PART D. EVALUATION OF ALTERNATIVE MEASURES

for the study

GROUND WATER LEVEL ANALYSIS BY COMPUTER MODELING:
AMERICAN BOTTOMS GROUND WATER STUDY

by

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PREFACE

Groundwater Level Analysis by Computer Modeling is an in-depth investigation of groundwater flow in the American Bottoms area. There were five objectives to this study. They were 1) to compile current hydrologic data pertaining to the area, 2) to develop a computer model that could simulate the movement of groundwater, 3) to analyze existing and future groundwater levels in the area, 4) to present alternatives to lower or maintain groundwater levels at specified elevations in a designated area of interest and 5) to provide documentation of the model including a user's guide.

The five objectives of this study are addressed in five separate reports that may be used independently or conjunctively.

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A brief summary of each part of the study is given here. Each part has an introduction, an explanation of methods, results and references. Part E, the model user's guide, includes attachments for data and program listings.

Acknowledgments

A project of this size required the cooperation of many Illinois State Water Survey employees. Their efforts were important in the completion of this project. Noteworthy contributions were made by James D. Miller in gathering background information for Part A, by Mark C. Collins in modifying the ISWS aquifer model for Part B and by Anne Klock in making groundwater level probability exceedance calculations for Part C. Graphics were done by John Brother, Bud Motherway and Linda Riggin. Word processing was done by Pamela Lovett and Kathy Brown. A special appreciation was gained for the timely assistance of consultants at the University of Illinois Computer Services Office and the Boeing Computer Service Customer Service.

SUMMARY OF STUDIES

Groundwater Levels and Pumpage

The American Bottoms is a 175 square mile area of the Mississippi River valley lowlands that includes the urban industrial areas of East St. Louis, Granite City and Alton. Groundwater is a major source of water for the area and is used for industrial, public and irrigation supplies. Groundwater levels prior to industrial and urban development were near land surface. Intensive industrial development and construction of a system of drainage
ditches, levees, and canals to protect developed areas have altered the water resources in the area. In recent years, water level rises due to reductions in pumpage, high river stages, and high precipitation producing favorable recharge conditions have caused damage to underground structures. The U.S. Army Corps of Engineers, St. Louis District has sponsored this study to examine groundwater flow in the area and its relationship to Mississippi River stage and precipitation.

Water levels and pumpage information collected over many years by the State Water Survey have been summarized and are presented in Part A. Pumpage is presented for major and minor pumping centers and is classified as public, industrial, domestic or irrigation. Hydrographs are presented for ten different observation wells for their period of record. Mississippi River stages, precipitation at St. Louis airport and pumpage at Granite City are included with the hydrographs to illustrate their interdependence. Piezometric surface maps are presented for five different groundwater conditions.

Groundwater Flow Model

The groundwater model used was a modified form of the Illinois State Water Survey aquifer model (Prickett and Lonnquist, 1971). Modifications were made to incorporate the dynamic effects of river stage and precipitation. The model was calibrated by historically matching two five-year periods with constant one-month time steps. Hydrographs of actual and simulated water levels at ten observation wells and the nearest model cell for the two five-year periods are presented. Two piezometric surface maps of actual and simulated water levels are also presented. The model was found to consistently calculate water levels within two feet of the actual measured water level within a specified area of interest.

Existing and Future Conditions

Groundwater conditions were evaluated by simulating historical Mississippi River stage and precipitation and constant pumpage for a thirty-year period. Pumpage was simulated as 1) constant for the thirty-year period at historical 1980 rates and locations, 2) forecast 2000 rates and locations and 3) no pumpage except for a dewatering site maintained by the Illinois Department of Transportation.

Groundwater levels were evaluated with the aid of groundwater level exceedance probability plots. Groundwater level exceedance probability plots were constructed for ten model cells by compiling the maximum yearly water level from monthly simulated values. Plots were based on simulation of the thirty-year period from 1951 to 1980. The Weibold formula was used for probability calculations.

Mississippi River stage and precipitation records were available from 1905 to the present. One simulation was conducted for a period of 75 years to compare the period of simulation with the length of the exceedance plot. The longer period of record was desirable; however, because low river stages
as well as high river stages and low and high precipitation occur during the thirty-year period from 1951 to 1980, the impact on exceedance is minimal. Also, the cost of simulations dictated use of the shorter period.

Alternative Measures

Pumpage systems and gravity drainage collectors to maintain water levels were evaluated by the same methods used in evaluation of existing and future conditions. Two pumpage and one gravity collector systems were designed to meet three specified groundwater levels. Systems were designed for forecast 2000 pumpage and no pumpage conditions. In all, twenty systems were simulated. Systems were designed to meet the specified target elevation in all cells for 90 percent of the months simulated. Exceedance probability was calculated for ten cells, but is illustrated for only five cells. Piezometric surface maps are presented for June 1973 conditions for designs with year 2000 pumpage.

Digital Flow Model Description and User's Guide

The computer model is documented by sections describing model capabilities, theory and assumptions. Explanation for preparing data files and understanding output is also included, as are three sample problems. Four attachments are provided to: 1) list and explain file names supplied on magnetic tape, 2) list data of all inputs to the model, 3) list the Fortran V source code for the model, and 4) define all variables in the computer code.

The text for Part D, Evaluation of Alternative Measures, follows.
PART D. EVALUATION OF ALTERNATIVE MEASURES

INTRODUCTION

This report on the evaluation of alternative measures to maintain or reduce groundwater levels was prepared by the Illinois State Water Survey (ISWS) as part of the study entitled, Groundwater Level Analysis by Computer Modeling, American Bottoms Groundwater Study funded by the U.S. Department of the Army, St. Louis District, Corps of Engineers. This report is Part D of the final report.

This section presents a number of alternatives to maintain and reduce groundwater levels and evaluates them with the aid of a two-dimensional, finite difference, digital model. The model used was verified and described in Part B. It was used to evaluate existing and future conditions without alternatives presented in Part C.

Two methods are examined to maintain or reduce groundwater levels. They are pumpage from wells and gravity drainage to collectors. Both alternatives were considered exclusive of the other, though in practice the two systems would be considered conjunctively.

Pumpage from wells is considered evenly distributed over the entire model area. The wells fully penetrate the aquifer. This treatment is necessary because the digital model determines the average water level. No effort is made in this study to consider the cost versus benefit of using a few high capacity wells rather than many low capacity wells in an area modeled as a single cell. A single well in a cell is not appropriate because it is not an even distribution of pumpage.

Gravity drainage to collectors is considered to be flow to a surface water body that is in hydraulic connection to the aquifer. An open trench is
described because it is most easily evaluated for model input parameters; however, other drainage devices such as horizontal wells can be considered.

Previous Work

Alternative measures evaluated by computer modeling were considered in a prior study (Corps of Engineers, 1979). That study conducted in part by the ISWS treated alternatives in a more general way. The present study is more specific and detailed both in design of the systems and in the way in which they were modeled.

Explanation of Area of Interest

The area of interest critical to this study was provided by the Corps of Engineers and is illustrated in Figure 3 of Part B. Alternative measures were required to maintain or reduce water levels only in the area of interest. The criteria for inclusion as an area of interest were residential, commercial and industrial development and susceptibility to damage based on historical damage occurrence.

Explanation of Target Elevations

Alternative measures are designed to maintain groundwater levels at three target elevations. Target elevations were provided by the Corps of Engineers. The target elevations are 3.8 and 14 feet below the land surface elevation. In general, these elevations correspond to maximum water elevations that will not cause damage to roadbeds and crops, basements, and underground utilities (particularly sewers).

Description of Alternatives and 20 Conditions

Alternative measures are evaluated by subjecting them to simulation of the Mississippi River stage and precipitation conditions for the period 1951
through 1980. The impact of variable pumpage in the area for that period was minimized by simulating pumpage as being constant at projections for the year 2000 or as if there was no pumpage at all. The no pumpage condition does include estimated withdrawals for the Illinois Department of Transportation (IDOT) dewatering site in National City. This was included because these withdrawals would be made if there was no other pumpage in the area.

Two systems to meet each of the three target elevations were desired for each pumpage condition (2000 and no pumpage), thus, the total number of systems is 24; twelve pumpage systems and twelve gravity collector systems. This number was reduced to 20 because there was little difference between gravity collector designs for the 3 and 8 foot target elevations. Table 1 summarizes the evaluation of the alternatives.

METHODS OF ANALYSIS

Pumping Systems

Two different pumping systems were required to meet each of the target elevations and pumpage conditions. Pumpage system one employs pumps at each node and is required to achieve compliance with the target elevation. Pumpage system two is required to achieve compliance with the target elevation at 90 percent of the nodes within the area of interest to minimize the number of pumps. It is required to induce no more than 20 feet of drawdown below the target elevation as averaged over each model cell, and it is preferred that locations be near existing drainageways when possible.

System One

Design of the first pumpage system was done by modifying the digital model to perform a simple mass balance at each node in the area of interest.
Table 1. Summary of alternative conditions that were evaluated.

<table>
<thead>
<tr>
<th>Alternative Measure</th>
<th>Target Elevation</th>
<th>Configuration</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>PUMPING</td>
<td>3'</td>
<td>System 1</td>
<td>No Pumpage 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>System 2</td>
<td>No Pumpage 2</td>
</tr>
<tr>
<td></td>
<td>8'</td>
<td>System 1</td>
<td>No Pumpage 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>System 2</td>
<td>No Pumpage 2</td>
</tr>
<tr>
<td></td>
<td>14'</td>
<td>System 1</td>
<td>No Pumpage 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>System 2</td>
<td>No Pumpage 2</td>
</tr>
<tr>
<td>GRAVITY COLLECTORS</td>
<td>3'</td>
<td>System 1</td>
<td>No Pumpage 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>System 1</td>
<td>No Pumpage 2</td>
</tr>
<tr>
<td></td>
<td>8'</td>
<td>System 1</td>
<td>No Pumpage 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>System 1</td>
<td>No Pumpage 2</td>
</tr>
<tr>
<td></td>
<td>14'</td>
<td>System 2</td>
<td>No Pumpage 2</td>
</tr>
</tbody>
</table>

1) Expressed as depth below ground surface elevation for each grid cell.

2) The No Pumpage condition includes forecast pumpage at IDOT (Illinois Department of Transportation) dewatering site at National City, Illinois and no other pumpage in the area.
This was done to determine if a pump would be required to meet the target elevation and to determine the capacity of the pump. Because of computer costs and data file handling problems, approximations were made to determine pumpage requirements.

It was decided to estimate pumpage based on various periods. The model contains approximately 400 cells in the area of interest. Because a thirty-year period was used for the analysis, a monthly pumping period would have potentially required accommodating 144,000 (400 cells multiplied by 30 years multiplied by 12 month/year) pumps. By reducing this to three pumping periods per year the number of pumps was reduced to 36,000.

A brief analysis was performed to determine the best arrangement of months in the three periods. The periods selected were to estimate pumpage based on three three-month periods: January, February and March; April, May and June; and October, November and December. This arrangement was compared with three four-month periods: January, February, March and April; May, June, July and August; and September, October, November and December. The analysis consisted of simulation of a five-year period by each method to determine which produced the best results. The three three-month periods were selected because recharge is low and evapotranspiration is high during July, August, and September and, therefore, a natural reduction in water levels occurs.

The second approximation was to estimate the water that would have to be withdrawn rather than make an exact determination. An approximation was made because of the additional execution time the model would require to make the calculation exact, and the additional effort to modify the model code to make the calculation did not seem appropriate.
Approximate recharge (the quantity of water that reaches the aquifer by-infiltration), evapotranspiration (the quantity of groundwater that evaporates or is transpired by plants), and the quantity of water that would have to be removed from storage from the aquifer (the unconsolidated sand and gravel material that makes up the valley fill) at each cell were required. The amount of groundwater present and the recharge were balanced against evapotranspiration. The groundwater level at the cell was then changed to the target elevation. This was done to avoid including the water that would have to be removed from storage at each calculation. The amount was summed with the other months in the period and then increased by 25 percent to account for horizontal flow from adjacent cells. Twenty-five percent was selected arbitrarily. The total for the three-month period was rounded to the nearest million gallons per day. This method consistently calculated pumpage schemes that satisfied the requirements for 90 percent compliance without exceeding 20 feet below the target elevation.

This method of estimation was formulated over a number of simulations and therefore the pumpage alternatives do not appear to be consistent. Figures 1, 2, 3, 4, 6, and 8 illustrate the locations and length of operation of pumps in months for system one. Figures 2 and 8 illustrate designs that utilize more pumps to achieve the target elevation than the method described above which is illustrated in figures 3 and 6.

The size of pumps are not illustrated in the above mentioned figures because the pumps sizes vary for a single location as required to meet the target elevation for each three-month period. The sizes are presented in Part E as Attachment III that includes listings of data sets. Data set names are IPA101, IPA201, IPA301, IPA121, IPA221 and IPA321.
Figure 1. Location and length of operation of pumps for the target elevation of 3 feet below the land surface elevation; and pumpage at IDOT, for system one.
Figure 2. Location and length of operation of pumps for the target elevation of 8 feet below the land surface elevation, and pumpage at IDOT, for system one.
Figure 3. Location and length of operation of pumps for the target elevation of 14 feet below the land surface elevation, and pumpage at IDOT, for system one.
Figure 4. Location and length of operation of pumps for the target elevation of 3 feet below the land surface elevation, and year 2000 pumpage, for system one.
Figure 5. Contour map of the simulated depth to groundwater from the land surface elevation for June, 1973 for the 3 feet target elevation and year 2000 pumpage for pumpage system one.
Figure 6. Location and length of operation of pumps for the target elevation of 8 feet below the land surface elevation, and year 2000 pumpage, for system one.
Figure 7. Contour map of the simulated depth to groundwater from the land surface elevation for June, 1973 for the 8 feet target elevation and year 2000 pumpage for pumpage system one.
Figure 8. Location and length of operation of pumps for the target elevation of 14 feet below the land surface elevation, and year 2000 pumpage, for system one.
Figure 9. Contour map of the simulated depth to groundwater from the land surface elevation for June, 1973 for the 14 feet target elevation and year 2000 pumpage for pumpage system one.
Figures 5 and 7 illustrate the depth to water from the land surface. Depth to water maps are presented for systems designed for the 2000 pumpage condition.

System Two

The purpose of the design of the second set of pumpage systems was to minimize the number of pumps. The approach taken was to specify that the pumps operated continuously for the entire period simulated. Though this is not practical, it does provide a practical solution for a substantial portion of the record.

The primary disadvantage to this approach is that it is not necessary to pump water when the piezometric surface is below the target elevation. This situation occurs during periods of below normal precipitation and lower than normal river stages.

The primary advantage to this approach is that it limits the consideration to one type of system design. Consideration of more detailed designs would require evaluation of many combinations of pump sizes and periods of operation. The time involved is well beyond the scope of this study and may be considered in the future.

Pumpage was specified in increments ranging from .25 to 3 million gallons per day. In most cases, the location and size of pumps were based on the results of the first pumpage designs.

Figures 10, 11, 12, 13, 15, and 17 illustrate the locations and capacities of pumps for system two.

Gravity Collector Systems

The gravity collector systems were also examined by considering two systems. The first system was to emphasize shallow collectors which are
Figure 10. Location and size of pumps for the target elevation of 3 feet below land surface elevation, and pumpage at IDOT, for system two.
Figure 11  Location and size of pumps for the target elevation of 8 feet below land surface elevation, and pumpage at IDOT, for system two
Figure 12. Location and size of pumps for the target elevation of 14 feet below land surface elevation, and pumpage at IDOT, for system two.
Figure 13. Location and size of pumps for the target elevation of 3 feet below land surface elevation, and year 2000 pumpage, for system two.
Figure 14. Contour map of the simulated depth to groundwater from the land surface elevation for June, 1973 for the 3 feet target elevation and year 2000 pumpage for pumpage system two.
Figure 15. Location and size of pumps for the target elevation of 8 feet below land surface elevation, and year 2000 pumpage, for system two.
Figure 16. Contour map of the simulated depth to groundwater from the land surface elevation for June, 1973 for the 8 feet target elevation and year 2000 pumpage for pumpage system two.
Figure 17. Location and size of pumps for the target elevation of 14 feet below land surface elevation, and year 2000 pumpage, for system two.
Figure 18. Contour map of the simulated depth to groundwater from the land surface elevation for June, 1973 for the 14 feet target elevation and year 2000 pumpage for pumpage system two.
close together. The second plan was to emphasize deeper collectors which are further apart. Both plans were to include existing drainage canals and the proposed Dobrey Slough Ditch.

Gravity collectors were modeled as river cells. This method of treatment is described in ISWS Bulletin 55 (Prickett and Lonnquist, 1971). Cells representing gravity collectors were given values for the elevation of the water surface in the collector, the recharge factor and an elevation of the bottom of the gravity collector bed. The recharge factor (R) is determined at each cell by the equation,

$$ R_{i,j} = \left( \frac{K'}{m'} \right) A_s, $$

where $K'$ is the vertical hydraulic conductivity in gallons per day per square foot (gpd/ft$^2$), $m'$ is thickness of the collector bed in feet and $A_s$ is the area of the collector bed represented by the cell in square feet.

Inclusion of the collectors in the model requires stipulation of the above mentioned values even when they cannot be readily verified. For instance, collector dimensions are dependent on the collector depth and the volume of water the collector is designed to conduct. Dimensions used in the model are typical; however, they do not necessarily represent a viable design. For instance, $A_s$ represents the bottom area of the collector and the collector area is selected to achieve a certain target elevation that may not be practical or even viable. Also, the materials making up the collector bottom are assumed to be the same throughout the American Bottoms.

The recharge factor has a unique value for each of the gravity collector systems according to the depth of the collector. The value of $R$ is larger as the depth of the collector increases. This is because the area of the collector exposed for leakage increases as the dimensions increase and the thickness of fine grain material that retards flow is reduced. The values
calculated using the above equation for the first design are \( R = 80,000 \) gpd/ft (gallons per day per foot) for the 3 foot target elevation below land surface, \( R = 160,000 \) gpd/ft for the 8 foot target elevation and \( R = 240,000 \) gpd/ft for the 14 foot target.

These values of recharge rate were obtained by assuming an average canal length of 2640 feet (1/2 mile) cell and a bottom width of 30, 40 or 50 feet respectively. The vertical hydraulic conductivity, \( K' \), is approximately 10 gpd/ft\(^2\). This is in the range of a silty sand. The value of \( m' \) varies with depth of the collector and was given values of 10, 5 and 2 feet, corresponding to the target elevations of 3, 8 and 14 feet, respectively.

System One

Gravity collectors were designed with the aid of Corps of Engineers furnished plans for existing canals in the American Bottoms area and with the aid of previously simulated estimates of water withdrawals to meet the target elevations. The initial bed elevation of the collectors was estimated by adding the target depth from the land surface elevation and an approximate typical depth of 10 feet from the land surface to the canal bed of existing canals in the area. The elevation of existing canals was lowered by approximately 3, 8 or 14 feet to meet required target elevations.

Figures 19, 20, 21, 22, 24, and 26 illustrate the locations of gravity collectors for system one.

System Two

A second design studied emphasized deeper but fewer collectors. It was done only for the 14 foot target depth because both the 3 and the 8 foot depths designs were not considered viable if they were to have deeper and fewer collectors than those in plan one.
Figure 19. Location of gravity collectors for the target elevation of 3 feet below land surface elevation, and pumpage at IDOT, for system one.
Figure 20. Location of gravity collectors for the target elevation of 8 feet below land surface elevation, and pumpage at IDOT, for system one.
Figure 21. Location of gravity collectors for the target elevation of 14 feet below land surface elevation, and pumpage at IDOT, for system one.
Figure 22. Location of gravity collectors for the target elevation of 3 feet below land surface elevation, and 2000 year pumpage, for system one.
AMERICAN BOTTOMS AREA, E. ST. LOUIS, IL.

DIFFERENCE IN HEADS FROM LAND SURFACE ELEVATION

JUNE. 1973

Figure 23. Contour map of the simulated depth to groundwater from the land surface elevation for June, 1973 for the 3 feet target elevation and year 2000 pumpage for gravity collector system one.
Figure 2k. Location of gravity collectors for the target elevation of 8 feet below land surface elevation, and 2000 year pumpage, for system one.
Figure 25. Contour map of the simulated depth to groundwater from the land surface elevation for June, 1973 for the 8 feet target elevation and year 2000 pumpage for gravity collector system one.
Figure 26. Location of gravity collectors for the target
elevation of 14 feet below land surface elevation, and 2000 year
pumpage, for system one.
Figure 27. Contour map of the simulated depth to groundwater from the land surface elevation for June, 1973 for the 14 feet target elevation and year 2000 pumpage for gravity collector system one.
Figures 28 and 29 illustrate the locations of gravity collectors for plan two.

EVALUATION OF ALTERNATIVES

Exceedance probability curves for pumping systems and gravity collector systems are presented for ten locations for evaluation of alternative measures. The analysis is divided into two parts, pumping systems and gravity collector systems. A table summarizing exceedance probability calculations at ten locations is presented for each part. Exceedance probability curves for the five locations are presented for selected systems using pumpage forecasts for the year 2000.

Pumping Systems

A total of 12 pumping systems were designed and evaluated. A summary of these systems are presented in Table 2.

Figures 31 through 60 illustrate the groundwater level exceedance probability curves for pumpage alternatives to meet the three target elevations and the pumpage condition as forecast for the year 2000. Each figure presents two curves: 1) the conditions with no alternative project, as determined in Part C, and 2) the conditions as determined by the alternative design.

Gravity Collector Systems

A total of 8 gravity collector systems were designed and evaluated. A summary of these systems are presented in Table 3.

Figures 61 through 80 illustrate the groundwater level exceedance probability curves for selected gravity collector system alternatives to meet the three target elevations and the pumpage condition as forecast for the year.
Figure 28. Location of gravity collectors for the target elevation of 14 feet below land surface elevation, and pumpage at IDOT, for system two.
Figure 29. Location of gravity collectors for the target elevation of 14 feet below land surface elevation, and 2000 year pumpage, for system two.
Figure 30. Contour map of the simulated depth to groundwater from the land surface elevation for June, 1973 for the 14 feet target elevation and year 2000 pumpage for gravity collector system two.
Table 2  Summary of Water Level Exceedance Probability Curves for Pumping Systems

<table>
<thead>
<tr>
<th>Model Location</th>
<th>N12</th>
<th>J13</th>
<th>R15</th>
<th>V18</th>
<th>S20</th>
<th>T23</th>
<th>N21</th>
<th>K28</th>
<th>P33</th>
<th>R37</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation of land surface (ft amsl)</td>
<td>410</td>
<td>409</td>
<td>415</td>
<td>421</td>
<td>414</td>
<td>416</td>
<td>417</td>
<td>412</td>
<td>420</td>
<td>419</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Target Depth (below land surface)</th>
<th>Pumpage Condition</th>
<th>System Configuration</th>
<th>(Percent Exceedance for Target Elevation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 feet No Pumpage none</td>
<td>&lt;     &lt;     &lt;     &lt;</td>
<td>&lt;     &lt;     &lt;     &lt;</td>
<td>5     &lt;     &lt;     &lt;</td>
</tr>
<tr>
<td>Year 2000 none</td>
<td>&lt;     &lt;     &lt;     &lt;</td>
<td>&lt;     &lt;     &lt;     &lt;</td>
<td>&lt;     &lt;     &lt;     &lt;</td>
</tr>
<tr>
<td></td>
<td>1     &lt;     &lt;     &lt;</td>
<td>&lt;     &lt;     &lt;     &lt;</td>
<td>5     &lt;     &lt;     &lt;</td>
</tr>
<tr>
<td></td>
<td>2     &lt;     &lt;     &lt;     &lt;     &lt;</td>
<td>4     &lt;     &lt;     &lt;</td>
<td></td>
</tr>
<tr>
<td>8 feet No Pumpage none</td>
<td>5     6     &lt; 3.5</td>
<td>10    &lt;     &lt;     &lt;</td>
<td>7     &lt; 3.5</td>
</tr>
<tr>
<td>Year 2000 none</td>
<td>1     &lt;     &lt;     &lt;</td>
<td>5     &lt;     &lt;     &lt;</td>
<td>&lt;     &lt;     &lt;     &lt;</td>
</tr>
<tr>
<td></td>
<td>2     &lt;     &lt;     &lt;</td>
<td>14    &lt;     &lt;     &lt;</td>
<td>&lt;     &lt;     &lt;     &lt;</td>
</tr>
<tr>
<td>14 feet No Pumpage none</td>
<td>&gt; 70   &gt; 91    &gt;</td>
<td>&gt;     &lt;     &lt;     &lt;</td>
<td>68    66    &lt;</td>
</tr>
<tr>
<td>Year 2000 none</td>
<td>1     &lt;     &lt;     &lt;</td>
<td>&lt;     &lt;     &lt;     &lt;</td>
<td>7     &lt;     &lt;     &lt;</td>
</tr>
<tr>
<td></td>
<td>2     &lt;     &lt;     &lt;</td>
<td>&lt;     &lt;     &lt;     &lt;</td>
<td>3.5   3.5   &lt;     &lt;     &lt;</td>
</tr>
<tr>
<td></td>
<td>&gt; 64   &gt; 84    &gt;</td>
<td>91    &lt;     &lt;     &lt;</td>
<td>30    &lt;     &lt;     &lt;</td>
</tr>
<tr>
<td></td>
<td>1     &lt;     &lt;     &lt;</td>
<td>7     &lt;     &lt;     &lt;</td>
<td>11    &lt;     &lt;     &lt;</td>
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<tr>
<td></td>
<td>2     &lt;     &lt;     &lt;</td>
<td>4     3.5   &lt;     &lt;     &lt;</td>
<td></td>
</tr>
</tbody>
</table>

< - exceedance was less than 3.5 percent.
> - exceedance was greater than 96.5 percent.
Figure 31: Groundwater level exceedance curves for the condition of no alternative project and for pumpage system one to meet a target elevation of 3 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell J 13.
Figure 32. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system one to meet a target elevation of 3 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell R 15.
Figure 33. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system one to meet a target elevation of 3 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell V 18.
Figure 34. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system one to meet a target elevation of 3 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell K 28.
Figure 35. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system one to meet a target elevation of 3 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell P 33.
Figure 36. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system two to meet a target elevation of 3 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell J 13.
Figure 37. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system two to meet a target elevation of 3 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell R 15.
Figure 38. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system two to meet a target elevation of 3 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell V 18.
Figure 39. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system two to meet a target elevation of 3 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell K 28.
Figure 40. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system two to meet a target elevation of 3 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell P 33.
Figure 41. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system one to meet a target elevation of 8 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell J 13.
Figure 42. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system one to meet a target elevation of 8 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell R 15.
Figure 43. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system one to meet a target elevation of 8 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell V 18.
Figure 44. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system one to meet a target elevation of 8 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell K 28.
Figure 45. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system one to meet a target elevation of 8 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell P 33.
Figure 46. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system two to meet a target elevation of 8 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell J 13.
Figure 47. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system two to meet a target elevation of 8 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell R 15.
Figure 48. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system two to meet a target elevation of 8 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell V 18.
Figure 49. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system two to meet a target elevation of 8 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell K 28.
Figure 50. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system two to meet a target elevation of 8 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell P 33.
Figure 51. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system one to meet a target elevation of 14 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell J 13.
Figure 52. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system one to meet a target elevation of 14 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell R 15.
Figure 53. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system one to meet a target elevation of 14 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell V 18.
Figure 54. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system one to meet a target elevation of 14 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell K 28.
Figure 55. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system one to meet a target elevation of 14 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell P 33.
Figure 56. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system two to meet a target elevation of 14 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell J 13.
Figure 57. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system two to meet a target elevation of 14 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell R 15.
Figure 58. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system two to meet a target elevation of 14 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell V 18.
Figure 59. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system two to meet a target elevation of 14 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell K 28.
Figure 60. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system two to meet a target elevation of 14 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell P 33.
Figure 61. Groundwater level exceedance curves for the condition of no alternative project and for pumpage system one to meet a target elevation of 3 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell J 13.
Table 3. Summary of Water Level Exceedance Probability Curves for Gravity Collector Systems

<table>
<thead>
<tr>
<th>Model Location</th>
<th>N12</th>
<th>J13</th>
<th>R15</th>
<th>V18</th>
<th>S20</th>
<th>T23</th>
<th>N21</th>
<th>K28</th>
<th>P33</th>
<th>R37</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation of land surface (ft amsl)</td>
<td>410</td>
<td>409</td>
<td>415</td>
<td>421</td>
<td>414</td>
<td>416</td>
<td>417</td>
<td>412</td>
<td>420</td>
<td>419</td>
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<tr>
<td>Target Depth (below land surface)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Pumpage System Condition Configuration (Percent Exceedance for Target Elevation)</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>3 feet</td>
<td>No Pumpage</td>
<td>none</td>
<td>&lt;</td>
<td>&lt;</td>
<td>&lt;</td>
<td>&lt;</td>
<td>&lt;</td>
<td>&lt;</td>
<td>5</td>
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</tr>
<tr>
<td>Year 2000</td>
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<td>&lt;</td>
<td>&lt;</td>
<td>&lt;</td>
<td>&lt;</td>
<td>&lt;</td>
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<tr>
<td>8 feet</td>
<td>No Pumpage</td>
<td>none</td>
<td>5</td>
<td>6</td>
<td>&lt;</td>
<td>3.5</td>
<td>10</td>
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<td>&lt;</td>
<td>7</td>
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<tr>
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<tr>
<td>14 feet</td>
<td>No Pumpage</td>
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<td>&gt;</td>
<td>70</td>
<td>&gt;</td>
<td>91</td>
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<td>&lt;</td>
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<td>&lt;</td>
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<td>&lt;</td>
<td>&lt;</td>
</tr>
</tbody>
</table>

< - exceedance was less than 3.5 percent.
> - exceedance was greater than 96.5 percent
Figure 62. Groundwater level exceedance curves for the condition of no alternative project and for gravity collector system one to meet a target elevation of 3 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell R 15.
Figure 63. Groundwater level exceedance curves for the condition of no alternative project and for gravity collector system one to meet a target elevation of 3 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell V 18.
Figure 64. Groundwater level exceedance curves for the condition of no alternative project and for gravity collector system one to meet a target elevation of 3 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell K 28.
Figure 65. Groundwater level exceedance curves for the condition of no alternative project and for gravity collector system one to meet a target elevation of 3 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell P 33.
Figure 66. Groundwater level exceedance curves for the condition of no alternative project and for gravity collector system one to meet a target elevation of 8 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell J 13.
Figure 67. Groundwater level exceedance curves for the condition of no alternative project and for gravity collector system one to meet a target elevation of 8 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell R 15.
Figure 68. Groundwater level exceedance curves for the condition of no alternative project and for gravity collector system one to meet a target elevation of 8 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell V 18.
Figure 69. Groundwater level exceedance curves for the condition of no alternative project and for gravity collector system one to meet a target elevation of 8 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell K 28.
Figure 70. Groundwater level exceedance curves for the condition of no alternative project and for gravity collector system one to meet a target elevation of 8 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell P 33.
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Figure 72. Groundwater level exceedance curves for the condition of no alternative project and for gravity collector system one to meet a target elevation of 14 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell R 15.
Figure 73. Groundwater level exceedance curves for the condition of no alternative project and for gravity collector system one to meet a target elevation of 14 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell V 18.
Figure 74. Groundwater level exceedance curves for the condition of no alternative project and for gravity collector system one to meet a target elevation of 14 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell K 28.
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Figure 76. Groundwater level exceedance curves for the condition of no alternative project and for gravity collector system two to meet a target elevation of 14 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell J 13.
Figure 77. Groundwater level exceedance curves for the condition of no alternative project and for gravity collector system two to meet a target elevation of 14 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell R 15.
Figure 78. Groundwater level exceedance curves for the condition of no alternative project and for gravity collector system two to meet a target elevation of 14 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell V 18.
Figure 79. Groundwater level exceedance curves for the condition of no alternative project and for gravity collector system two to meet a target elevation of 14 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell K 28.
Figure 80. Groundwater level exceedance curves for the condition of no alternative project and for gravity collector system two to meet a target elevation of 14 feet below the land surface. Curves represent simulated water levels for the period from 1951 to 1980 using year 2000 forecast pumpage for model cell P 33.
2000. Each figure presents two curves; 1) the conditions with no alternative project, as determined in Appendix C, and 2) the conditions as determined by the alternative system one.

REFERENCES


U.S. Army Corps of engineers, St. Louis District, 1979: American Bottoms groundwater study, reconnaissance report.