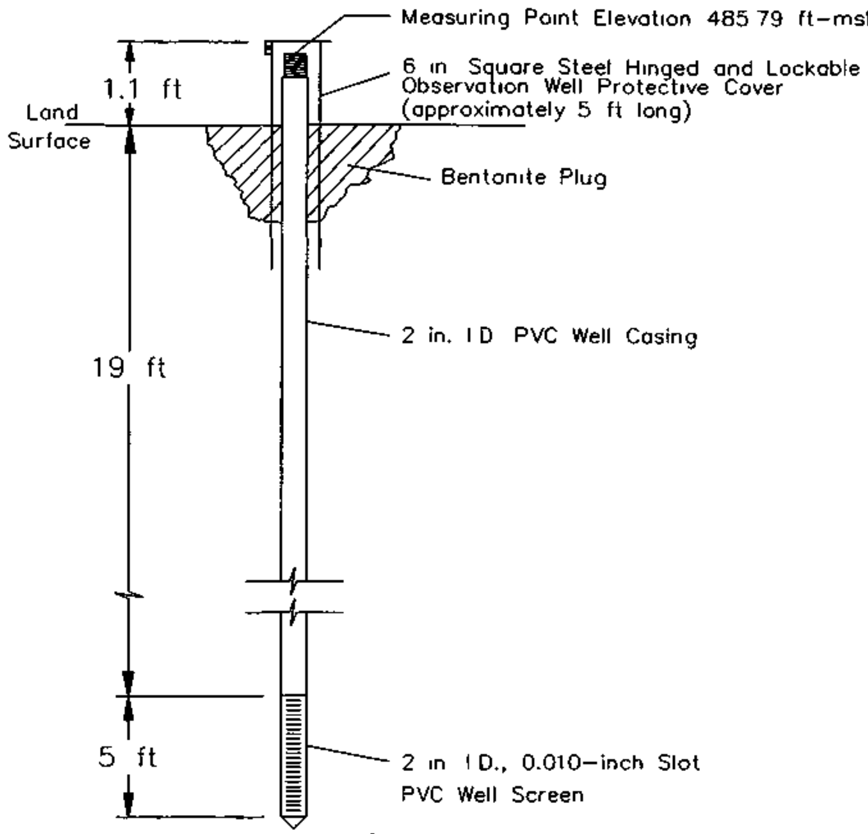
Located about 50 ft south of the Amoco Oil pipeline and about 200 ft west of the old Illinois Central railroad grade, or approximately 5150 east and 1500 ft north of the southwest corner of Section 7.

Geology:

Depth (ft)	*Description of materials*
0-4	Brown medium sand, some organics
4-5	Brown fine to medium sand
5-6	Brown clayey sand
6-43	Light brown fine to medium sand

Well Construction Features:

Four 10-ft lengths of 2-in. diameter schedule 40 PVC threaded pipe set from +2 to 38 ft.
One 5-ft length of 2-in. diameter schedule 40 0.010 in. (40 slot) PVC screen set from 38 to 43 ft.
Bentonite plug from 0 to 1 ft below land surface.
6-in. square metal well protector.



Drawing not to scale

Illinois State Water Survey Drillers Log
Section 7 1c, T 21N , R 8W , Mason County
SWS Hole # R-286

Depth (feet)	Description of Materials
0–4.0	Brown medium sand, some organics
4.0–5 0	Brown fine to medium sand
5.0–6 0	Brown clayey sand
6 0–25 0	Light brown fine to medium sand

Sand Lake Observation Well 7

Appendix B. Continued

ILLINOIS STATE WATER SURVEY WELL CONSTRUCTION REPORT

Sand Lake Observation Well: SLOW7

ISWS Hole Number: R-286
Date Drilled: June 8, 1995

Location: Section 7.lc, T.21N., R.8W.
County: Mason

Driller: Coulson
Hydrogeologist: Buck

Static Water Level: 6.65 ft below land surface
Casing Top Elevation: 485.79 ft-msl

Located about 50 ft south of the Amoco Oil pipeline and about 200 ft west of the old Illinois Central railroad grade, or approximately 5150 east and 1500 ft north of the southwest corner of Section 7.

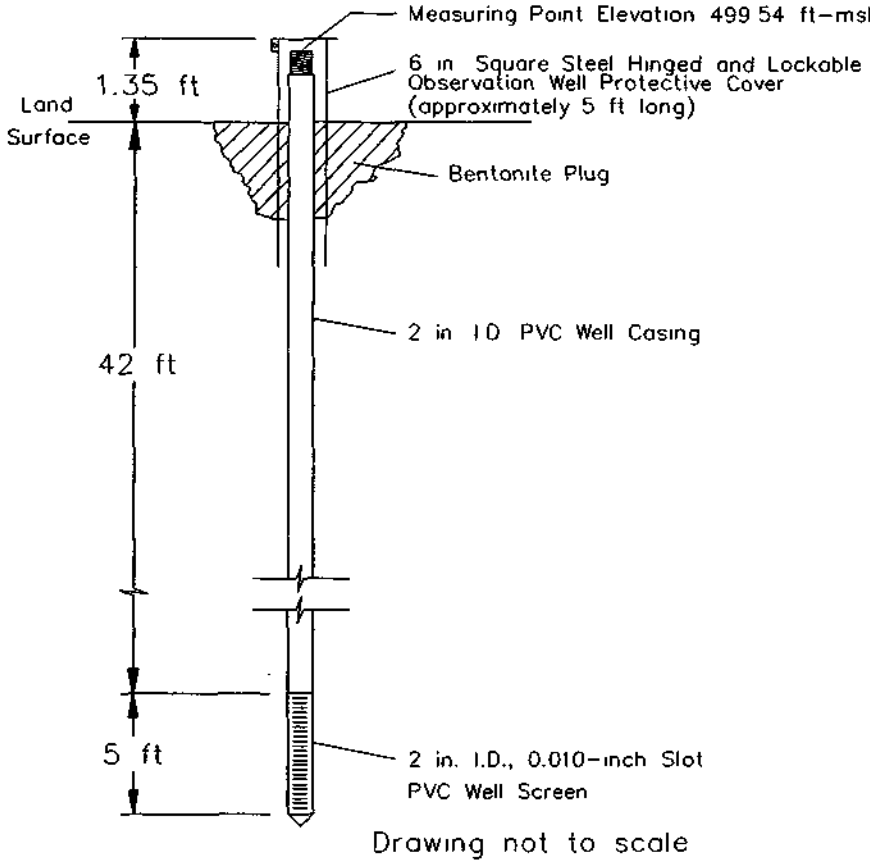
Geology:

Depth (ft)	*Description of materials*
0-4	Brown medium sand, some organics
4-5	Brown fine to medium sand
5-6	Brown clayey sand
6-25	Light brown fine to medium sand

Well Construction Features:

Two 10-ft lengths of 2-in. diameter schedule 40 PVC threaded pipe set from +1 to 19 ft.
One 5-ft length of 2-in. diameter schedule 40 0.010 in. (40 slot) PVC screen set from 19 to 24 ft.
Bentonite plug from 0 to 1 ft below land surface.
6-in. square metal well protector.

Appendix B. Continued



Illinois State Water Survey Drillers Log
Section 7.2b, T 21N , R 8W., Mason County
SWS Hole # R-375

Depth (feet)	Description of Materials
0-47.0	Brown medium sand

Sand Lake Observation Well 8

ILLINOIS STATE WATER SURVEY WELL CONSTRUCTION REPORT

Sand Lake Observation Well: SL0W8

ISWS Hole Number: R-375	Location: Section 7.2b, T.21N., R.8W.
Date Drilled: November 12, 1996	County: Mason
Driller: Coulson	Static Water Level: 27.84 ft below land surface
Hydrogeologist: Buck	Casing Top Elevation: 499.54 ft-msl

Located about 200 ft north of the Amoco Oil pipeline and about 500 ft east of the old sheds, or approximately 4700 east and 1300 ft north of the southwest corner of Section 7.

Geology:

Depth (ft)	*Description of materials*
0-47.0	Brown medium sand

Well Construction Features:

One 2.5-ft length of 2-in. diameter schedule 40 PVC threaded pipe set from +0.5 to 42 ft.
Four 10-ft lengths of 2-in. diameter schedule 40 PVC threaded pipe set from 2 to 42 ft.
One 5-ft length of 2-in. diameter schedule 40 0.010 in. (40 slot) PVC screen set from 42 to 47 ft.
Bentonite plug from 0 to 1 ft below land surface.
6-in. square metal well protector.

Appendix C. Soil Textural Classifications

Appendix C.

Soil Separates

Soil separate	*Diameter limits (millimeters[2])*	*Diameter limits (inches[2])*
Very coarse sand	2.00 - 1.00	3.1×10^{-3} - 1.55×10^{-3}
Coarse sand	1.00 - 0.50	1.55×10^{-3} - 7.75×10^{-3}
Medium sand	0.50 - 0.25	7.75×10^{-3} - 3.86×10^{-3}
Fine sand	0.25-0.10	3.86×10^{-3} - 1.55×10^{-4}
Very fine sand	0.10 - 0.05	1.55×10^{-4} - 7.75×10^{-5}
Silt	0.05-0.002	7.75×10^{-5}-3.10×10^{-6}
Clay	Less than 0.002	Less than 3.10×10^{-6}

Broad Textural Classes Recognized by Soil Managers

1. Sands - soils generally containing more than 70 percent sand type material
2. Silts - soils generally containing more than 80 percent silt type material
3. Clays - soils generally containing more than 40 percent clay type material
4. Loams - intermediate mixture of sand, silt, and clay materials

Field Textural Class Determination Techniques

Sand: Sand grains readily visible and, when squeezed, a cast will form that will fall apart when released.

Loamy Sand: Individual sand grains visible and, when squeezed, a cast will form that will not fall apart but will break when handled.

Sandy Loam: Individual sand grains visible and, when squeezed, a cast will form that can be handled carefully without breaking.

Loam: Uniform mixture of sand, silt, and clay that feels gritty and, when squeezed, will form a cast that can be handled without breaking.

Silt Loam: Ranges from gritty to floury depending on size of the sand particles and, when squeezed, the cast can be passed from hand to hand without breaking and the soil will not ribbon. It may give a broken appearance when pressed over the forefinger.

Silt: Very smooth and floury feeling that may come close to forming a ribbon but will most likely break in the process.

Appendix C. Concluded

Sandy Clay Loam: Plastic soil that may have visible sand grains and will form a ribbon which barely sustains its own weight.

Clay Loam: Heavy with few visible sand grains that will form a ribbon which barely sustains its own weight.

Silty Clay Loam: Heavy, uniform mass with a rough appearance that forms a ribbon which will barely sustain its own weight.

Sandy Clay: Plastic soil that will form a ribbon capable of sustaining its own weight and may appear to have a gritty feel or visible sand grains.

Silty Clay: Soil that will form a ribbon capable of sustaining its own weight and will appear rough or broken.

Clay: Plastic to very plastic soil that will appear greasy or sticky and is capable of forming a long ribbon which will support its own weight.

Note: Adapted from Sopher and Baird, 1978

Appendix D. Soil Sample Field Texture Definitions

Appendix D.

Sand Lake - Soil Sample No. 1 Location- (50 ft S of SPOW7) 4,000 ft W , 600 ft N of SE/c Sec 8, T 21N, R 8W, Mason Co Equipment 7/8 in. x 12 in chrome plated soil probe using slide hammer							Date collected: 12/15/95
Sample Depth (in.)	Unified Soil Classification System	Munsell™ Soil Color Chart Description					
	Dry Sample Description	Dry			Wet		
		Hue	Value/ Chroma	Description	*Hue	Value/ Chroma	Description
0-7	Olive gray fine sand with some silt	10YR	5/2	Grayish Brown	10YR	2/1	Black
7- 14	Olive gray fine sand	10YR	4/1	Dark gray	10YR	2/1	Black
14-21	Light brown to brown fine sand	10YR	5/1	Gray	10YR	2/1	Black
21-28	Olive gray to brown fine sand	10YR	4/1	Dark gray	10YR	2/1	Black
28-35	Light brown fine sand with light gray streaks	10YR	5/2	Grayish brown	10YR	3/2	Very dark grayish brown
35-42	Light brown fine sand	10YR	4/1	Dark gray	10YR	3/2	Very dark grayish brown
42-49	Light brown fine sand	10YR	5/1	Gray	10YR	3/2	Very dark grayish brown
49-56	Light brown fine sand	10YR	5/2	Grayish brown	10YR	3/3	Dark brown
56-63	Light brown fine sand	10YR	5/2	Grayish brown	10YR	3/2	Very dark grayish brown
63-70	Light brown fine sand with yellow streaks	10YR	5/3	Brown	10YR	3/4	Dark yellowish brown
70 - 77 (sample 1)	Light brown fine sand	10YR	5/2	Grayish brown	10YR	3/2	Very dark grayish brown
70 - 77 (sample 2)	Light brown fine sand - (interbedded gray balls)	10YR	5/2	Grayish brown	10YR	6/3	Pale brown
			3/3	dark brown		2/2	Very dark brown
77-85	Yellowish orange fine sand	10YR	5/4	Yellowish brown	10YR	4/6	Dark yellowish brown
85-92	Light brown fine sand	10YR	5/3	Brown	10YR	3/4	Dark yellowish brown
92-99	Light brown fine sand with yellowish orange streaks	10YR	5/4	Yellowish brown	10YR	4/6	Dark yellowish brown
99 - 106	Light brown fine sand	10YR	5/3	Brown	10YR	3/6	Dark yellowish brown

Sand Lake - Soil Sample No.2 | Date collected: 4/10/96

Location 5 ft. southeast of SG4
4750 ft W, 1500 ft, of SE/c
Sec 8, T 21N, R 8W., Mason Co

Equipment 7/8 in x 21 in. chrome plated soil probe using slide hammer

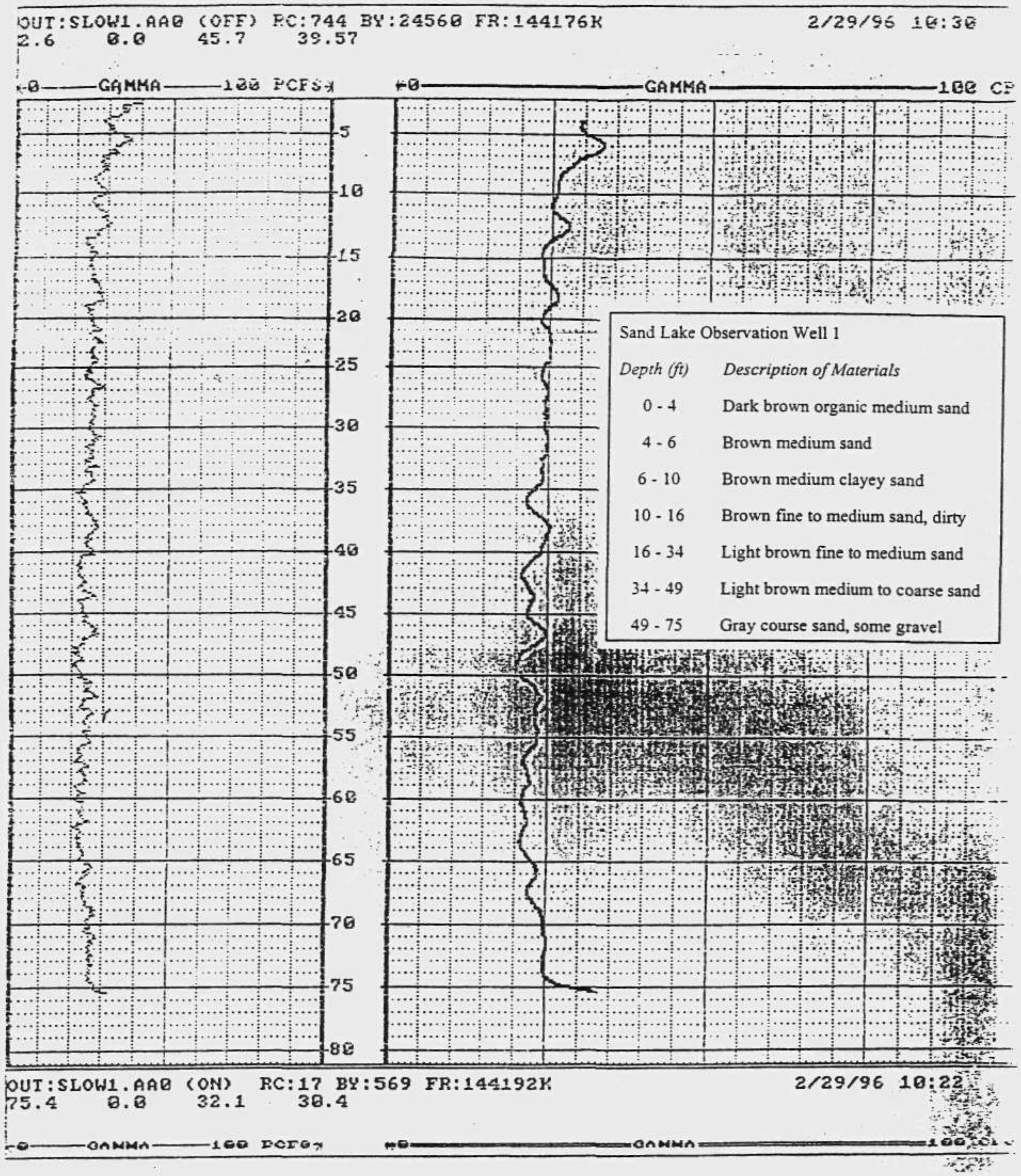
Sample Depth (in.)	Unified Soil Classification System Sample Description	Munsell™ Soil Color Chart Description					
		Dry			Wet		
		*Hue	Value/ Chroma	Description	*Hue	Value/ Chroma	Description
0-12	Olive gray to dark gray clay silt with organic matter	10YR	5/2	Grayish brown	10YR	3/1	Very dark gray
12-24	Greenish gray to olive gray silty fine sand	10YR	6/1	Gray	10YR	3/1	Very dark gray
24-36	Greenish gray to olive gray to light brown fine clayey sand w/ yellow streaks	10YR	6/2	Light brownish gray	5YR	4/6	Yellowish red
		7.5YR	6/8	Reddish yellow	10YR	3/1	Very dark gray
36-48	Olive gray fine silty sand (some clay present)	10YR	5/1	Gray	10YR	2/1	Black
48-60	Greenish to olive gray silty sand	10YR	5/2	Grayish brown	10YR	2/1	Black
60-72	Greenish to olive gray fine sandy clay	10YR	4/2	Dark grayish brown	10YR	3/2	Very dark grayish brown
			5/6	Yellowish brown	10YR	4/6	Yellowish brown
72-84	Light brown fine sand with greenish gray streaks	10YR	5/2	Grayish brown	10YR	3/1	Very dark gray
			4/6	Dark yellowish brown	10YR	4/6	Dark yellowish brown
84-96	Light brown fine sand with olive gray steaks	10YR	5/1	Gray	10YR	3/2	Very dark grayish brown
			4/6	Dark yellowish brown	10YR	3/4	Dark yellowish brown
96 - 108	Light brown fine sand with some yellowish/orange streaks	10YR	5/2	Grayish brown	10YR	2/1	Black
			7/4	Very pale brown	10YR	4/6	Very pale brown
108 -120	Olive gray fine sand	10YR	5/1	Gray	10YR	3/2	Very dark grayish brown
			5/6	Yellowish brown	10YR	-	Yellowish brown
120-132	Olive gray fine sand with yellow streaks	10YR	5/1	Gray	10YR	3/1	Very dark gray
			5/6	Yellowish brown	10YR	4/6	Very pale brown
132 - 144	Olive gray fine sand with yellow streaks	10YR	5/1	Gray	10YR	3/1	Very dark gray
			5/8	Yellowish brown	10YR	4/6	Yellowish brown

Appendix D. Concluded

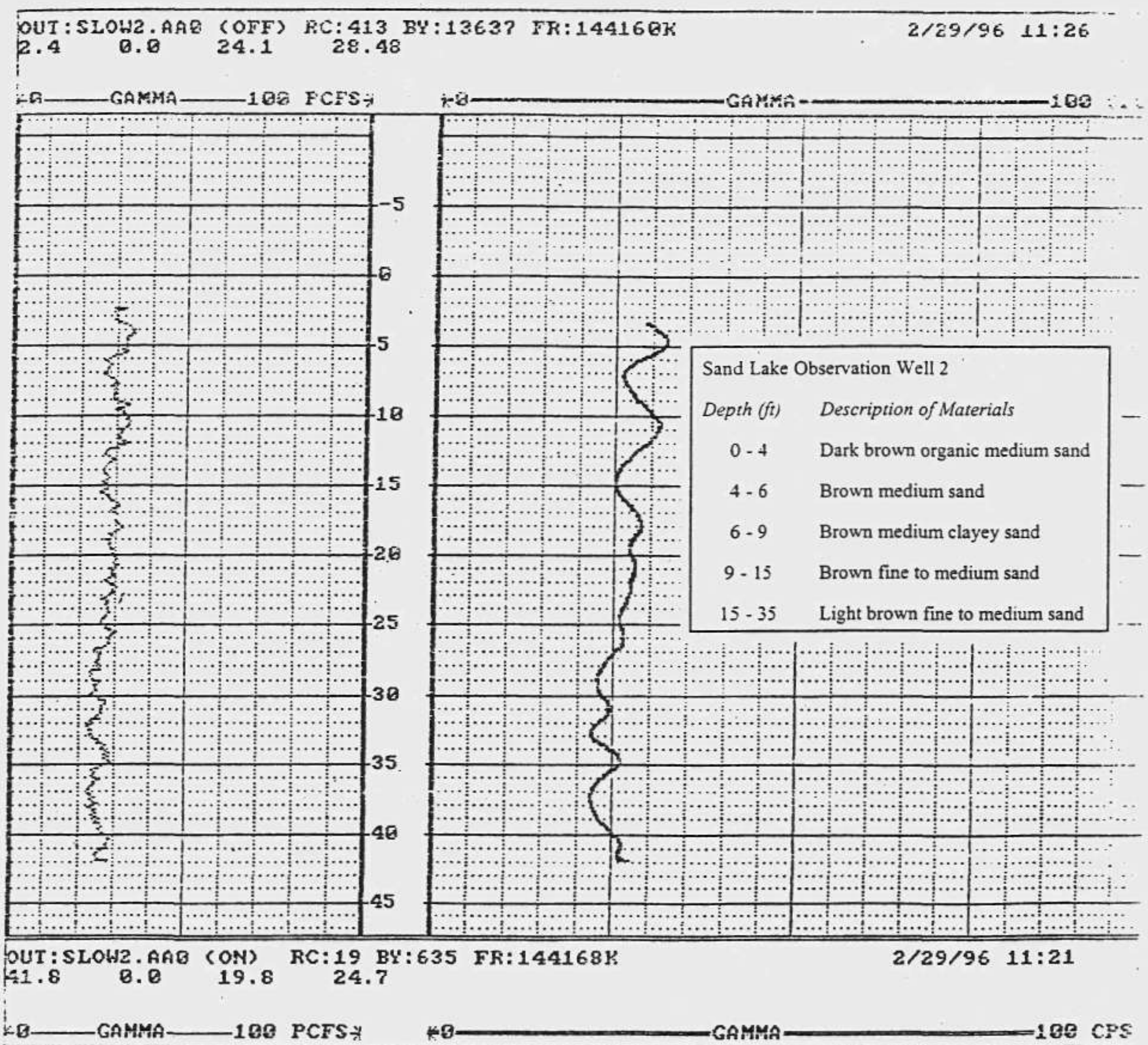
Note: * The Hue notation of a color indicates its relation to Red, Yellow, Green, Blue, and Purple. The symbol for hue is the letter abbreviation of the color of the rainbow (R for red, YR for yellow red, and Y for yellow) preceded by numbers from 0 to 10. With each letter range, the hue becomes more yellow and less red.

Appendix E. Observation Well Gamma Logs

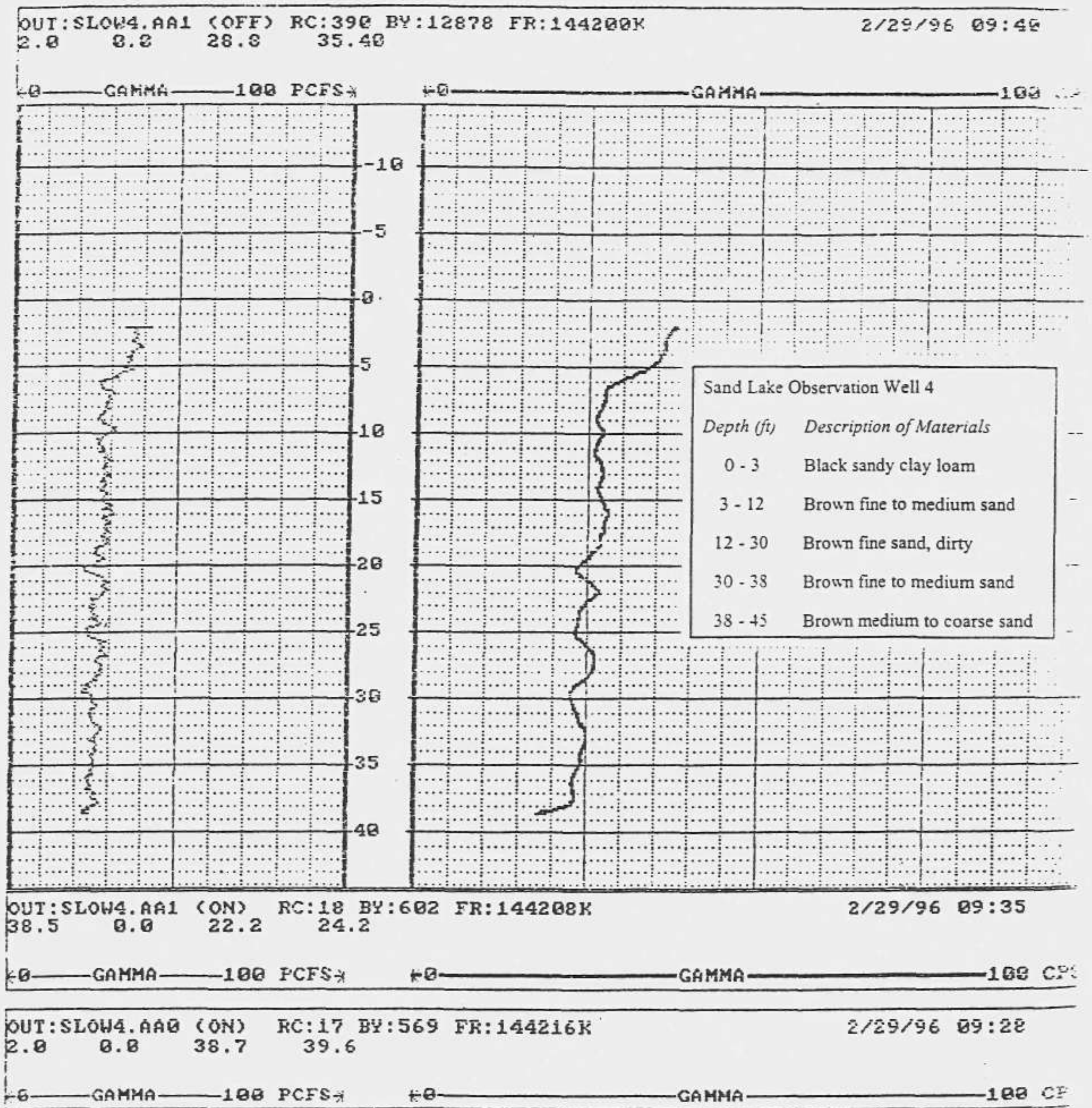
Appendix E.


OUT:SLOW1.AA0 (OFF) RC:744 BY:24560 FR:144176K 2/29/96 10:30
2.6 0.0 45.7 39.57
0 GAMMA 100 PCFS
0 GAMMA 100 CP
Sand Lake Observation Well 1
Depth (ft) Description of Materials
0 - 4 Dark brown organic medium sand
4 - 6 Brown medium sand
6 - 10 Brown medium clayey sand
10 - 16 Brown fine to medium sand, dirty
16 - 34 Light brown fine to medium sand
34 - 49 Light brown medium to coarse sand
49 - 75 Gray course sand, some gravel
OUT:SLOW1.AA0 (ON) RC:17 BY:569 FR:144192K 2/29/96 10:22
75.4 0.0 32.1 30.4

Appendix E. Continued



Appendix E. Concluded



Appendix F. Illinois State Geological Survey Geotechnical Laboratory Mechanical Analysis of Soil Samples

Appendix F.

		Sand							"Fines"	
	gravel	very coarse	coarse	medium		fine	very fine		silt	clay
Sample name (lab no.)	***2.00**	**1.00**	**0.500**	**0.355**	**0.250**	**0.125**	**0.090**	**0.063**	**0.063-0.004**	**<.004**
ISWS Mason Co. 0-7" (10848)	99.64	99.82	97 04	85 04	47.64	12.25	9 22	7.26	6.75	0.51
50' S of SPOW7 7-14" (10849)	100 00	99 92	96.50	84.48	48 73	14 46	10 80	9 02	8.26	0.76
14-21" (10850)	100 00	99 89	98.03	87.54	51.62	14.40	10 85	9.25	7.31	1 94
21-28" (10851)	100.00	99.94	97.33	86.62	50.49	13.42	10.81	9.11	7.66	1.45
28-35" (10852)	100.00	99.96	97.70	88.97	53.90	13.86	11.17	9.50	7.99	1.51
35-42" (10853)	100.00	99 94	98 38	89.77	54.57	14.34	11.50	9.83	8.58	1.25
42-49" (10854)	100.00	99 90	98.81	91.25	57.92	15 61	12.06	10 70	9 68	1.02
49-56" (10855)	100 00	99.96	98 67	91 01	58 08	14.50	10.85	9.55	9.03	0 52
56-63" (10856)	100.00	99 74	97 63	87.81	49 39	8 86	6.58	5.53	**	
63-70" (10857)	100.00	100 00	99 07	91.98	50.54	7.06	5.36	4 51	**	
70-77" (10858)	100.00	100.00	98 88	90.47	50 62	8.87	6.58	5.77	5.43	0 34
70-77" (10858B)	100.00	100.00	98 57	90.38	54.21	11.43	8.05	6.92	**	
77-85" (10859)	100.00	100.00	99.24	91.25	45.79	5.16	3.68	3.01	**	
85-92" (10860)	100.00	100.00	98 90	91.70	51.17	9.18	7.22	6.18	**	
92-99" (10861)	100.00	99.93	98.35	92.14	50.72	4 95	3.68	2.89	**	
99-106" (10862)	100 00	100.00	98 84	91 80	51.29	6.16	4.20	3.44	**	
ISWS Mason Co. 0-12" (10863)	98.95	99.23	90.74	78.55	57.92	28.84	24.16	21.22	19 14	2.08
5' SE of S64 12-24" (10864)	100.00	99.93	98.92	94 53	78 78	30 43	25.66	23.31	22.34	0.97
24-36" (10865)	99.82	99.86	96 97	91.03	73 32	29.23	25 62	21.14	20.15	0.99
36-48" (10866)	99.74	96.95	86.89	78 44	60.50	25.00	20.74	17.11	16.02	1 09
48-60" (10867)	100.00	99 89	96.71	89.51	70.70	28.58	24.93	20.94	14.59	6.35
60-72" (10868)	100.00	99 23	94 02	87.39	68.43	18.55	14.08	11.81	7.57	4.24
72-84" (10869)	100.00	99.58	97.59	95.69	89.49	13.25	7.10	5.73	4.74	0.99
84-96" (10870)	100.00	99.47	94.39	91.57	85 21	9 84	5 48	4.29	3.68	0.61
96-108" (10871)	100.00	99.95	98 27	94.61	83.16	14.44	9.06	7.62	6.48	1.14
108-120" (10872)	100 00	99 86	97 90	93.88	81.04	16.67	12.72	10 96	7 50	3.46
120-132" (10873)	100 00	99.98	98 75	93.72	76 36	11.69	8.91	7.46	6.56	0.90
132-144" (10874)	100 00	99 95	97 65	90.90	72 86	13.41	8.14	6 86	5 79	1 07

Notes: Job J949

*Sieve mesh size in millimeters

**Not enough "Fines" material present to differentiate silt and clay fractions

Appendix G. Thornthwaite Method for Evaporation Estimates

Appendix G.

Potential Evaporation (PET) Calculations (C.W. Thornthwaite, 1948)

$PET=1.6(10t/I)^{a}$

where:

t = mean monthly temperature (°C)
I = heat index in °C
$a = 0.000000675I^{3} - 0.000077II^{2}\ \ 0.01792I + 0.49239$

where:

I (heat index) = $\sum \mathbf{i}$
and $i = (t/5)^{1\,514}$

Peoria Station from 1961-1990

Month	*Temperature maximum (°F)*	*Temperature minimum (°F)*	*Mean temperature (°F)*	*Temperature conversion (°F to °C)*	*i (°C)*
January	29.9	13.2	21.6	-5.8	0.0
February	34.9	17.7	26.3	-3.2	0.0
March	48.1	29.8	39.0	3.9	0.7
April	62.0	40.8	51.4	10.8	3.2
May	72.8	50.9	61.9	16.6	6.1
June	82.2	60.7	71.5	21.9	9.4
July	85.7	65.4	75.6	24.2	10.9
August	83.1	63.1	73.1	22.8	10.0
September	76.9	55.2	66.1	18.9	7.5
October	64.8	43.1	54.0	12.2	3.9
November	49.8	32.5	41.2	5.1	1.0
December	34.6	19.3	27.0	-2.8	0.0
					$\sum$i = 52.7

Note: Temperature conversion - (°F-32)(5/9)

So for each measurement at Sand Lake, PET was determined by calculating a mean temperature for the period between measurements and using the following equation:

$$PET=1.6(10t/52.6)^{1\,318847}$$

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