APPLICATION OF A MANAGEMENT MODEL TO THE

OGALLALA GROUNDWATER AQUIFER OF

THE OKLAHOMA PANHANDLE

By

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CHAPTER I

INTRODUCTION

Water, unlike most of our natural resources, can have no substitute. As man's needs increase toward the ultimate supply, better methods must be found to manage and protect this resource. California, a state subject to water shortages, has taken the first step in this direction. California's regulatory system has developed to such an extent that a complete, new set of laws was passed dealing with groundwater. At the same time, a digital computer model was developed for part of the state to aid in the management of this system (14).

Also, in Texas, investigators have found that the Texas High Plains portion of the Ogallala groundwater formation is being depleted. A computer management model is presently being developed to aid in the management of this groundwater reservoir (2).

A groundwater management model is a mathematical representation of the movement of water as a result of both natural flow and flow from wells. The model is responsive to economic and legal constraints affecting the real system as well as physical conditions. A groundwater management model combines these constraints with constraints set by a regulatory board to control the amount of water each user takes from the system. The model then projects such data as the amount the water table has lowered each year and the economic life of the reservoir.

This study was concerned primarily with an existing management model and its application to the Ogallala groundwater formation which underlies most of the Oklahoma Panhandle. The scope of this study was limited to the physical application of this model, within the legal and economic constraints applicable, to the Ogallala groundwater formation in Oklahoma.

The objectives of this study were to determine the laws affecting groundwater reservoirs in Oklahoma, to consider the different plans of Oklahoma in water resource development as to their economic impact on the groundwater supplies of the Panhandle, and to use an existing model to predict the movement of water in the Ogallala formation. The legal aspects include the role of the State in groundwater management, the agency, if any, to which rights are delegated to manage groundwater reservoirs, and the laws affecting the transfer of water.

The final objective of this study was to determine the sensitivity of the existing computer model to changes in input data. This becomes very important because of the lack of exact data for the Oklahoma Panhandle.

It is hoped that this study will result in a method for managing the Ogallala groundwater formation in the Oklahoma Panhandle so that either the impending water shortage may be met, or planned for in this area.

CHAPTER II

LITERATURE SURVEY

Legal Considerations

The statutory authority for the use of groundwater in Oklahoma is governed by the Oklahoma Groundwater Law, and is administered by the Oklahoma Water Resources Board. All applications for the appropriation of groundwater must be filed through the Water Resources Board.

A 1963 amendment of Title 82 of the Oklahoma Statutes (15) establishes the priority of claims for appropriation of groundwater, excluding domestic use. These priorities are listed in Table I.

An adjudication as used in priority two is defined as a "suit to determine all existing rights to the use of water from a particular groundwater basin." This suit may be brought by the Attorney General after having been furnished a survey of the groundwater basin in question by the Water Resources Board. After the suit is brought, the court determines the priorities.

Under this Act, domestic use is excluded from the priorities. The Act defines domestic use as use of water by a natural individual or by a family or household for household purposes, for farm and domestic animals up to the normal grazing capacity of the land, and for the irrigation of land not exceeding three acres for gardens, orchards, and lawns. Water for such purposes may be stored in an amount not to exceed a two-year supply.

TABLE I

PRIORITIES OF USE OF GROUNDWATER

Rank of Priority	Type of Priority
1	Water put to beneficial use prior to November 15, 1907.
2	Priorities based upon adjudication initiated prior to June 10, 1963.
3	Priorities based upon application filed prior to June 10, 1963.
4	Priorities based upon application filed after June 10, 1963.
5	Priorities based upon the withdrawal by the Federal Government.
6	Priorities based upon a present beneficial use initiated prior to June 10, 1963, and after November 15, 1907, where the right has been perfected under the rules and regulations adopted by the Oklahoma Water Resources Board.
7	Priorities based upon beneficial use from sediment pools in Soil Conservation Service structures.

Rarick (8) interprets the groundwater law of Oklahoma to imply that waste of the groundwater in Oklahoma is prohibited. Waste is defined as taking or using groundwater in any manner so that water is lost for beneficial use, permitting any groundwater to reach a pervious stratum and be lost in caverns or otherwise pervious materials encountered in a well, appropriating, taking, or using water in excess of the safe annual yield measured by the average annual recharge of the area owned or leased, and drilling of wells in locations which substantially reduces the yield of water.

The Water Resources Board, as stated previously, has the responsibility of enforcement of groundwater law. In the Rules and Regulations of the Water Resources Board (11), the following charge is made:

> "The legislature of this state has charged the water resources board with the duty, responsibility, and authority to make such rules, regulations, and orders that it may deem necessary or convenient.....to adopt, modify, repeal.....and enforce rules and regulations for the prevention, control, and abatement of new or existing pollution."

The rules and regulations then define "pollution" as contamination or other alteration of the physical, chemical, or biological properties of any natural waters of the state, or the discharge of water into receiving water that would cause loss of beneficial use, or harm to beneficial use, of the water.

The rules and regulations of the Water Resources Board (11) also control the use of injection wells. An "injection well" is defined as an artificial excavation or opening in the ground made for the purpose of injecting, transmitting, or disposing of waste, or injecting fresh or salt water into a subsurface stratum. A permit is required for an injection well.

Economic Considerations

The value of water in any region depends almost entirely on the use to which the water is put. The value of water for irrigation is much less than the value of water for industrial or domestic purposes. E. F. Renshaw (10) attempted to rank the value of water by use. In 1958, he ranked the value of water per acre-ft by taking national averages of the values. His results are shown in Table II.

TABLE II

COMPARISON OF THE VALUE OF WATER FOR DIFFERENT USES

Use	Value ($/acre-ft)
Domestic	100.19
Industrial	40.73
Irrigation	1.67
Power	0.71
Waste Disposal	0.63
Inland Navigation	0.05
Commercial Fisheries	0.025

In Renshaw's analysis, the value of water for waste disposal was assumed to be a function of two variables. These were the alternative cost of waste disposal and treatment, and the extent to which society will permit the receiving water to become polluted. Also, from his analysis it can be seen that the value of water for irrigation is about one per cent of the value for domestic purposes. This shows that in a competitive system the individual using water for domestic purposes could afford a higher cost for water than an individual using water for irrigation.

For the economics of irrigation alone, in 1952, the Texas

Agricultural Experiment Station (6) compiled values for irrigation water. Their results are shown in Table III.

These tests reflect the effect of flow from length of time a well is operated on the cost of the water. From these results it can be seen that the longer a well is pumped and the greater the flow from each well, the lower the cost.

TABLE III

THE COST OF WATER IN THE TEXAS HIGH PLAIN*

Hrs. pumped (avg)	Avg. Yield (gpm)			
	500	500-750	750-1000	1000
463	22.42	13.86	10.44	7.78
865	16.42	9.94	7.47	5.59
1463	13.21	8.12	6.09	4.57

*Value in $/acre-ft.

In 1967, Clark (1) cited a study made in determining the value of irrigation water. These values are a result of applying a linear programming technique to different study regions and optimizing output so that the maximum value per acre-ft of water is obtained. The lowest return value of irrigation water obtained was $9.00/acre-ft for low value crops on poor soil, and the highest value was $32.06/acre-ft for high value crops on good soil.

The feasibility of alternative water resources for an area is therefore determined by the economic system of the area. A more expensive supply of water can be allowed for a region that is primarily industrial than a region that is primarily agricultural.

Mathematical Considerations

The basic concepts of groundwater flow are based on Darcy's law and the concept of continuity (2). In the parallelepiped in Figure 1, S^* is the volume of water stored, V_s is the velocity in the s direction, and t is time.

The total inflow per elemental area into the cube is given by:

$$V_x + V_y + V_z \tag{2.1}$$

The total outflow per elemental area is given by:

$$V_x + \frac{\partial V_x}{\partial x} dx + \frac{\partial V_y}{\partial y} dy + V_z + \frac{\partial V_z}{\partial z} dz \tag{2.2}$$

When the inflow is subtracted from the outflow and multiplied by the respective areas, then the total change in volume in a unit time is:

$$\frac{\partial V_x}{\partial x} dx\ A_x + \frac{\partial V_y}{\partial y} dy\ Ay + \frac{\partial V_z}{\partial z} d_z\ A_z = \frac{\partial S^*}{\partial t} \tag{2.3}$$

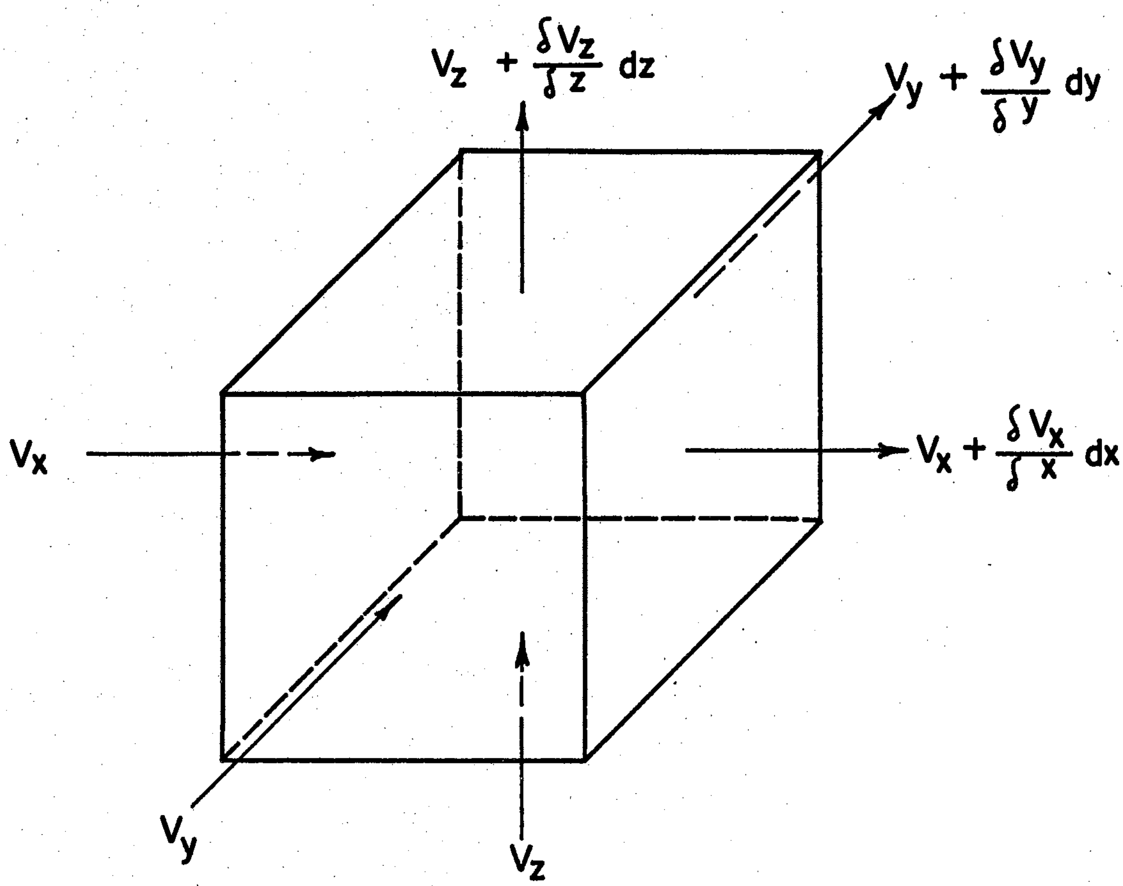
Where t denotes time, and S^* is the volume of water stored in the parallelepiped.

The total storage in time t is given by:

$S^* = dz \cdot dx \cdot dy \cdot S$

where S is the storage coefficient.

The Dupuit assumptions of groundwater flow are assumed to hold for this case. The Dupuit assumptions say that for small inclinations of the line of seepage, the streamlines can be taken as horizontal and the hydraulic gradient is equal to the slope of the free surface and is



V_s = velocity in the s direction.

$\frac{\delta V_s}{\delta s}$ = change of velocity in s direction with respect to distance.

ds = width of unit cube in s direction.

Figure 1. Elemental cube of fluid flow.

invariant with depth (4). This indicates that vertical velocities are negligible. Also, the dz term can be taken as equal to h. Then equation (2.3) becomes:

$$\frac{\partial V_x}{\partial x} dx\ A_x + \frac{\partial V_y}{\partial x} dy\ A_y = \frac{\partial (h\ dy\ dx\ S)}{\partial t}$$

The respective areas can be expressed as:

$$A_x = h \cdot dy$$

$$A_y = h \cdot dx$$

Equation (2.5) then becomes:

$$\frac{\partial V_x}{\partial x} dx\ dy\ h + \frac{\partial V_y}{\partial y} dx\ dy\ h = dy\ dx\ S \frac{\partial h}{\partial t}$$

or

$$\frac{\partial V_x}{\partial x} + \frac{\partial V_y}{\partial y} = \frac{S}{h} \frac{\partial h}{\partial t} \tag{2.6}$$

Darcy's law (4) can be used to express velocity components in terms of h as follows:

$$V_x = -P_x \frac{\partial h}{\partial x} \tag{2.7}$$

Px = Kx

Py = Ky

$$V_y = -P_y \frac{\partial h}{\partial y} \tag{2.8}$$

By substituting equations (2.7) and (2.8) into equation (2.6) and assuming an isotropic, homogeneous aquifer $\boxed{(P_x = P_y),}$ the following expression is obtained:

$$-P \frac{\partial^2 h}{\partial x^2} - P \frac{\partial^2 h}{\partial y^2} = \frac{S}{h} \frac{\partial h}{\partial t} \tag{2.9}$$

In this study, the grid system used for describing the study area is a system of polygons. If the basic continuity equation as developed before is applied to the polygon in Figure 2, then the following

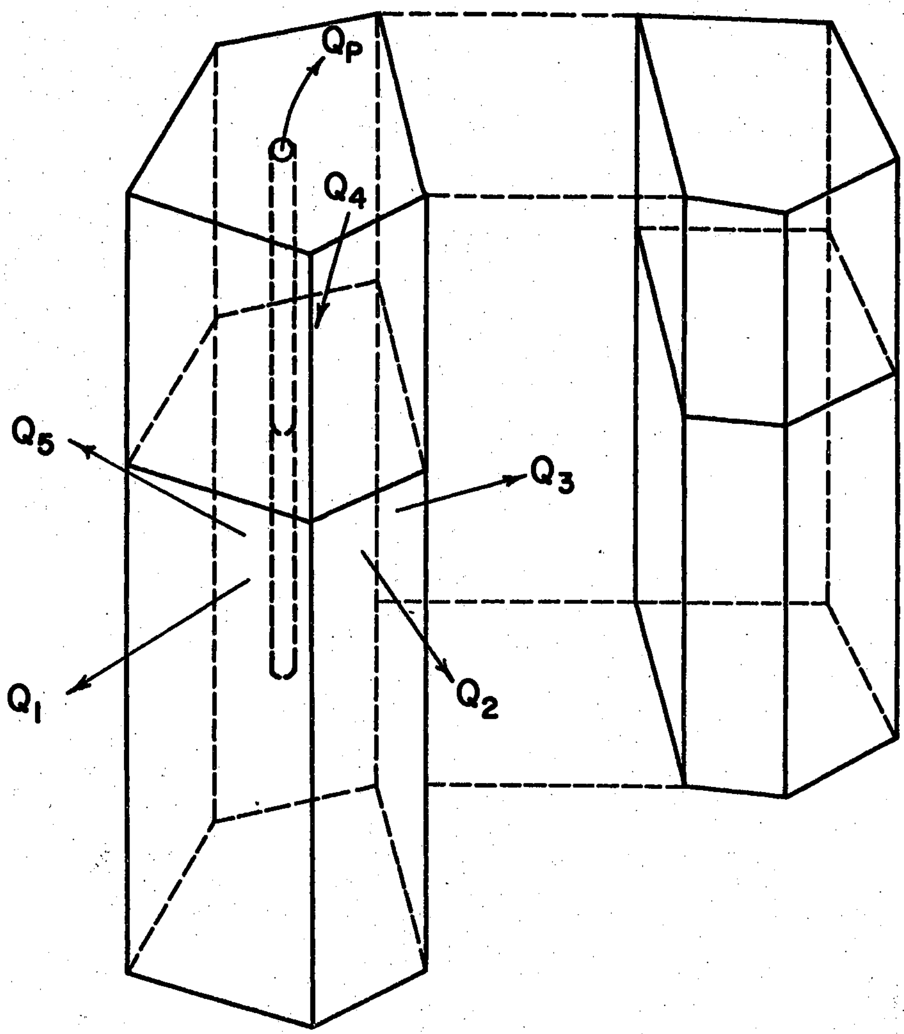


Figure 2. Elemental polygon showing flows into and out of the polygon.

expression results:

$$\Sigma Q_i - Q_p = A\ S\ \frac{\partial h}{\partial t} \qquad (2.10)$$

where

Q_i = flow rate across i^{th} face

Q_p = net withdrawal

A = area of the element.

Now, by using Darcy's law, equation (2.10) becomes:

$$P\Sigma h_i\ W_i\ \frac{\partial h}{\partial x_i} - Q_p = A\ S\ \frac{\partial h}{\partial t} \qquad (2.11)$$

where

W_i = width of i^{th} face

n = number of faces of polygon

h = saturated thickness of i^{th} node.

Equation (2.11) can be approximated by finite difference approximation as follows:

$$\frac{\partial h}{\partial t} = \frac{h^j - h^{j-1}}{\Delta t} \qquad (2.12)$$

where j denotes time steps, and t - time increments.

$$\frac{\partial h}{\partial x_m} = \frac{h^j - h_m{}^{j-1} + h^{j-1} - h_m{}^{j-1}}{2\ L_m} \qquad (2.13)$$

where m denotes the node adjacent to the node under consideration, and L_m = the distance between two nodes.

$$h_m = \tfrac{1}{4}\left(h^j + h_m{}^j + h^{j-1} + h_m{}^{j-1}\right) \qquad (2.14$$

If equations (2.12), (2.13), and (2.14) are substituted into equation (2.11), then we have

$$P\Sigma\left[\tfrac{1}{4}\left(h^j + h_i{}^j + h^{j-1} + h_i{}^{j-1}\right) W_i \frac{\left(h^j - h_i{}^j + h^{j-1} - h_i{}^{j-1}\right)}{2L_i}\right] - Q_p$$

$$= A_i S \frac{\left(h^i - h^{j-1}\right)}{\Delta t} \qquad (2.15)$$

By using an initial value approach, equation (2.15) can be programmed for computer by using relaxation techniques to predict future values of h. In the program values of $\overset{K}{P}$, W, $\overset{/\text{distance}}{L}$, Q, A, S, and Δt, as well as initial values of h are read in and new values of h are calculated for each time step, t. The Texas Tech Computer Program is contained in Appendix A.

P = ~~Conductivity~~ Permeability.

L = distance between two nodes.

W = width of Face

Q = flow rate

A = Area

S = storage coefficient.

Δt = Time increment.

CHAPTER III

THE STUDY AREA

The Ogallala groundwater aquifer is an extensive formation located throughout portions of Nebraska, Kansas, Colorado, New Mexico, Oklahoma, and Texas, as shown in Figure 3. The formation is dissected in Kansas by the Arkansas River, and in Texas and Oklahoma by the South Canadian River.

The portion of the Ogallala for the Oklahoma Panhandle was used in this study. In this area the formation consists of interbedded sands, siltstone, clay, lenses of gravel, thin limestone, and caliche. Portions of the aquifer are capable of storing and transmitting large volumes of water.

In the Oklahoma Panhandle, the Ogallala groundwater formation is the main source of water. This area of the state is engaged primarily in agriculture and ranching. As a result there are large volumes of water used from the formation daily. Also, the Ogallala aquifer is the primary source of water for municipalities. Recently, this area has experienced increased growth in irrigation and now requires an increased volume of water. As a result, the Ogallala aquifer is being used more extensively than ever before.

In the Oklahoma Panhandle, the Ogallala aquifer ranges in thickness from 0 to more than 700 ft. The depth to water ranges from 150 to 250

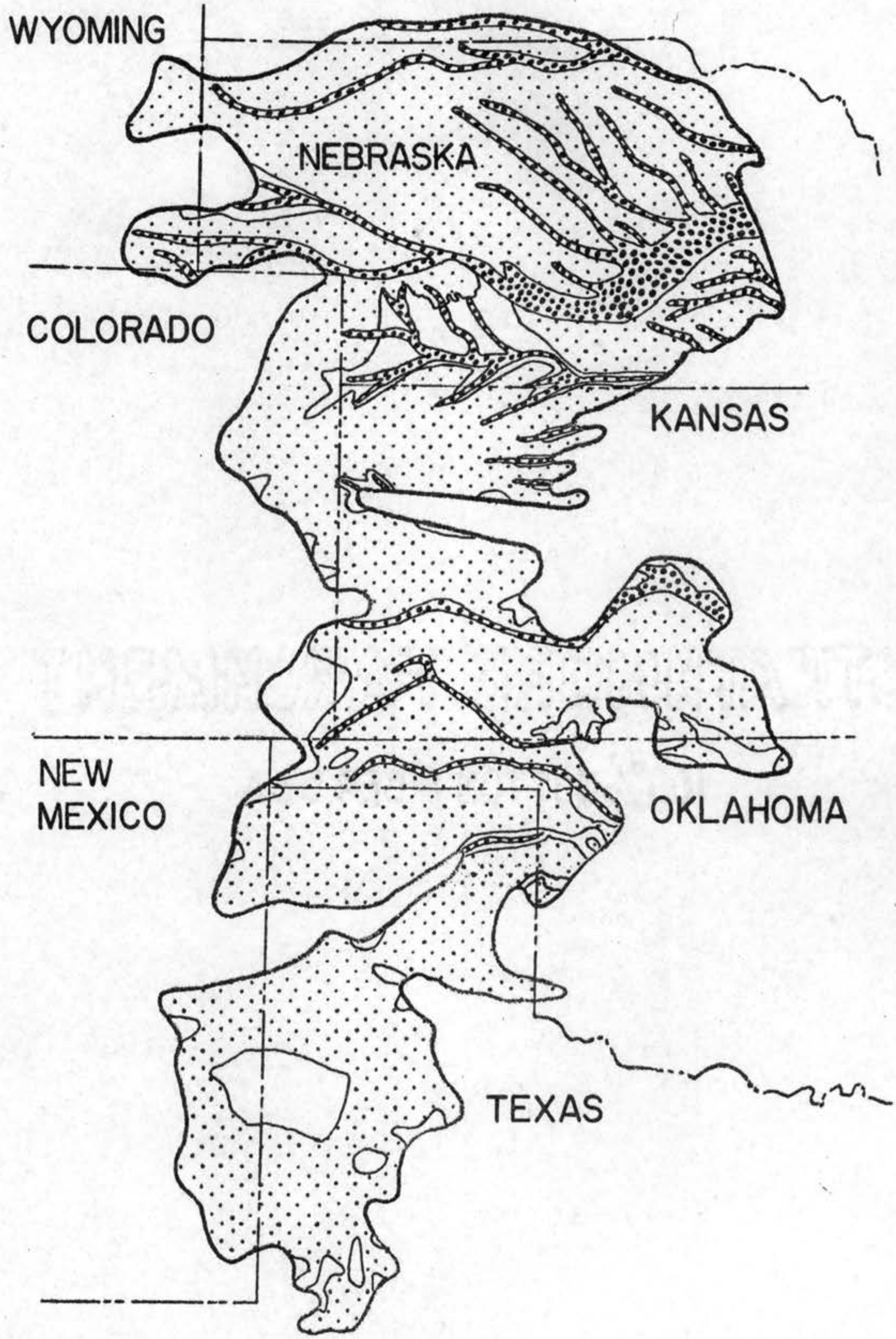


Figure 3. Location map for Ogallala groundwater aquifer.

ft. The average annual precipitation of this area ranges from 16 to 20 inches per year, while the average annual lake evaporation ranges from 58 to 64 inches per year (7).

In the Oklahoma Panhandle, wells can produce from 500 to more than 1000 gallons per minute. This makes the Ogallala a valuable water supply for irrigation purposes. As a result, more and more wells are being developed. The High Plains of Texas experienced the same growth in the early 1960's. As a result, the Ogallala is being depleted in the Texas Panhandle. This could also happen in the Oklahoma Panhandle.

There is very little surface water available in the Oklahoma Panhandle. Most of the surface water available is very silty and, therefore, an expensive source of water because of treatment costs. This prohibits a conjunctive operation unless imported water is used.

The surface of the study area consists of fine silts and clays which allow very slow infiltration, and it has been found that the top soil must be removed before good infiltration rates can be obtained. The slow infiltration with the low precipitation and high evaporation results in a very low average annual recharge. The average annual recharge has been estimated to be about 0.3 inches per year in the study area (3). The Ogallala aquifer can then be considered to be a closed system, with only the flow from wells and flow within the aquifer affecting the water level. Although there are some flows across the boundary of the study area, these flows can be estimated and included in the model.

Because of the great expense of running pumping tests to obtain values of the physical properties in the aquifer, these values were either obtained from Texas Tech University (2) or estimated. The portion of the aquifer in the Texas High Plains is very similar to that in the Oklahoma Panhandle, and therefore the values of the physical data are good estimates of the actual values. The value used for transmissibility was 400 gpd/ft^2, and the value used for the storage coefficient was 0.15.

To facilitate the application of the Texas Tech computer program to a case study in the Oklahoma Panhandle, a small section was chosen. The specific area chosen was Township 2 North, Range 14 East of the Cimarron Meridian in Texas County, Oklahoma. There are thirty-five wells in the area. The locations of these wells are shown in Figure 4. These locations were estimated as the center of the closest one-quarter of a section. The pumpage of all wells could not be obtained, so values of Q from the wells were estimated and then varied in the model. This township is one of the more dense areas for irrigation wells in the Oklahoma Panhandle. This is, therefore, one of the more critical areas.

To define the grid system in the study area, a program was developed to generate polygons for each node. This program computes data necessary for the model, and is shown in Appendix B.

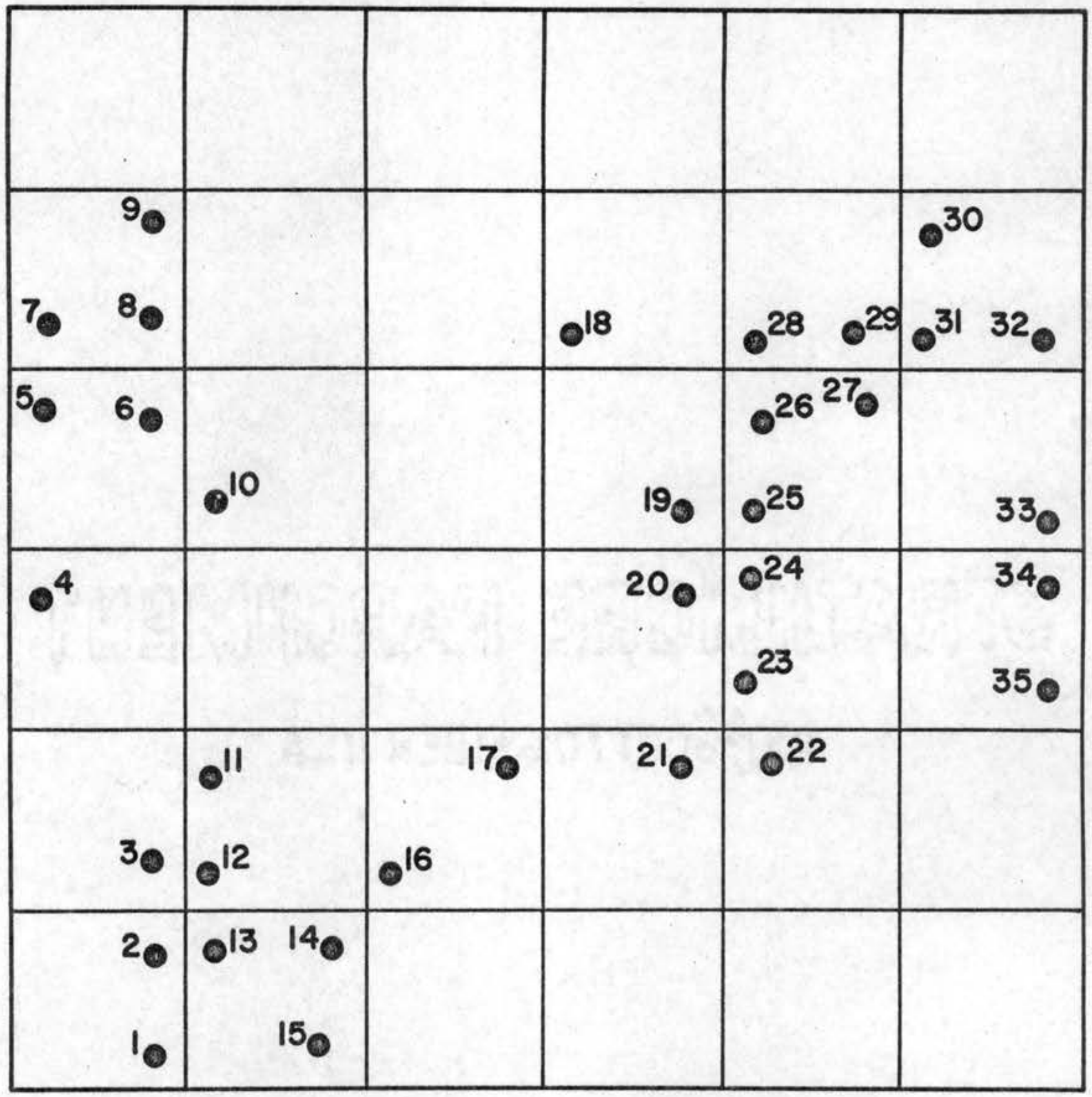


Figure 4. Location map for thirty-five wells - Township 2 North, Range 14 East, Cimarron Meridian, Texas County, Oklahoma.

CHAPTER IV

METHODS AND PROCEDURE

General

The application of a management model to the water resources of a region involves the legal framework of the state pertaining to water, the economics of the region under consideration, and the physical properties of the area. The application of a management model to a groundwater reservoir is further complicated in Oklahoma because a different set of laws pertaining only to groundwater has been developed.

The first assumption made is that the law allows a management agency to control the appropriation of groundwater. From this assumption the remaining legal framework was established by determining the laws that affect groundwater use and applying these to the study area. At the same time, the economics of the study area were investigated to determine the value of water in the study area as well as the value of alternative water supplies in this area.

Legal Framework

In establishing the legal framework for the management model, the laws of Oklahoma dealing with groundwater were researched and interpreted to determine which would affect the establishment and operation of the management model.

The initial aspect of groundwater law investigated were those laws dealing with the statutory authority of the use of groundwater and the methods of appropriation of groundwater. These statutes determine whether state law will allow an agency to manage a groundwater reservoir or the right to groundwater is given to landowners, regardless of use. Another important aspect of groundwater law is the priority to water right of appropriators of groundwater with respect to their type of beneficial use. Groundwater law should also include some method of ranking beneficial uses of water.

Another aspect of groundwater law investigated were those laws dealing with the amount of water that can be taken from a groundwater reservoir. There are two distinct philosophies relating to groundwater use. One is the strict conservationist's view, which is that no more than the natural or artificial replenishment should be taken each year. The other view involves the concept of mining groundwater in the same sense that we mine other natural resources. Some states, such as California, have reached an equilibrium somewhere between these extremes so that they mine the groundwater as well as provide facilities such as recharge wells to increase the annual recharge of the aquifer. The Oklahoma laws were investigated to determine how much if any mining of groundwater is allowed. The definition of waste prohibits the mining of groundwater.

The final aspect of groundwater law investigated were those laws concerning possible pollution of the groundwater through management decision as to recharge water and methods of injection of this water. Recharge water as used here is defined as water that will be placed in the aquifer by artificial means, such as injection wells or infiltration basins. It is sometimes possible to justify economically the recharge methods, although the quality of the recharge water is poorer than the quality of the groundwater. In this study an attempt was made to determine the effect the groundwater law would have on recharge water.

While investigating the groundwater law of Oklahoma, special attention was given to laws that could cause technological external diseconomies. A technological external diseconomy, as used here, is defined as an external constraint resulting from a law or other factor such as public opinion that would cause the most economical method of management or use of the groundwater resources to be bypassed. Special attention was given to the ruling of the courts of the interbasin transfer of water.

These laws when integrated give the framework within which groundwater use must operate. Also they give the guidelines for a management agency not only from the operational standpoint but also from the quality control standpoint. The framework itself is inherently flexible in that so many times a law depends on an individual interpretation of terms as to the extent of applicability of the law. In this study, an attempt was made to interpret these laws and therefore develop more rigid guidelines for the use of the management model.

Economic Considerations

The economics of groundwater use depend almost entirely on the type of use of the water, and whether the region under consideration is primarily agricultural or industrial. Under a strict market system of resource allocation, the economical system that receives the greatest net benefit from a resource is better able to compete for the resource. For the other type of allocation system, the public management agency, it may prove more economical or socially acceptable to supply the resource at a cost that all economical systems with the region can afford. In either case, it is important to estimate the net value of the resource as to use.

In this study an attempt was made to find values of water as related to use in the literature search. The first step was to find values so that different uses could be ranked as to the net benefit received for use of the water. The next step was to determine the type of economical system operating in this area, and then apply the ranked values in this area as to the maximum cost that could be charged for the groundwater or any alternative source of water that may be considered.

The Computer Model

The computer model developed for the management of the aquifer is a tool by which future water levels in the aquifer can be predicted. The computer model used was developed at Texas Tech University based on the California Model (14). Physical constants of the aquifer were either estimated or obtained from Texas Tech University.

There were two types of data required for input to the program. These are data associated with the grid system used for the model, and the data representing the physical constants of the aquifer. The physical constants of the aquifer were the most difficult to obtain. This is because the United States Geological Survey is just beginning to conduct well tests in the Oklahoma Panhandle, and much of the data is not available.

The grid system used for the study area was a system of polygons with one polygon associated with each node. The data required from the grid system was the area of each polygon, the lengths between a node and the adjacent nodes, and the width of faces of the polygons. To facilitate the calculation of this data, a computer program was written for calculation purposes. A copy of the computer program is contained in Appendix B.

Because of the lack of precise data for the management model in the Oklahoma Panhandle, a series of tests was made with the computer program determining the sensitivity of the program to changes in permeability, storage coefficient, and flow from wells. In this series of tests the permeability was allowed to vary between 300 gpd/ft^2 and 500 gpd/ft^2, Q was allowed to vary from 500 gpm to 1000 gpm, and the storage coefficient was allowed to vary from 0.10 to 0.20. Using unique combinations of variables and constants, the drawdown after five years was compared to the drawdown after five years based on values of permeability of 400 gpd/ft^2, storage coefficient of 0.15, and Q of 800 gpm.

CHAPTER V

RESULTS

Legal Interpretations

In groundwater management models there are two types of management systems that can be considered. These are the public agency system and the market system. Under the public agency system, the management agency takes into account all users in an area and attempts to supply the area with an economical supply that all can afford. This may not be true under a market system, because different users would compete for the supply and, in cases of shortages, the supply would go to the user that receives the largest value for the resource. Also, under the market system, public opinion would not have as much effect on policy decisions as on the decisions of the public agency system.

In Oklahoma groundwater law, there is some indication that a public management agency is required. The groundwater law definitely states that the Water Resources Board has the power to appropriate groundwater. It can then be assumed that the agency that has the control over the appropriation of the water also has the power to manage the system. Therefore, it can be assumed that public opinion will influence some of the management decisions of the agency.

It is very important in groundwater management programs to rank users in terms of priorities as to use. This is important, in times of water shortages, to give the management agency a method for determining the users most entitled to the water. The groundwater law gives a rank of priorities as stated in Chapter II. The management agency would then have to use these priorities as a basis for operating the groundwater aquifer.

One important aspect of groundwater management is whether the law allows mining of the resource or not. Mining of groundwater is defined as using more water from an aquifer than the average annual recharge. This means that if mining of the aquifer is allowed, then at some time in the future a point would be reached when using groundwater would no longer be economical. The exact time would be the amount of time that would prove most economical. Under Oklahoma groundwater law, mining of the Ogallala aquifer would be prohibited because this would violate the ruling on waste. Therefore, this gives a very restrictive constraint on the operation of the aquifer by allowing only an equivalent drawdown of only 0.3 inches per year. This would make it impossible to use the Ogallala aquifer to any great extent.

The next area of groundwater law that was considered was that concerning conjunctive use of the groundwater reservoir. Conjunctive use is defined as using a groundwater reservoir in conjunction with surface water to achieve the most economical operation of the aquifer. This would include such factors as artificial recharge and interbasin transfer.

Artificial recharge is not prohibited, but care must be taken to use only water that is chemically and physically compatible with the water in the aquifer. Otherwise, pollution would result, which would be prohibited by law. Another factor to consider in artificial recharge is that if silty water is injected into the aquifer, the loss in transmissibility of the aquifer near the well would not warrant the possible savings resulting from artificial recharge.

Interbasin transfer of water is defined as the transporting of water from the basin of occurrence to another basin for use. Under Oklahoma law, the interbasin transfer of water is allowed. This means that sources of water could be imported from other parts of Oklahoma or other states to provide sources of water for conjunctive use.

Economic Factors

In Chapter II it was shown that the value of water for irrigation is much lower than for industrial or domestic uses. The value of water for irrigation purposes ranges from $9.00/acre-ft to $32.06/acre-ft. In the Oklahoma Panhandle, the primary source of income is either irrigation of farm lands or ranching. As a result, all future plans for the management of water resources in this area must be competitive.

This becomes an important factor when considering alternative supplies of water for the area. The cost of an alternative supply must be low enough to allow the user to make a profit. Also, artificial recharge projects must be competitive, or they will prove to be uneconomical.

The Polygon Generation Program

The data generation program was developed to aid in setting up the grid system. The grid system used in this study was a system of irregular polygons developed by bisecting the lines connecting a center node to an adjacent node. When this is done for all adjacent nodes and the bisectors are connected, a boundary results that separates the center node from all adjacent nodes, as shown in Figure 5. Average values of permeability, storage coefficient, and flow can then be set up for each node that will apply only to the polygon associated with the node.

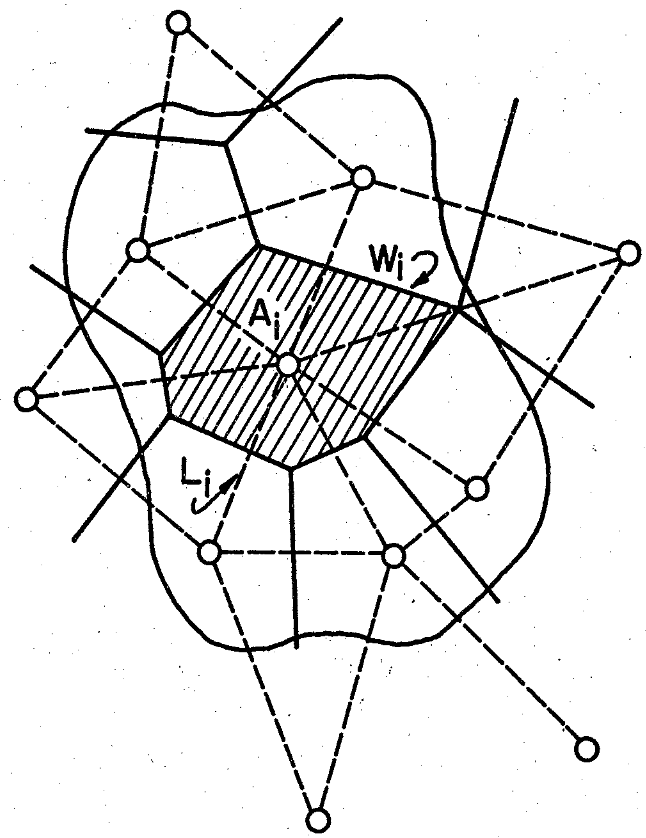
The program developed in this study was used to calculate the length between nodes, the width of all faces of each polygon, and the surface area of each polygon. This data was then input to the Texas Tech University Model.

The most difficult problem encountered in using the data generation program was that of establishing boundaries in the program. This was accomplished by assuming "boundary" nodes outside the boundary that were equidistant from the boundary as a node inside. The perpendicular bisector then approximately defined the boundary in the program.

This program was then applied to the 35 wells in the study area. The areas of all of the nodes are shown in Table IV, and the lengths between nodes and the widths of the faces are shown in Appendix B.

Some nodes had large areas and flow paths associated with them. This resulted from sparse density of wells in some sections of the study area. For example, the nearest well to node 18 was a full mile, and the area associated with that node was almost four square miles.

Another set of data required for the program were elevations in the study area. These included elevations of the nodes, bottom of the aquifer at the nodes, and water table at the nodes. These are given in Appendix B.



L_i = Length between two nodes.

W_i = Width of a face.

A_i = Area of the polygon

Figure 5. Typical polygon of grid system.

TABLE IV

DATA OUTPUT OF POLYGON GENERATION PROGRAM AREA OF POLYGON

Node	Area (Square Miles)	Area (Acres)
1	0.59	377.6
2	0.50	320.0
3	0.83	531.2
4	1.02	652.8
5	0.38	243.2
6	0.48	307.2
7	0.37	236.8
8	0.75	480.0
9	3.10	1984.0
10	2.17	1388.8
11	1.19	761.6
12	0.34	217.6
13	0.31	198.4
14	0.44	281.6
15	1.28	819.2
16	2.00	1280.0
17	2.19	1401.6
18	3.94	2521.6
19	0.88	563.2
20	0.84	537.6
21	1.27	812.8
22	2.67	1708.8
23	0.56	358.4
24	0.50	320.0
25	0.37	236.8
26	0.35	224.0
27	0.54	345.6
28	1.50	960.0
29	1.00	640.0
30	1.37	876.8
31	0.35	224.0
32	0.50	320.0
33	0.60	384.0
34	0.50	320.0
35	1.91	1222.4

The Computer Model

The Texas Tech University computer model was used to predict the level of the water table in 1975. The base values used for the first run were: P = 400 gpd/ft^2, Q = 800 gpm, and S = 0.15. The results of this computer run are contained in Table V. The reason that the water table rose at some nodes, i.e., negative values, was that the computer model, through the relaxation methods, balances the water table after each iteration. This should simulate the natural movement of water within the aquifer due to the balancing of the hydraulic gradient of the water table. To check the accuracy of this effect, the net drawdown of each node and the total water use was computed. This value was checked against the total outflow from the wells and found to agree within a ± two per cent error. During all runs of the computer program, the natural recharge was not included because of the negligible amount.

A series of parametric studies was made with the computer program to determine the sensitivity of the program to values of Q, S, and P. In each run, two of the variables were held at the base value, while one of them was varied through a certain range. The reason for this was to determine how accurate field determinations of these values must be. After the program was run for five years, the values of drawdown were compared to values of drawdowns obtained from the base values of P, Q, and S. These values were compared to a range of the residual value in the program. The residual term in the computer program is in a range within which the sum of the inflows and outflows at each node must balance. This term is required because the approximation technique, at best, gives an approximation of the inflows and outflows.

TABLE V

DRAWDOWN - BASE VALUES*

Node	H (1970)	H (1975)	h**
1	3100.0	3093.0	7.0
2	3092.0	3090.5	1.5
3	3103.0	3095.0	8.0
4	3115.0	3110.0	4.4
5	3110.0	3107.2	2.8
6	3110.0	3108.0	2.0
7	3100.0	3105.8	-5.8
8	3105.0	3109.1	-4.1
9	3125.0	3112.5	12.5
10	3110.0	3108.0	2.0
11	3075.0	3076.9	-1.9
12	3075.0	3074.0	1.0
13	3065.0	3070.5	-5.5
14	3060.0	3055.2	4.8
15	3055.0	3055.9	-0.9
16	3040.0	3043.5	-3.5
17	3040.0	3043.3	-3.3
18	3150.0	3141.7	8.3
19	3090.0	3081.6	8.4
20	3060.0	3062.8	-2.8
21	3050.0	3048.4	1.6
22	3055.0	3051.7	3.3
23	3045.0	3046.2	-1.2
24	3045.0	3048.7	-3.7
25	3040.0	3056.1	-16.1
26	3065.0	3070.7	-5.7
27	3045.0	3055.2	-10.2
28	3090.0	3090.5	-0.5
29	3080.0	3076.5	3.5
30	3075.0	3070.4	4.6
31	3060.0	3064.2	-4.2
32	3045.0	3054.2	-9.2
33	3030.0	3035.0	-5.0
34	3030.0	3030.5	-0.5
35	3025.0	3028.7	-3.7

*P = 400 gpd/ft^2, S = 0.15, Q = 800 gpm

**Positive value indicates drawdown.

The residual term used for runs involving changes in P was 2.0 acre-ft per time step, which is equivalent to a maximum of 1.0 ft. of error in five years. However, for runs involving Q and S, the program became unstable and this value had to be increased to 4.0 acre-ft/time step, or an equivalent of 2.0 ft of drawdown in five years. The results of these computer runs are shown in Tables V through XI.

From the results of the computer runs for the parametric studies, when permeability was varied by 12.5 per cent, the difference in the drawdown compared to the base value was within the residual error. Also, when the permeability was varied by 25 per cent, only a few nodes were outside the range of the residual error. Therefore, the program is considered insensitive to a range of permeabilities.

When the storage coefficient was first run, a residual error of 2.0 acre-ft/time step caused the program to become unstable. The residual error was then increased to 4.0 acre-ft/time step. The storage coefficient was then allowed to vary within a 33 per cent range of the base value. The results show that the differences in drawdown fell outside the range of the residual error. Therefore, the program is sensitive to storage coefficient.

Varying the flow from wells required that the residual term be increased to 4.0 acre-ft per time step. The flow was first varied by 12.5 per cent. This resulted in very little change in drawdown. Even a range up to 40 per cent failed to exceed the residual error. Therefore, it can be concluded that the program is very insensitive to Q. Thus, there is no need for a wide scale survey of the study area to determine flows, because a good estimate will suffice.

TABLE VI

SENSITIVITY OF PROGRAM TO CHANGE IN PERMEABILITY*

Selected Nodes	H (1970)	H (1975)	h	h- h(base) (Abs. Val.)
		Permeability = 300 gpd/ft^2		
2	3092.0	3090.8	1.2	0.3
4	3115.0	3111.4	3.6	0.8
6	3110.0	3107.9	2.1	0.1
8	3105.0	3108.6	-3.6	0.5
10	3110.0	3108.4	1.6	0.4
22	3055.0	3052.3	2.7	0.6
24	3045.0	3047.1	-2.1	1.6
26	3065.0	3069.1	-4.1	1.6
28	3090.0	3090.4	-0.4	0.1
30	3075.0	3071.2	3.8	0.8
		Permeability = 350 gpd/ft^2		
2	3092.0	3090.6	1.4	0.1
4	3115.0	3111.0	4.0	0.4
6	3110.0	3107.9	2.0	0.0
8	3105.0	3108.9	-3.9	0.2
10	3110.0	3108.2	1.8	0.2
22	3055.0	3052.0	3.0	0.3
24	3045.0	3047.9	-2.9	0.6
26	3065.0	3069.9	-4.9	0.8
28	3090.0	3090.5	-0.5	0.0
30	3075.0	3070.8	4.2	0.4

*S = 0.15, Q = 800 gpm.

TABLE VII

SENSITIVITY OF PROGRAM TO CHANGE IN PERMEABILITY*

Selected Nodes	H (1970)	H (1975)	h	h- h(base) (Abs. Val.)
		Permeability = 450 gpd/ft^2		
2	3092.0	3090.3	1.7	0.2
4	3115.0	3110.2	4.8	0.4
6	3110.0	3108.0	2.0	0.0
8	3105.0	3109.3	-4.3	0.2
10	3110.0	3107.8	2.2	0.2
22	3055.0	3051.4	3.6	0.3
24	3045.0	3049.4	-4.4	0.7
26	3065.0	3071.4	-6.4	0.7
28	3090.0	3090.5	-0.5	0.0
30	3075.0	3070.1	4.9	0.3
		Permeability = 500 gpd/ft^2		
2	3092.0	3090.1	1.9	0.4
4	3115.0	3109.8	5.2	0.8
6	3110.0	3108.0	2.0	0.0
8	3105.0	3109.5	-4.5	0.4
10	3110.0	3107.6	2.6	0.6
22	3055.0	3051.1	3.9	0.6
24	3045.0	3050.1	-5.1	1.4
26	3065.0	3072.1	-7.1	1.4
28	3090.0	3090.5	-0.5	0.0
30	3075.0	3069.8	5.2	0.6

*S = 0.15, Q = 800 gpm.

TABLE VIII

SENSITIVITY OF PROGRAM TO CHANGE IN STORAGE COEFFICIENT*

Selected Nodes	H (1970)	H (1975)	h	h- h(base) (Abs. Val.)
	Storage Coefficient = 0.10			
2	3092.0	3088.9	3.1	1.6
4	3115.0	3108.7	6.3	1.9
6	3110.0	3108.7	1.3	0.7
8	3105.0	3113.1	-8.1	4.0
10	3110.0	3107.1	2.9	0.9
22	3055.0	3048.8	6.2	2.9
24	3045.0	3050.5	-5.5	1.8
26	3065.0	3072.4	-7.4	1.7
28	3090.0	3090.2	-0.2	0.3
30	3075.0	3069.0	6.0	1.4
	Storage Coefficient = 0.20			
2	3092.0	3091.2	0.8	0.7
4	3115.0	3111.6	3.4	1.0
6	3110.0	3108.6	1.4	0.6
8	3105.0	3111.0	-6.0	1.9
10	3110.0	3108.5	1.5	0.5
22	3055.0	3052.4	2.6	0.7
24	3045.0	3047.5	-2.5	1.2
26	3065.0	3069.6	-4.6	1.1
28	3090.0	3090.6	-0.6	0.1
30	3075.0	3071.3	3.7	0.9

*Permeability = 400 gpd/ft^2, Q = 800 gpm.

TABLE IX

SENSITIVITY OF PROGRAM TO CHANGES IN Q*

Selected Nodes	H (1970)	H (1975)	h	h- h(base) (Abs.Val.)
		Q = 500 gpm		
2	3092.0	3091.1	0.9	0.6
4	3115.0	3110.9	4.1	0.3
6	3110.0	3108.5	1.5	0.5
8	3105.0	3109.6	-4.6	0.5
10	3110.0	3108.1	1.9	0.1
22	3055.0	3051.8	3.2	0.1
24	3045.0	3049.3	-4.3	0.6
26	3065.0	3071.4	-6.4	0.7
28	3090.0	3090.7	-0.7	0.7
30	3075.0	3070.7	4.3	0.3
		Q = 600 gpm		
2	3092.0	3090.9	1.1	0.4
4	3115.0	3110.8	4.2	0.2
6	3110.0	3108.3	1.7	0.3
8	3105.0	3109.5	-4.5	0.4
10	3110.0	3180.1	1.9	0.1
22	3055.0	3051.8	3.2	0.1
24	3045.0	3049.1	-4.1	0.4
26	3065.0	3071.1	-6.1	0.4
28	3090.0	3090.7	-0.7	0.2
30	3075.0	3070.6	4.4	0.2

*Permeability = 400 gpd/ft^2, S - 0.15.

TABLE X

SENSITIVITY OF PROGRAM TO CHANGES IN Q*

Selected Nodes	H (1970)	H (1975	h	h- h(base) (Abs.Val.)
		Q = 700 gpm		
2	3092	3090.7	1.3	0.2
4	3115.0	3110.7	4.3	0.1
6	3110.0	3108.1	1.9	0.1
8	3105.0	3109.3	-4.3	0.2
10	3110.0	3108.0	2.0	0.0
22	3055.0	3051.7	3.3	0.0
24	3045.0	3048.9	-3.9	0.2
26	3065.0	3070.9	-5.9	0.2
28	3090.0	3090.6	-0.6	0.1
30	3075.0	3070.5	4.5	0.1
		Q = 900 gpm		
2	3092.0	3090.3	1.7	0.2
4	3115.0	3110.5	4.5	0.1
6	3110.0	3107.8	2.2	0.2
8	3105.0	3108.9	-3.9	0.2
10	3110.0	3107.9	2.1	0.1
22	3055.0	3051.6	3.4	0.1
24	3045.0	3048.5	-3.5	0.2
26	3065.0	3070.5	-5.5	0.2
28	3090.0	3090.4	-0.4	0.1
30	3075.0	3070.3	4.7	0.1

*Permeability = 400 gpd/ft^2, S = 0.15.

TABLE XI

SENSITIVITY OF PROGRAM TO CHANGES IN Q*

Selected Nodes	H (1970)	H (1975)	h	h- h (base) (Abs.Val.)
		Q = 1000 gpm		
2	3092.0	3090.1	1.9	0.4
4	3115.0	3110.4	4.6	0.2
6	3110.0	3107.6	2.4	0.4
8	3105.0	3108.8	-3.8	0.3
10	3110.0	3107.8	2.2	0.2
22	3055.0	3051.6	3.4	0.1
24	3045.0	3048.3	-3.3	0.4
26	3065.0	3070.3	-5.3	0.2
28	3090.0	3090.3	-0.3	0.2
30	3075.0	3070.3	4.7	0.1

*Permeability = 400 gpd/ft^2, S = 0.15.

Discussion of Results

It appears that until the ruling of waste is redefined, legally the Ogallala aquifer cannot be used to any great extent. However, to date the state agencies have not applied this ruling to the Ogallala aquifer. It then seems that this ruling could be changed to allow a basis to manage the State's groundwater resources.

Other than this, the law tends toward management of the groundwater resources. For example, the law gives a state agency, the Water Resources Board, the power to administer groundwater law and the right to appropriate groundwater. The law also gives the Water Resources Board the power to administer matters pertaining to the operation of groundwater reservoirs such as artificial recharge. With very few legal changes, the Water Resources Board could also become the management agency for applying the groundwater management mode.

There have been some large scale plans to meet the future water requirement of Oklahoma. The Oklahoma Plan, a plan developed by the Department of Interior to bring water from the southeast part of the state to the areas that need water, is one such plan. In this plan, each area will either supply excess water, or use water as demand requires. This plan includes all existing groundwater supplies, as well as surface water supplies. This is an example of a case where the Ogallala groundwater aquifer will be used conjunctively with surface supplies. The only economic requirement resulting from this study is that the cost of the water fall within the \$9.00/acre-ft to \$32/acre-ft range for agricultural areas.

The polygon generation program was developed to aid in calculating data for the grid system. It will handle as large a study area as required without much error, provided care is taken in setting up the boundaries and defining adjacent nodes. The program is further explained and definition of the terms are contained in Appendix B.

The mathematical model proved to be a suitable program after some small changes. The greatest problem arising from the use of this program was input data other than that pertaining to the grid system. Sets of data are contained in the results that were used for this study. The most critical data was determined to be the data involving the physical aspects of the groundwater aquifer, Q, S, and P.

As a result of the inaccuracy of the physical data, a parametric study was made on Q, S, and P. The results show that the program is relatively insensitive to variation in Q and P, but quite sensitive to variations in the storage coefficient, S. This implies that tests will have to be made to determine the storage coefficient.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary

Many states are now reaching the point where water resource plans for the entire state are needed for their effective management. Although some states have taken steps to implement laws and techniques for the management of their water resources, many states still lack effective tools to implement a management program. One objective of this study was to determine the legal and economic framework under which this state can manage the Ogallala groundwater aquifer.

Many tools can be used by a management agency to operate a groundwater reservoir. In this study, a computer model was used to predict values of drawdown in the future due to use from wells. To aid in the collection of data for the computer model, a program was written to calculate properties of the grid system used. This data, with other data obtained from Texas Tech University or estimated, were then put into the model to predict future levels of the water table.

At the same time, parametric tests were made on the model to determine it's sensitivity to varying data. These tests were made on the permeability, storage coefficient, and flow from wells. Only variations in the storage coefficient appreciably affected the model.

Conclusions

One objective of this study was to determine the laws affecting groundwater management in Oklahoma. The management of groundwater depends on groundwater law as it pertains to management agencies, methods of appropriations, priorities of appropriations, and amounts that can be taken. These laws, integrated with the economics of the region, can produce a framework for the management mode. The most difficult problem encountered in this part of the study was determining the interpretation of the courts in some areas of groundwater law.

The physical application of the computer model resulted in projection of the future water levels of groundwater reservoirs. These projections could be used to not only discover early trouble areas, but also to give some indication as to the length of time before a new source of water is required.

The polygon generation program gives good results when care is taken in defining adjacent nodes and boundary nodes. The accuracy of the data obtained from this computer program is important, because it affects the accuracy of the results of the model. The parametric studies indicate that accurate tests should be made to determine values of the storage coefficient in the study area.

Suggestions for Future Research

As a result of this study it was determined that more work could be done to develop a more accurate computer program. The program could include a technique for concentrating flows during certain months or time periods. Also, a method for analyzing vertical changes in physical properties is needed.

Another area of future research that could be helpful is applying a linear programming technique with the computer model to achieve the optimum operation of the aquifer.

An important factor in groundwater management is that concerning artificial recharge. A feasibility study could be made on artificial recharge as to new recharge methods or new water treatment methods to provide water for recharge purposes.

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APPENDIX A

COMPUTER MODEL FOR A GROUNDWATER RESERVOIR

This program simulates the movement of water in a groundwater aquifer and calculates the values of head at each node for each year of simulation.

Input data required for this program is in three parts. First, the data generated by the polygon generation program is needed to define the grid system. Secondly, physical data of the aquifer is needed. Finally, program control data is needed.

The data generated from the polygon generation program must be converted to terms of acres and feet. As input, the area of each node must be multiplied by the storage coefficient of each node and entered into the program as AS(i). Also, ratios of width of face to length between nodes must be calculated.

The permeability can be input in two ways. For the runs in this study, a uniform permeability was assumed so that the term COEFFA was used to introduce permeability. It if is required to include different permeabilities at different nodes, then for Y(i), the ratio of width of faces to length between nodes, calculate the product of Y(i) and permeability. When this is done, the COEFFA term must be entered as 1.00. The program has the capability of including a Q at each well node, but does not have the capability to vary flow with time.

The program control data includes such factors as the time step, the total time of the run, and the closure error allowed. The closure error is the most critical factor of the program control data. The program balances the flow from wells, the change in storage, and the flow within the aquifer within this tolerance. If the closure error is chosen too small, then the program becomes unstable.

Lines 0013 to 0107 establish a system to read in data and check for the correct order. Also, in this part the input data is printed out and labeled so that the programmer can check the data. Lines 0112 to 0188 contain the relaxation method that calculates the level of the water table in the aquifer after each time step. The program prints only values at the end of five years or the end of time period. The terms used in the program are as follows:

BL = bottom elevation of node (ft)
SL = surface elevation of node (ft)
D = thickness of aquifer (ft)
AQ = flow from a well (acre-ft/time step)
HO = initial water table elevation (ft)
H = water table elevation at time, t (ft)
Relax = the storage change at a node (acre-ft/time step)
Res = the residual error after balancing all flows (acre-ft/time step)
Error = the error closure allowed (acre-ft/time step)
Node 1, Node 2 = the center node and adjacent node between which a flow path (width of face/length of node) is defined
Delta = time step (yrs)
NWELLC = node number associated with a well
Y = the ratio of width of face to the distance between nodes.

```
      COMMON S(177),COEFF(177),QS(177)
      COMMON H(35),HC(35)
      COMMON Y(177),Q(177)
      DIMENSION BL(35),SL(35),AS(35),RELAX(177),RES(177)
      DIMENSION NODE1(177),NODE2(177),B(177),C(177),P(177)
      DIMENSION AQ(35),DRY(35),ACS(35)
      DIMENSION XNODE(35),YNODE(35),NWELLC(35),N1(177),N2(177)
      DIMENSION SLX(35)
      DATA LMAX,MMAX /151,35/
      MESS=0
12345 CONTINUE
      READ(5,101)LIST,MAJOR,MINOR
  101 FORMAT(3I10)
      READ(5,102)ERROR,COEFFA,TIME
  102 FORMAT(3F13.4)
      DO 1211 I=1,MMAX
      READ(5,1210) XNODE(I),YNODE(I),NWELLC(I)
 1210 FORMAT(2F10.2,I5)
 1211 CONTINUE
      DO 131 M=1,MMAX
  131 READ(5,14)N1(M),AQ(M)
   14 FORMAT(I7,3X,F6.0)
C   CHECK DATA FOR CORRECT ORDER
      DO 140 M=1,MMAX
      IF(N1(M)-NWELLC(M))139,140,139
  139 MESS=1
      II=N1(M)
      III=M
      JJ=NWELLC(M)
      JJJ=M
C   MESSAGE=1 FEED DATA FOR A WELL NOT IN CLASS C OR OUT OF ORDER
      GO TO 10000
  140 CONTINUE
      DELTA=1./FLOAT(MAJOR*MINOR)
      DO 15 M=1,MMAX
      IF(AQ(M))640,15,15
  640 AQ(M)= AQ(M)*.2
   15 AQ(M)=-AQ(M)
      READ(5,100)(NODE1(L),NODE2(L),Y(L),L=1,LMAX)
  100 FORMAT(2(I7,1X,I7,1X,F10.2,1X),I7,1X,I7,1X,F10.2)
      READ(5,104)(N1(M),BL(M),SL(M),AS(M),H(M),M=1,MMAX)
  104 FORMAT(I7,5X,F7.0,6X,F7.0,6X,F11.0,11X,F11.0)
C   CHECK FOR OUT OF ORDER CARDS
      DO 105 M=1,MMAX
      IF(N1(M)-NWELLC(M))106,105,106
  106 MESS=2
      II=N1(M)
      III=M
      JJ=NWELLC(M)
      JJJ=M
C   MESSAGE=2 PHYSICAL WELL DATA FOR A WELL NOT IN CLASS C OR OUT OF ORDER
C   WELL WAS READ
      GO TO 10000
  105 CONTINUE
```

```
      DO 103 M=1,MMAX
  103 COEFF(M)=COEFFA
  999 DO 998 M=1,MMAX
  998 SLX(M)=SL(M)
C  IDENTIFY THE POSITION IN THE NWELLC ARRAY OF THE WELL NUMBERS IN THE NODE1
C  AND NODE2 ARRAYS.  STORE THIS POSITION NUMBER IN N1 AND N2
      DO 1400 M=1,LMAX
      IF(M-1)990,990,985
  985 IF(NODE1(M)-NODE1(M-1))990,986,990
  986 N1(M)=N1(M-1)
      GO TO 1105
  990 DO 1000 L=1,MMAX
      IF(NODE1(M)-NWELLC(L))1000,1100,1000
 1000 CONTINUE
      MESS=4
      II=NODE1(M)
      III=M
      JJ=NWELLC(L)
      JJJ=L
C  MESSAGE=J NODE1 WAS NOT FOUND IN THE CLASS C WELLS
      GO TO 10000
 1100 N1(M)=L
 1105 DO 1200 L=1,MMAX
      IF(NODE2(M)-NWELLC(L))1200,1300,1200
 1200 CONTINUE
      MESS=5
      II=NODE2(M)
      III=M
      JJ=NWELLC(L)
      JJJ=L
C  MESSAGE=5 NODE2 WAS NOT FOUND IN THE CLASS C WELLS
 1300 N2(M)=L
 1400 CONTINUE
      DO 108 L=1,LMAX
      M=N1(L)
      N=N2(L)
      B(L)=(BL(M)+BL(N))*.5
  989 D(L)=(SLX(M)+SLX(N))/2.-B(L)
      P(L)=Y(L)*(COEFFA/4.0)
  108 CONTINUE
      WRITE(6,200)
  200 FORMAT(47H MODIFIED DWR PROGRAM FOR HIGH PLAINS OF OKLA  //
     126H  35 NODES AND 151 BRANCHS///5H NODE,5X,17HSTATE WELL NUMBER 5X
     2,7HSTORAGE,8X,7H UPPER ,9X,6HBOTTOM/31X7HFACTORS,6X,10HELEVATIONS,
     36X,10HELEVATIONS//)
      WRITE(6,201)(M,NWELLC(M),AS(M),SL(M),BL(M),M=1,MMAX)
  201 FORMAT(I4,11X,I7,10X,4HAS= ,F8.1,4X,4HSL= ,F8.1,4X,4HBL = ,F8.1)
      WRITE(6,202)
  202 FORMAT(//////7H BRANCH,4X,20HBETWEEN WELL NUMBERS 4X,19HPSELDO-PER
     2MEABILITY,3X,17H BOTTOM ELEVATION,6X,10H THICKNESS//)
      WRITE(6,203)(L,NODE1(L),NODE2(L),P(L),B(L),D(L),L=1,LMAX)
  203 FORMAT(I6,5X,I7,3X,I7,7X,3HK= ,F8.4,10X,3HB= ,F8.1,9X,3HD= ,F8.1)
      WRITE(6,204) LIST,MAJOR,MINOR,ERROR,COEFFA
  204 FORMAT(/////7H LIST =I6/8H MAJOR =I5/8H MINOR =I5/8H ERROR =F8.2/
```

```
     19H COEFFA =F7.4)
      TIME2=TIME+FLOAT(LIST)
      WRITE(6,205) TIME,TIME2
  205 FORMAT(/////16H SIMULATION FROM ,F8.2,3H TO,F8.2)
      WRITE(6,300)TIME,(M,NWELLC(M),H(M),M=1,MMAX)
  300 FORMAT(7H TIME= ,F8.2///(5H NODE,I4,3X,18HSTATE WELL NUMBER ,I7,5X
     1,3HH= ,F8.1))
      DO 150 L=1,LMAX
      B(L)=2.*B(L)
  150 P(L)=.5*P(L)
      DO 600 LISTS=1,LIST
      DO 601 M=1,MMAX
      DRY(M)=0.
  601 AQS(M)= 0.
      JDRY =0
      DO 500 MAJORS=1,MAJOR
      ITER=0
      DO 400 MINORS=1,MINOR
    1 TIME=TIME+DELTA
      DO 2 M=1,MMAX
      HO(M)=AMAX1(BL(M),H(M))
    2 AQ(M)=AQ(M)+AQS(M)
      IDRY = 0
    3 DO 4 M=1,MMAX
      RELAX(M)=AS(M)/DELTA
      S(M)=RELAX(M)*(AMAX1(BL(M),H(M))-HO(M))
    4 RES(M)=AQ(M)-S(M)
      ITER=ITER+1
      DO 5 L=1,LMAX
      N=N1(L)
      M=N2(L)
      Y(L)=P(L)*AMAX1(0.,H(M)+H(N)-B(L))
C   PREVENT FLOW FROM A DRY POLYGON
      IF (H(N)-H(M))701,703,711
C   FLOW FROM M TO N, M MUST NOT BE DRY
  701 IF(H(M)-BL(M))703,703,705
  703 Q(L)=0.
      GO TO 770
C   FLOW FROM N TO M, N MUST NOT BE DRY
  711 IF(H(N)-BL(N))703,703,705
  705 CONTINUE
      Q(L)=Y(L)*(H(M)-H(N))
  770 CONTINUE
      RELAX(M)=RELAX(M)+Y(L)
      RELAX(N)=RELAX(N)+Y(L)
      RES(M)=RES(M)-Q(L)
    5 RES(N)=RES(N)+Q(L)
    8 DO 12 M=1,MMAX
      RELAX(M)=1.0/RELAX(M)
      H(M)=AMAX1((H(M)+RELAX(M)*RES(M)),BL(M))
C     H(M)=H(M)+RELAX(M)*RES(M)
      IF(QS(M))12,9,9
    9 IF(H(M)-SL(M))11,11,10
   10 QS(M)=RES(M)
```

```
CARD
          RES(M)=0.
          H(M)=SL(M)
          GO TO 12
       11 QS(M)=0.
       12 CONTINUE
    11100 FORMAT(1H ,10F12.1)
          DO 13 M=1,MMAX
          IF(ERROR-ABS(RES(M)))33,13,13
C         IF(ERROR-ABS(RES(M)))33,13,13
       33 IF(H(M)-BL(M))3,34,3
       34 IDRY=IDRY+1
       13 CONTINUE
          IF(IDRY)400,400,390
      390 DO 395 M=1,MMAX
          IF(H(M)-BL(M))391,391,395
      391 JDRY=1
          DRY(M)=DRY(M)+RES(M)
      395 CONTINUE
      400 CONTINUE
          WRITE(6,404)TIME,ITER
      404 FORMAT(/////5HTIME,F8.2,I10,11H ITERATIONS)
      410 CONTINUE
          QST=0.
          DO 403 M=1,MMAX
          IF(QS(M))403,403,401
      401 WRITE(6,402)M,QS(M)
      402 FORMAT(5H NODE,I4,3X,4HQS= F8.1)
          QST=QST+QS(M)
      403 CONTINUE
          WRITE(6,405)QST
      405 FORMAT(/22H TOTAL SURFACE FLOW = F10.1)
      500 CONTINUE
          IF(JDRY) 5010, 5010, 5000
     5000 DO 5005 M=1,MMAX
          IF(DRY(M))5003,5005,5003
     5003 DRY(M)=AQ(M)-DRY(M)*DELTA
          WRITE(6,5002)M,NWELLC(M),AQ(M),DRY(M)
     5002 FORMAT(1H 4HNODE I5,16H STATE WELL NO. I9,31H WITH EXPECTED WITHDR
         1RAWALS OF F10.0,19H ACRE FT REDUCED TO F10.0, 8H ACRE FT)
     5005 CONTINUE
     5010 CONTINUE
      501 CONTINUE
          WRITE(6,302)TIME,(M,NWELLC(M),H(M),M=1,MMAX)
      302 FORMAT(7H1TIME= ,F8.2///(5H NODEI4,3X,18HSTATE WELL NUMBER I7,
         15X,4HH = F8.1))
          WRITE(6,301)
      301 FORMAT(1H1)
      600 CONTINUE
      621 GO TO 622
    10000 WRITE(6,11000) MESS,II,III,JJ,JJJ
    11000 FORMAT(1H ,19HTROUBLE AT MESSAGE  I4,9HWELL NO. I7,11H SUBSCRIPT
         1I4,14H AND WELL NO. I7,11H SUBSCRIPT I4)
      622 CONTINUE
          CALL EXIT
```

APPENDIX B

POLYGON DATA GENERATION PROGRAM

This program generates data for an irregular polygon grid system for use in a mathematical model of a groundwater reservoir. To set up this program, the wells in the study area must be assigned numbers from 1 to L, where L = total number of wells. To define the boundaries of the system, the following method must be used. For vertical or near-vertical boundaries, define nodes outside the boundaries that have the same y coordinate and are equidistant from the boundaries as nodes in the boundary that are adjacent to the boundaries. For horizontal or near-horizontal boundaries, define nodes that have the same x coordinate and are equidistant from the boundary as nodes adjacent to the boundary.

If this is done for each boundary, then each node adjacent to the boundary should have at least one exterior node associated with it. After this is done, then a process of setting up adjacent nodes must be performed. To do this, start with node 1 of the study area and define all adjacent nodes including exterior nodes associated with each node. Repeat this process for each node. The best way to do this is to define the nearest one or two nodes in each quadrant associated with a center node.

The node numbers and the coordinates associated with each node, including exterior nodes, are the only input data required for this program. The program then computes the length between nodes for each polygon, the width of all faces for each polygon, and the area of each polygon.

In the program, statements 1 through 10 are for input data. Statements 10 through 12 compute and write the length between nodes. Statements 30 through 55 compute and write the width of faces of the polygon, and statements 55 through 70 compute and write the area of the polygon.

It must be noted, however, that although the program computes lengths between a node adjacent to a boundary and an exterior node, only the widths and lengths within the boundary are needed for input data for the model. The other values result from defining the boundary. The data output must be further reduced by computing width to length ratios, W/L. Also, the area must be multiplied by the factor 640 to change square miles to acres.

The definitions of terms used in the data generation program are as follows:

N = total number of nodes
L = number of interior nodes
M = number of adjacent nodes associated with an interior node
X (I) = X coordinate of node (Mi)
Y (I) = Y coordinate of node (Mi)
NWELL (I) = node number of well
XNLEN (I,J) = length between center node, I, and exterior node J (Mi)
Zmaj, Zmin = intersection points of the faces of the polygon
Wid (I,J) = width of face between center node, I, and adjacent node, J (Mi)
area (I) = area of the polygon (Mi^2).

```
          DIMENSION X(64),Y(64),NWELL(64),MWELL(64)
          DIMENSION B(10),C(10),S(10),W(10)
          DIMENSION XNLEN(64,64),ZMAJ(64,64),ZMIN(64,64)
          DIMENSION SLOPE(64,64),B(64,64),WID(64,64),AREA(64)
        1 FORMAT(2I5)
        2 FORMAT(2F10.2,I5)
        3 FORMAT(I5)
        4 FORMAT(14I5)
      100 FORMAT(3X,16HLENGTH FROM NODE,3X,I5,3X,7HTO NODE,3X,I5,3X,F10.2)
      103 FORMAT(//,10X,12HPOLYGON NODE,5X,13HEXTERIOR NODE,5X,13HWIDTH OF F
         1ACE,//)
      104 FORMAT(14X,I5,13X,I5,11X,F10.2,//)
      106 FORMAT(5X,4HNODE,2X,I5,4X,4HAREA,2X,F15.2,//)
              READ(5,1)N,L
C  N=NO OF WELLS OR NODES
C  L= THE NO OF NODES - THE NO OF NODES USED TO SET UP BOUNDARIES
                     DO 10 I=1,N
   10         READ(5,2)X(I),Y(I),NWELL(I)
C  READ NODES ASSOCIATED WITH CENTER NODE I
                     DO 11 I=1,L
              READ(5,3)M
              READ(5,4)(MWELL(J),J=1,M)
C  COMPUTE LENGTHS FROM CENTER NODES TO ADJACENT NODES
                     DO12 J=1,M
                     XNLEN(I,MWELL(J))=SQRT((X(MWELL(J))-X(I))*(X(MWELL(J))-X(I
     1))+(Y(MWELL(J))-Y(I))*(Y(MWELL(J))-Y(I)))
   12         WRITE(6,100)I,MWELL(J),XNLEN(I,MWELL(J))
   11                CONTINUE
              WRITE(6,103)
                     DO 70 I=1,L
              READ(5,3)KN
C  KN= THE NO OF ADJ WELLS + 1
                     J=0
              READ(5,4)(MWELL(LL),LL=1,KN)
C  AT J = KN SUBSTITUTE NODE = 1 AGAIN
                     M=KN-1
                     DO 50 KK=1,M
                     J=J+1
C  AT J=M SUBSTITUTE NODE J=1 AGAIN
                     IF(X(MWELL(J))-X(I))30,31,30
   30                IF(Y(MWELL(J))-Y(I))32,33,32
   32                IF(X(MWELL(J+1))-X(I))34,35,34
   34                IF(Y(MWELL(J+1))-Y(I))40,42,40
   31                IF(Y(MWELL(J+1))-Y(I))36,38,36
   33                IF(X(MWELL(J+1))-X(I))39,41,39
C  COMPUTE ZMAJ AND ZMIN WHEN Y(MWELL(J)-Y(I) NE 0, X(MWELL(J+1)-X(I) E O
   35                ZMIN(I,MWELL(J))=(Y(MWELL(J+1))+Y(I))/2.0
                     SLOPE(I,MWELL(J))=(Y(MWELL(J))-Y(I))/(X(MWELL(J))-X(I))
                     B(I,MWELL(J))=(SLOPE(I,MWELL(J))+1.0/SLOPE(I,MWELL(J)))*(X
     1(MWELL(J))+X(I))/2.0+Y(I)-SLOPE(I,MWELL(J))*X(I)
                     ZMAJ(I,MWELL(J))=(B(I,MWELL(J))-ZMIN(I,MWELL(J)))/SLOPE(I,
     1MWELL(J))
C  COMPUTE ZMAJ AND ZMIN FOR X(MWELL(J))-X(I) NE 0 AND Y(MWELL(J+1))-Y(I) E O
   42                ZMIN(I,MWELL(J))=(Y(MWELL(J+1))+Y(I))/2.0
```

```
               SLOPE(I,MWELL(J))=(Y(MWELL(J))-Y(I))/(X(MWELL(J))-X(I))
               B(I,MWELL(J))=(SLOPE(I,MWELL(J))+1.0/SLOPE(I,MWELL(J)))*(X
     1(MWELL(J))+X(I))/2.0+Y(I)-SLOPE(I,MWELL(J))*X(I)
               ZMAJ(I,MWELL(J))=(B(I,MWELL(J))-ZMIN(I,MWELL(J)))/SLOPE(I,
     1MWELL(J))
               GO TO 50
C COMPUTE ZMAJ AND ZMIN FOR X(MWELL(J))-X(I) E O  Y(MWELL(J+1))-Y(I) NE O
   36          ZMIN(I,MWELL(J))=(Y(MWELL(J))+Y(I))/2.0
               SLOPE(I,MWELL(J+1))=(Y(MWELL(J+1))-Y(I))/(X(MWELL(J+1))-X(
     1I))
               B(I,MWELL(J+1))=(SLOPE(I,MWELL(J+1))+1.0/SLOPE(I,MWELL(J+1
     1)))*(X(MWELL(J+1))+X(I))/2.0+Y(I)-SLOPE(I,MWELL(J+1))*X(I)
               ZMAJ(I,MWELL(J))=(B(I,MWELL(J+1))-ZMIN(I,MWELL(J)))/SLOPE(
     1I,MWELL(J+1))
               GO TO 50
C  COMPUTE ZMAJ AND ZMIN FOR X(MWELL)-X(I) E O AND Y(MWELL(J+1))-Y(I) E O
   38          ZMAJ(I,MWELL(J))=(X(MWELL(J+1))+X(I))/2.0
               ZMIN(I,MWELL(J))=(Y(MWELL(J))+Y(I))/2.0
               GO TO 50
C  COMPUTE ZMAJ AND ZMIN FOR Y(MWELL(J))-Y(I) EO ANDX(MWELL(J+1))-X(I) NE O
   39          ZMAJ(I,MWELL(J))=(X(MWELL(J))+X(I))/2.0
               SLOPE(I,MWELL(J+1))=(Y(MWELL(J+1))-Y(I))/(X(MWELL(J+1))-X(
     1I))
               B(I,MWELL(J+1))=(SLOPE(I,MWELL(J+1))+1.0/SLOPE(I,MWELL(J+1
     1)))*(X(MWELL(J+1))+X(I))/2.0+Y(I)-SLOPE(I,MWELL(J+1))*X(I)
               ZMIN(I,MWELL(J))=-ZMAJ(I,MWELL(J))/SLOPE(I,MWELL(J+1))+B(I
     1,MWELL(J+1))
               GO TO 50
C COMPUTE ZMAJ AND ZMIN WHEN ALL DIFERENCES NE O
   40          SLOPE(I,MWELL(J))=(Y(MWELL(J))-Y(I))/(X(MWELL(J))-X(I))
               B(I,MWELL(J))=(SLOPE(I,MWELL(J))+1.0/SLOPE(I,MWELL(J)))*(X
     1(MWELL(J))+X(I))/2.0+Y(I)-SLOPE(I,MWELL(J))*X(I)
               SLOPE(I,MWELL(J+1))=(Y(MWELL(J+1))-Y(I))/(X(MWELL(J+1))-X(
     1I))
               B(I,MWELL(J+1))=(SLOPE(I,MWELL(J+1))+1.0/SLOPE(I,MWELL(J+1
     1)))*(X(MWELL(J+1))+X(I))/2.0+Y(I)-SLOPE(I,MWELL(J+1))*X(I)
               ZMAJ(I,MWELL(J))=(B(I,MWELL(J+1))-B(I,MWELL(J)))/(1.0/SLOP
     1E(I,MWELL(J+1))-1.0/SLOPE(I,MWELL(J)))
               ZMIN(I,MWELL(J))=-ZMAJ(I,MWELL(J))/SLOPE(I,MWELL(J))+B(I,M
     1WELL(J))
               GO TO 50
C COMPUTE ZMAJ AND ZMIN FOR Y(MWELL(J))-Y(I) E O AND X(MWELL(J+1))-X(I) E O
   41          ZMIN(I,MWELL(J))=(Y(MWELL(J))+Y(I))/2.0
               ZMAJ(I,MWELL(J))=(X(MWELL(J+1))+X(I))/2.0
               GO TO 50
   50          CONTINUE
C  COMPUTE THE WIDTH OF FACES OF THE POLYGON
               KOUNT=0
   51          KOUNT=KOUNT+1
               IF(KOUNT-M)53,54,55
   54          WID(I,MWELL(M))=SQRT((ZMAJ(I,MWELL(1))-ZMAJ(I,MWELL(M)))*(
     1ZMAJ(I,MWELL(1))-ZMAJ(I,MWELL(M)))+(ZMIN(I,MWELL(1))-ZMIN(I,MWELL(
     1M)))*(ZMIN(I,MWELL(1))-ZMIN(I,MWELL(M))))
            WRITE(6,104)I,MWELL(1),WID(I,MWELL(M))
```

```
CARC
                GO TO 51
      53        WID(I,MWELL(KCUNT))=SQRT((ZMAJ(I,MWELL(KCUNT+1))-ZMAJ(I,MW
               1ELL(KCUNT)))*(ZMAJ(I,MWELL(KCUNT+1))-ZMAJ(I,MWELL(KCUNT)))+(ZMIN(I
               1,MWELL(KCUNT+1))-ZMIN(I,MWELL(KCUNT)))*(ZMIN(I,MWELL(KCUNT+1))-ZMI
               1N(I,MWELL(KCUNT))))
             WRITE(6,1C4)I,MWELL(KCUNT+1),WID(I,MWELL(KCUNT))
                GC TC 51
C     COMPUTE THE AREA CF THE PCLYGCN
      55        CONTINUE
                AREA(I)=C
                JJJ=0
      83        JJJ=JJJ+1
                IF(JJJ-M)84,81,71
      81        SARE=XNLEN(I,MWELL(1))*WID(I,MWELL(M))/4.0
                AREA(I)=AREA(I)+SARE
                GC TC 83
      84        SARE=XNLEN(I,MWELL(JJJ+1))*WID(I,MWELL(JJJ))/4.0
                AREA(I)=AREA(I)+SARE
                GC TC 83
      71     WRITE(6,1C6)I,AREA(I)
      70        CCNTINUE
                CALL EXIT
                END
```

TABLE XII

DATA OUTPUT OF POLYGON GENERATION PROGRAM
(Length Between Nodes and Width of Faces)

Exterior Node	Center Node	Length	Width	Ratio W/L
2	1	0.50	1.00	2.00
13	1	0.71	0.35	0.49
15	1	1.00	0.25	0.25
3	2	0.50	1.00	2.00
12	2	0.71	0.00	0.00
13	2	0.50	0.50	1.00
1	2	0.50	1.00	2.00
4	3	1.58	0.53	0.34
11	3	0.71	0.71	1.00
12	3	0.50	0.50	1.00
2	3	0.50	1.00	2.00
5	4	1.00	0.50	0.50
6	4	1.12	0.19	0.17
10	4	1.12	0.75	0.67
11	4	1.41	0.71	0.50
3	4	1.58	0.53	0.34
7	5	0.50	0.50	1.00
6	5	0.50	0.75	1.50
4	5	1.00	0.50	0.50
5	6	0.50	0.75	1.50
7	6	0.71	0.00	0.00
8	6	0.50	1.00	2.00
10	6	0.71	1.18	1.66
4	6	1.12	0.19	0.17
9	7	0.71	0.71	1.00
8	7	0.50	0.50	1.00
6	7	0.71	0.00	0.00
5	7	0.50	0.50	1.00
18	8	2.50	0.50	0.20
6	8	0.50	1.50	3.00
7	8	0.50	0.50	1.00
9	8	0.50	1.50	3.00
18	9	2.55	1.53	0.60
8	9	0.50	1.50	3.00
7	9	0.71	0.71	1.00
18	10	2.24	1.49	0.67
17	10	2.12	0.82	0.39
11	10	1.50	1.00	0.67

TABLE XII (continued)

4	10	1.12	0.75	0.67
6	10	0.71	1.77	2.49
10	11	1.50	1.00	0.67
17	11	1.50	0.50	0.33
16	11	1.12	0.56	0.50
12	11	0.50	0.75	1.50
3	11	0.71	0.71	1.00
4	11	1.41	0.71	0.50
3	12	0.50	0.50	1.00
11	12	0.50	0.75	1.50
16	12	1.00	0.25	0.25
14	12	0.71	0.35	0.49
13	12	0.50	0.50	1.00
12	13	0.50	0.50	1.00
14	13	0.50	0.50	1.00
15	13	0.71	0.35	0.49
1	13	0.71	0.35	0.49
2	13	0.50	0.50	1.00
12	14	0.71	0.35	0.49
16	14	0.71	1.06	1.49
15	14	0.50	1.00	2.00
13	14	0.50	0.50	1.00
1	15	1.00	0.25	0.25
13	15	0.71	0.35	0.49
14	15	0.50	2.38	4.76
14	16	0.71	1.77	2.49
12	16	1.00	0.25	0.25
11	16	1.12	1.12	1.00
10	16	2.24	0.56	0.25
17	16	0.71	2.12	2.99
21	16	1.58	0.79	0.50
16	17	0.71	1.77	2.49
10	17	2.12	0.71	0.33
20	17	1.41	1.41	1.00
23	17	1.58	0.79	0.50
21	17	1.00	2.00	2.00
10	18	2.24	1.12	0.50
8	18	2.50	0.25	0.10
9	18	2.55	1.53	0.60
28	18	1.00	2.00	2.00
26	18	1.12	0.19	0.17
19	18	1.12	1.30	1.16
18	19	1.12	1.54	1.38
26	19	0.71	0.47	0.66
25	19	0.50	0.50	1.00
24	19	0.71	0.00	0.00
20	19	0.50	1.50	3.00
17	19	1.80	0.26	0.14
19	20	0.50	1.50	3.00
24	20	0.50	0.75	1.50
21	20	1.00	0.75	0.75
17	20	1.41	1.05	0.75

TABLE XII (continued)

16	21	1.58	0.26	0.16
17	21	1.00	1.50	1.50
20	21	1.00	0.50	0.50
23	21	0.71	0.35	0.49
22	21	0.50	1.50	3.00
21	22	0.50	2.00	4.00
23	22	0.50	1.00	2.00
35	22	1.58	2.11	1.34
22	23	0.50	1.00	2.00
21	23	0.71	0.35	0.49
24	23	0.50	1.00	2.00
34	23	1.58	0.00	0.00
35	23	1.50	0.50	0.33
23	24	0.50	1.00	2.00
20	24	0.50	0.50	1.00
19	24	0.71	0.00	0.00
25	24	0.50	1.00	2.00
34	24	1.50	0.50	0.33
19	25	0.50	0.50	1.00
26	25	0.50	0.50	1.00
27	25	0.71	0.71	1.00
33	25	1.50	0.00	0.00
24	25	0.50	1.00	2.00
25	26	0.50	0.50	1.00
19	26	0.71	0.47	0.66
18	26	1.12	0.19	0.17
28	26	0.50	0.75	1.50
29	26	0.71	0.00	0.00
27	26	0.50	0.50	1.00
25	27	0.71	0.71	1.00
26	27	0.50	0.50	1.00
29	27	0.50	0.50	1.00
31	27	0.71	0.47	0.66
33	27	1.12	0.75	0.67
26	28	0.50	0.75	1.50
18	28	1.00	2.00	2.00
29	28	0.50	2.00	4.00
28	29	0.50	2.00	4.00
31	29	0.50	2.00	4.00
27	29	0.50	0.50	1.00
32	30	0.71	0.71	1.00
31	30	0.50	0.50	1.00
30	31	0.50	0.50	1.00
32	31	0.50	0.75	1.50
33	31	1.12	0.19	0.17
27	31	0.71	0.47	0.66
29	31	0.50	0.50	1.00
30	32	0.71	0.71	1.00
33	32	1.00	0.50	0.50
31	32	0.50	0.75	1.50
32	33	1.00	0.50	0.50

TABLE XII (concluded)

34	33	0.50	1.00	2.00
27	33	1.12	0.75	0.67
31	33	1.12	0.19	0.17
33	34	0.50	1.00	2.00
35	34	0.50	1.00	2.00
24	34	1.50	0.50	0.33
23	35	1.50	0.50	0.33
34	35	0.50	1.00	2.00
22	35	1.58	2.37	1.50

TABLE XIII

ELEVATIONS OF THE STUDY AREA

Well No.	Saturated Thickness	Depth to Water	Surface Elevation	Top Elevation	Bottom Elevation
1	180	160	3260	3100	2920
2	170	170	3262	3092	2922
3	180	160	3262	3102	2923
4	250	150	3265	3115	2865
5	240	160	3270	3110	2870
6	250	155	3265	3110	2860
7	230	170	3270	3100	2870
8	240	170	3275	3105	2865
9	250	155	3280	3125	2875
10	220	130	3240	3110	2890
11	190	160	3235	3075	2885
12	180	105	3240	3075	2895
13	170	170	3235	3065	2895
14	160	170	3230	3060	2900
15	150	165	3220	3055	2905
16	170	170	3210	3040	2870
17	180	165	3205	3040	2860
18	200	90	3240	3150	2950
19	230	130	3220	3090	2860
20	220	140	3200	3060	2840
21	220	155	3205	3050	2830
22	240	145	3200	3055	2815
23	250	145	3190	3045	2795
24	260	140	3185	3045	2785
25	270	140	3180	3040	2770
26	250	135	3200	3065	2815
27	290	135	3180	3045	2755
28	270	110	3200	3090	2820
29	285	120	3200	3080	2795
30	260	110	3185	3075	2815
31	310	130	3190	3060	2750
32	320	140	3185	3045	2725
33	350	150	3180	3030	2680
34	340	150	3180	3030	2690
35	300	150	3175	3025	2725

VITA

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Candidate for the Degree of

Master of Science

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