LD

THE ECONOMICS OF GROUNDWATER MANAGEMENT WITH SPECIAL EMPHASIS ON THE HIGH PLAINS REGION OF WESTERN KANSAS

by

DAVID L. JORDENING

B.A., Kearney State Teachers College, 1964

9589

A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF ARTS

Department of Economics

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1972

Approved by:

Edgar S Bagley

Major Professor

TABLE OF CONTENTS

Chapter | Page

I INTRODUCTION 1

The Importance of Water
Objectives
Order of Presentation

II CONSTRAINTS ON GROUNDWATER DEVELOPMENT 13

Consideration of the Physical Characteristics of Aquifers
General Economic Considerations

III GROUNDWATER PROBLEMS OF KANSAS 21

Recognition of the Problem
General Characteristics of the Ogallala Formation
Western Kansas Groundwater Situation
Eastern Kansas

IV THE ECONOMICS OF GROUNDWATER MANAGEMENT 41

General Welfare Criteria of Resource Management
Resource Management Models
Groundwater Management Models

V SUMMARY AND CONCLUSIONS 71

The value of Groundwater Management Models
Limitations of the Models as a Practical Management Tool
The Models as Applicable to the Kansas Situation

BIBLIOGRAPHY 75

LIST OF FIGURES

Figure		Page
I	Trends In Water Use, 1950-1965	10
II	Diagrammatic Representation of the Hydrologic Cycle	11
III	Types of Interstices	20
IV	Land Suitable for Irrigation Overlying Groundwater Areas Capable of Producing Yields of 100 Gallon Per Minute or More to Wells	31
V	Total Land Suitable for Irrigation	32
VI	Map of Mean Annual Precipitation in Kansas 1921-1956	33
VII	Net Irrigation Requirements	34
VIII	Saturated Thickness of the Unconsolidated Deposits	35
IX	Depth to Water	36
X	Estimated Annual Natural Recharge to the Groundwater Reservoir	37
XI	Estimated Excess of Pumpage Over Recharge in 1966	38
XII	Extimated Excess of Pumpage Over Recharge in the Year 2000	39
XIII	Area of Potential Groundwater Depletion	40
XIV	Equilibria Between the Resource Mass and Its Environment and Equilibria Between the Extracting Industry and Alternative Uses of Capital in the Economy	66
XV	Streams of Net Rent Per Acre for Groundwater With Different Amounts of Water Applied Per Acre	68
XVI	Iso-Net-Output Map and Decision Rule	69
XVII	Plot of Net Annual Receipts From Mining and Capitalized Annual Loss in Value of Recharge	70

LIST OF TABLES

Table		Page
I.	Summary of Water Withdrawn Except for Hydroelectric Power in Millions Gallons Per Day, By Water-Use Regions, 1965	9
II.	Estimated World Water Supply	12
III.	Capitalized Value of Groundwater	67

CHAPTER I

INTRODUCTION

The Importance of Water

Increased concern for the optimal management of natural resources is the result of the sometimes sudden realization that insufficient quantities exist to satisfy needs for a given time, place and use. One of these natural resources is water.

In addition to being a basic requirement for life, water is used in the production process of almost every commodity that enters the market. The great demand for this resource can be illustrated by the fact that in 1965 the average withdrawal use of water was 1,600 gallons per capita per day or an average of 310 bgd (billion gallons per day). This includes withdrawals for public supply, rural domestic and livestock, irrigation and industrial uses but does not include non-withdrawal uses such as for water power, navigation and many recreational uses.[1] Even though man is totally dependent on water, it has only been recently recognized that the availability of water cannot be taken for granted and that water must be managed with sound conservation practices in order to insure availability for future use.

One fact that has emphasized the need for conservation and water-use guidelines is that the use of water has increased appreciably during recent years.

---

[1]U.S., Department of the Interior, Geological Survey, Estimated Use of Water in the United States, 1965, by C. Richard Murray, Geological Survey Circular No. 556 (Washington, D.C.: Government Printing Office, 1968), p. 1.

During the five year period, 1960-1965, the average use of water increased 15 percent, fresh water withdrawals for thermoelectric power generation increased 25 percent, and saline water withdrawals increased 33 percent. These figures show a sizable increase in the quantity of water demanded, but they do not reflect accurately the quantity of water actually consumed. Water can be reused up to the point where the quality of it is so impaired that it is rendered useless for other purposes. The quantity of water actually consumed--that is, water made unavailable for further possible withdrawal--was estimated to be 78 bgd for 1965, and increase of 28 percent since 1960. Table I, page 9, summarizes the withdrawal level by types of water and by water-use regions while figure I, page 10, shows the trend in withdrawal rates.

Hydrological Cycle

While the withdrawal of water has been increasing rapidly the total amount of water available on, above and below the surface of the earth is a fixed quantity. This fixed quantity is continually changing form and location. The fixed quantity and dynamic nature of water can be illustrated by a pictorial description of the hydrological cycle, figure II, page 11.

This phenomena, changing form and location of a fixed quantity, is caused by evaporation and transpiration (evaporation of water absorbed by plants) from the surface of the earth which creates water vapor resulting in cloud formations. Air and wind currents transport the cloud formations or vapor to other locations where it precipitates when the proper conditions prevail. Some of the precipitation is immediately returned to the atmosphere through the process of evaporation. Part of the precipitation falls on surface water or supplements surface water through runoff and part of the remaining portion supplements groundwater deposits through the process of seepage and infiltration.

Since the hydrological cycle is a never ending process of evaporation and precipitation which provides a perennial supply of fresh water to surface and groundwater reservoirs there is little danger that the total quantity of water in existence will be physically exhausted. Another factor preventing exhaustion is that man depends on only a very small fraction of the world's total water supply. Table II, page 12, shows that 99.4 percent of the world's water supply is brine, ice in oceans, inland seas, glaciers and polar ice caps --that is, in forms that are not easily utilized or normally thought of as feasible sources of supply (with the present state of technology).

The hydrological cycle produces a fairly constant quantity of water to the total land mass over time; however, there are likely to be extreme variations in the quantity that precipitates on any particular area of land, as well as the time at which it occurs. This variation in precipitation has forced water users to seek other sources of water. One of the more readily available sources with which to augment precipitation is groundwater deposits.

Importance of Groundwater

The total usable water supply is composed of groundwater, surface water and other minor components.[2] The magnitude of groundwater reservoirs and the characteristics of this form of the resource make it particularly important.

From table II, page 12, it is apparent that groundwater is the largest single component of the total usable fresh water supply. Using efficient methods of management, groundwater reservoirs could supply a large percentage of the total quantity of water demanded. In a paper presented by Harold

---

[2]Table II, page 12, shows the composition of the total water supply and the disparity between total water and usable water, the latter comprising only 0.6 percent of the total water supply. The usable water supply being defined as fresh water lakes, rivers, soil moisture, groundwater and atmosphere water.

Thomas at the National Symposium on Groundwater Hydrology and printed in the proceedings of the meeting the author states that ". . .groundwater yields almost 80 percent of the total potential supply for use".[3] The potential of groundwater as a source of supply can also be illustrated by the fact that withdrawal use of water in the U.S. could increase approximately three times the 1965 rate before daily use equaled the average recharge rate. The annual recharge in the U.S. is approximately one billion acre feet each year.[4] With this information and the water use rates from table I, page 9, the potential of groundwater as a future source of supply can be corroborated.

Another factor that contributes to the importance of groundwater is the fact that municipalities and other water users not located near surface water sources typically are forced to rely on groundwater sources for their water supply. For example; Houston, Texas, a city of 1,213,064, relies almost exclusively on groundwater for its municipal water supply.[5]

There are other qualitative factors which also enhance the future importance of groundwater. The fact that most groundwater--at this time--is relatively safe from pollution and seldom has to be treated to remove sedimentation, and the fact that it normally has a temperature range lower than that of surface water, increases its value to individuals and industry.

Even though at the present time groundwater accounts for only a minor share of the total water withdrawals, (see Table I), its value as a potential

---

[3]American Water Resources Association, Proceedings of the National Symposium on Groundwater Hydrology, "Management of Groundwater Resources", by Harold E. Thomas (Urbana, Illinois: PDQ Printing Service, 1967), p. 34.

[4]U.S., Department of the Interior, Geological Survey, Water Management Agricultural, and Groundwater Supplies, by R. L. Nace, Geological Survey Circular No. 415 (Washington, D.C.: Government Printing Office, 1961), p. 1.

[5]U.S., Department of the Interior, Geological Survey, Groundwater Resources--Development and Management, by C. S. Conover, Geological Survey Circular No. 442 (Washington, D.C.: Government Printing Office, 1961), p. 1.

source of water has been recognized in many areas. Many localities have become totally dependent on it for their water supply. This is illustrated by the fact that there were 600 towns and cities in the state of Texas in 1957 that depended on groundwater for their sole source of water.[6] The withdrawal of groundwater in Texas during the period 1952-1960 increased tenfold.[7] This area as well as other highly developed areas that depend on groundwater cannot continue to withdraw groundwater at such rapid rates indefinitely.

One index of the importance of groundwater to the national economy is the number of new water well constructions. Estimates of groundwater withdrawals increased 30 to 50 percent between 1950 and 1960.[8] In 1964, between one-half to three-quarter billion dollars were invested in new water-well construction. This investment represents approximately 1,700 well starts for each working day or a total of 435,700 new wells.[9]

The change in drilling activity varies from region to region and is determined by many factors, such as, regional growth and shifts in population, changes in irrigation practices, changes in technology, prevailing economic conditions and natural phenomena such as earthquakes and droughts. Even on a national basis, however, there was a 14 percent increase in drilling activity during 1960 and 1964.[10]

---

[6]Nace, op. cit., p. 6.

[7]Nace, op. cit., p. 6.

[8]U.S., Department of the Interior, Geological Survey, Regional Trends in Water-Well Drilling in the United States, by Gerald Meyer and G. G. Wyrick, Geological Survey Circular No. 533 (Washington, D.C.: Government Printing Office, 1966), p. 1.

[9]Ibid., p. 1.

[10]Ibid., p. 1.

Possible Limitations to Continual Groundwater Withdrawals

The problem that arises is that, even though groundwater is abundant in many areas and has a great potential as a future source of water for these particular areas, there is a great regional disparity in the initial endowments of this resource. Some areas have a fixed supply that can be exhausted over time. This is the case for many areas that are characterized by very low rates of natural recharge. The existing groundwater supplies are the result of many years of recharge and once depleted they would not be replenished by natural means for many years.[11] Unless pumping is controlled, the dependence of an area on groundwater supplies often leads to the problem of overdraft, that is, groundwater pumping in excess of natural recharge. It must be emphasized that many of the areas of large overdraft of groundwater are located in semiarid areas overlying water-yielding formations that are isolated from other formations by impermeable strata which prevent interbasin flows. This makes overdraft on the local level possible even though national recharge exceeds groundwater withdrawals.

When unlimited groundwater withdrawals are allowed to exist year after year the continual overdraft lowers the groundwater levels and it is possible that serious physical damage will be incurred--damage to the aquifer (a geological subsurface formation containing and transmitting groundwater), and damage to the overlying area. This damage may take the form of subsidence,

---

[10]Ibid., p. 1.

[11]It is estimated that it would take more than 1,000 years of natural recharge to replace the groundwater in the Texas portion of the High Plains area.

Conover, op. cit., p. 1.

compaction and cementation or contamination by sea water intrusion.[12] Even if physical damage to the aquifer does not result from overdraft, the economic consequences of a declining groundwater level will be the same--declining yields, increasing costs and perhaps the eventual loss of an economic resource.

It is possible that the loss of this resource will not seriously affect the area economy if there are alternative sources of water available. If, however, the economy is dependent on this source and a suitable alternative is not available its loss will have adverse economic consequences on the area economy and its surrounding environs dependent on this resource.

Objectives

The objective of this paper is to review the economics of groundwater management giving consideration to the future values of water. It is also an objective of this paper to review the groundwater problems of Kansas.

Order of Presentation

The remaining chapters of this study will be concerned with presenting the physical and institutional framework surrounding groundwater management, discussing the special groundwater problems of Kansas, and the presentation and evaluation of groundwater management models.

---

[12]All of these forms of damage, subsidence, compaction and cementation and sea water intrusion, can be caused by a lowering of the groundwater level. Subsidence is an actual settling of the land due to the removal of subsurface water, compaction and cementation is the bonding of subsurface water bearing material thereby prohibiting future saturation. Sea water intrusion or encroachment is the landward movement of salt water into previously freshwater aquifers.

Chapter two will present the necessary geological information required to understand the groundwater problem.

Chapter three will summarize the major groundwater problems of Kansas.

Chapter four will be a summary of the current literature concerning resource management nodels.

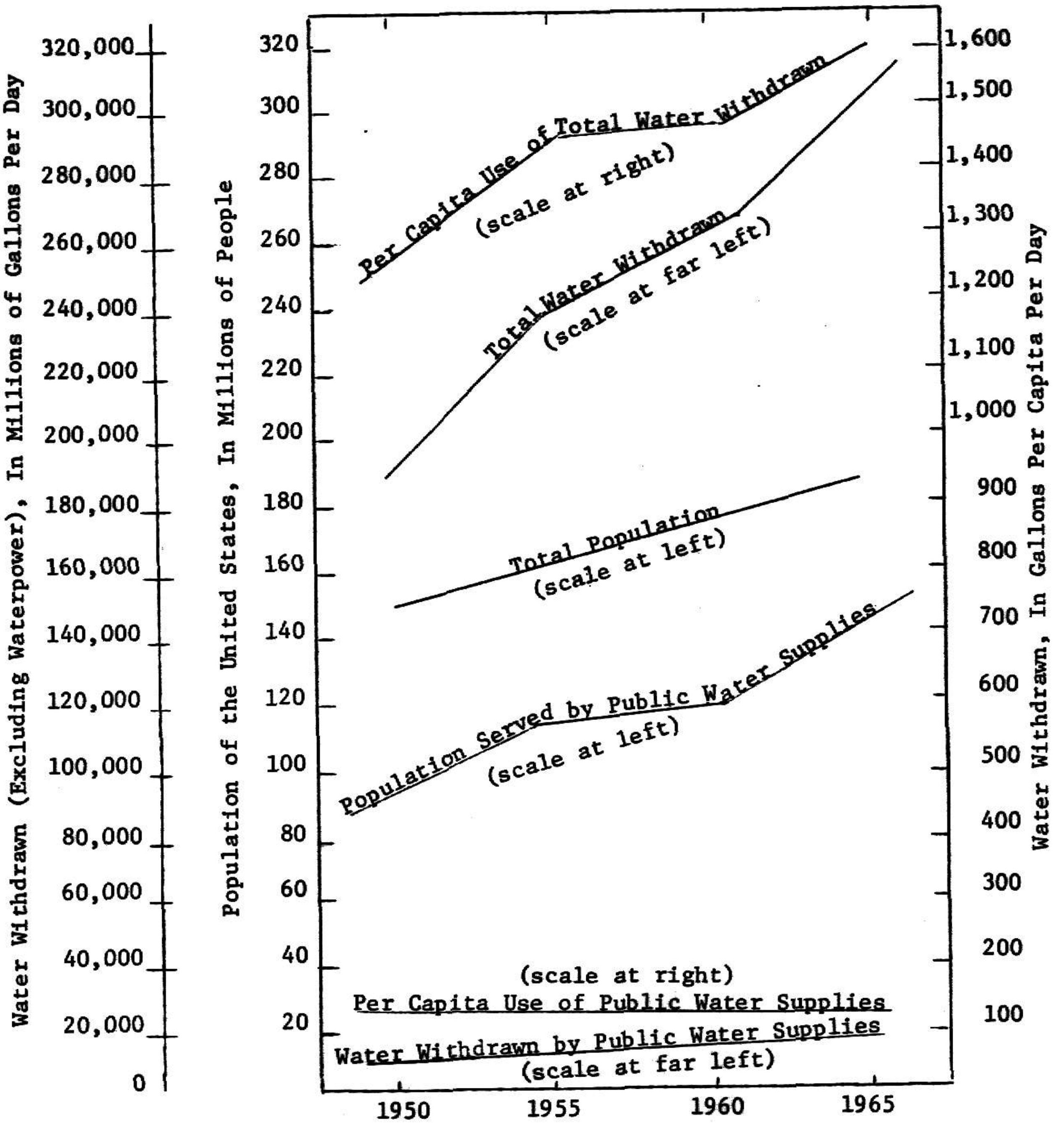
Chapter five will be a summary of this study and conclusions that were made after completing the study.

TABLE I. SUMMARY OF WATER WITHDRAWN EXCEPT FOR HYDROELECTRIC POWER IN MILLIONS GALLONS PER DAY, BY WATER-USE REGIONS, 1965

Regions	Ground Water	Surface Water	Sew-age	Total	Water Consumed
New England	510	6,700	1.1	7,200	360
Delaware-Hudson	1,500	23,000	0	24,000	1,100
Chespeake	520	8,900	130	9,600	390
South Atlantic	3,600	18,000	0	22,000	2,200
Eastern Gulf	730	5,700	0	6,400	490
Tennessee-Cumberland	240	7,900	0	8,200	400
Ohio	1,700	28,000	.3	30,000	940
Eastern Great Lakes-St. Lawrence	340	15,000	0	15,000	520
Western Great Lakes	810	17,000	0	18,000	600
Hudson Bay	56	210	0	270	71
Upper Mississippi	1.700	14,000	0	16,000	730
Upper Missouri	3,500	15,000	0	19,000	10,000
Lower Mississippi	1,300	3,900	0	5,200	1,000
Lower Arkansas-Red-White	1,300	2,200	0	3,400	1,200
Lower Missouri	240	1,500	0	1,800	200
Upper Arkansas-Red	4,100	2,900	1.5	7,000	4,500
Western Gulf	14,000	15,000	28	30,000	14,000
Colorado	4,700	12,000	58	17,000	8,400
Great Basin	1,600	5,300	51	6,900	3,800
South Pacific	13,000	25,000	400	38,000	15,000
Pacific Northwest	4,200	25,000	2.9	29,000	10,000
Hawaii	820	1,200	0	2,000	570
Alaska	26	120	0	140	11
Puerto Rico	150	1,500	0	1,700	270
Total-U.S.	61.000	250,000	670	310,000	78,000

Source: U.S., Department of the Interior, Geological Survey, Estimated Use of Water in the United Sates, 1965, by C. Richard Murray, Geological Survey Circular No. 556 (Washington, D.C.: Government Printing Office, 1968), p. 48.

Figure I. Trends In Water Use, 1950-1965



Source: U.S. Department of the Interior, Geological Survey, Estimated Use of Water in the United States, 1965, by C. Richard Murray, Geological Survey Circular No. 550 (Washington, D.C.: Government Printing Office, 1968), p. 11.

Figure II. Diagrammatic Representation of the Hydrologic Cycle (Adapted from ASCE Hydrology Handbook, 1949)

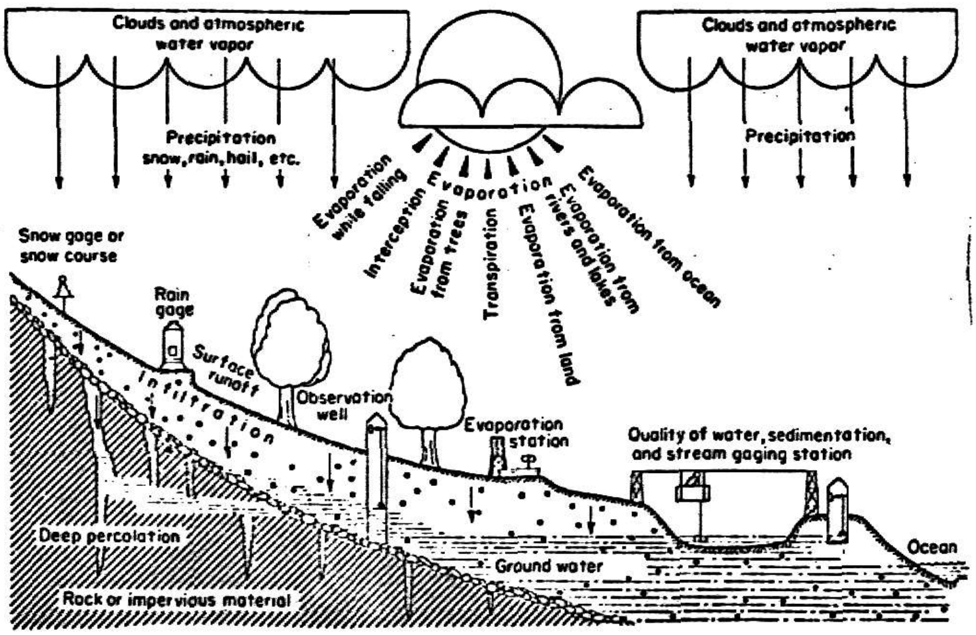


TABLE II. ESTIMATED WORLD WATER SUPPLY

Water Item	Volume (thousands) Cubic Miles	Percent of Total Water
Water in land areas:		
Fresh-water lakes	30	.009
Saline lakes and inland seas	25	.008
Rivers average instantaneous volume	.3	.0001
Soil moisture and vadose water	16	.005
Groundwater to depth of 4,000 m (about 13,100 ft.)	2,000	.61
Icecaps and glaciers	7,000	2.14
Total in land areas	9,100	2.8
Atmosphere	3.1	.001
World Oceans	317,000	97.3
Total, all items	326,000.0	100.0

Source: U.S., Department of the Interior, Geological Survey, Are We Running Out of Water?, by Raymond L. Nace, Geological Survey Circular No. 536 (Washington, D.C.: Government Printing Office, 1967), p. 2.

CHAPTER II

CONSTRAINTS ON GROUNDWATER DEVELOPMENT

Consideration of the Physical Characteristics of Aquifers

A prerequisite to formulating a comprehensive economic policy pertaining to groundwater extraction is the construction of a groundwater management model. An effective groundwater model can be constructed only if the model-builder is aware of the possible problems and restrictions that may be encountered in the extraction of groundwater. These constraints are typically imposed by the characteristics of the geographical area and the particular physical properties of the aquifer under consideration. This is the case because the characteristics of the geographical area frequently determine the need for supplemental water while the properties of the aquifer determine the feasibility of using groundwater sources to meet these supplemental water needs. Specifically, the properties of the aquifer determine the availability of water, the transmission of the water within the aquifer and the over-all usability of the aquifer. These factors in turn determine the optimal number of wells, the placement of wells, the potential size of the wells and the life expectancy of water producing units. These are some of the basic considerations that are typically encountered in groundwater management.

It is not within the scope of this chapter to establish all the hydrological considerations necessary but, rather, to elaborate on a few of the general physical and economic properties and their implications. These properties have been grouped into three broad categories: (1) size, depth and location of the aquifer, (2) composition and construction of the aquifer and (3) the recharge rate of the aquifer.

Size, Depth and Location of the Aquifer

The first general category--that of size, depth and location--is perhaps the most important because it sets obvious limits on the present and future extraction of groundwater. The size of the aquifer may vary from a narrow band of water-bearing material that is only a few feet thick, to areas that are completely undermined by aquifers that are several hundred feet thick. The depth of the aquifer is equally important because unless it is at a reasonable depth the extraction of water may not be economically feasible. The other feature, that of location, is also important because even if water bearing material is available at moderate depths the location may prohibit its use. For example, when considering an area possessing an aquifer common to both land areas and salt water bodies, the possibility of salt water encroachment may prevent present and future use unless costly protective measures are taken.

The implications of the above physical properties are important and must be synthesized into the management model because this first general category of physical properties helps determine the availability of water, the cost of acquiring water, and the length of life of the water producing units. These influences help determine the land use of the overlying area and the rate of water withdrawal.

Implicit in the above discussion is the degree of saturation of the water bearing material. The water in aquifers is stored and moves through numerous open spaces, called interstices. The water contained in the interstices is called subsurface water. If the interstices are completely saturated with water this portion of the subsurface water is called groundwater. Water contained in the interstices above the saturation zone is called vadose water.[1] The portion of subsurface water that is pertinent to this discussion is the water in the completely saturated formation--groundwater. The size, depth and location of the aquifer are of no importance unless the formation is completely saturated and of sufficient volume so as to be a potential source of water. The degree of saturation and the volume impounded is also dependent on the composition and construction of the aquifer and the natural recharge of the area. This is true because the construction of the aquifer might be such that the interstices are small and largely isolated preventing water movement form one interstice to another thereby limiting the volume and possibly preventing complete saturation. The degree of saturation and total volume is also dependent on the third general property because the overlying area may possess barriers to recharge or insufficient quantity of precipitation, both of which could prevent complete saturation or severely limit the total volume captured by the groundwater reservoir.

Composition and Construction of the Aquifer

The second major property that must be considered is the composition and construction of the aquifer. This property refers to the type and arrangement of the water bearing material which in turn determines the size, shape and continuity of the interstices. The material may be of various degrees of porosity and arranged in a variety of ways with each

---

[1]William C. Walton, Groundwater Resource Evaluation, (New York: McGraw-Hill Book Co., 1970), p. 29.

combination having unique consequences for groundwater development.[2] Figure III, page 20, illustrates the concept of porosity and arrangement.

The reason that this property must be considered is that the transmissibility and storage capacity of the aquifer is to a great degree dependent on these factors. Knowledge of the transmissibility of the aquifer is essential because this characteristic dictates or at least partially determines the spacing of wells, and the size of the area affected by either a temporary or permanent reduction in the water level. It also has implications regarding the type of supplemental water proposals that can be considered feasible in the event that overdraft has been tolerated and corrective measures become necessary.[3]

Natural Recharge of the Area

The third property--the rate of recharge--is also influenced by many factors. Only a small fraction of the annual precipitation of an area percolates downward and eventually reaches the water table (upper boundary of saturated material). Some of the factors that influence the amount of recharge are; the character and thickness of the soil, topography, vegetal cover, land use, soil moisture content, depth of the water table, intensity

---

[2] *Ibid.*, p. 31.

[3] If the aquifer is depleted the area may attempt to supplement their water supply. One way to supplement an area's water supply is to import water from other regions and store it in surface or groundwater reservoirs until needed. The feasibility of storing the imported water in subsurface reservoirs (artificial recharge) is affected in part by the composition and construction of the aquifer. The composition and construction may be such that the aquifer will not transmit the water from the point of origin to the general area of need in sufficient quantities to be a practical solution, thus eliminating this method of storage.

and duration of precipitation and other meteorological factors.[4]

The natural recharge of the area is important to groundwater management because it is the flow component of the resource. The flow component is the perennial addition to the stock resource that could be extracted without altering the groundwater level. The importance of this component varies from area to area but is an obvious management consideration. For example, if the conditions are such that the aquifer has reached a natural equilibrium level, the recharge to the aquifer equals the discharge from the aquifer. If this is the situation, further addition to the stock resource is not possible in the long-run because after the equilibrium level is reached further increments to the stock component will eventually be discharged from the aquifer to surface water bodies. In this case even though there may be no objections to utilizing the flow component of the resource with respect to its effect on groundwater storage there may be valid objections to the use of the flow component based on the detrimental effect it could have on area stream flow. This is the case because in many areas a large portion of the stream flow during dry periods is actually the groundwater flow component that has been discharged by the groundwater reservoir.

The opposite situation is the case of an aquifer that has not reached a natural equilibrium. In this situation the utilization of the flow component may be questionable depending on the water level of the aquifer. It could very well be the case that the flow component is more valuable if added to the stock component rather than utilized immediately because of its effect on future extraction costs, discounted future value of water, or the contingency value of the water retained in the ground.

---

[4]Walton, op. cit., p. 360.

General Economic Considerations

The economic considerations are the cost of acquiring water and the value of water in present and future production processes.

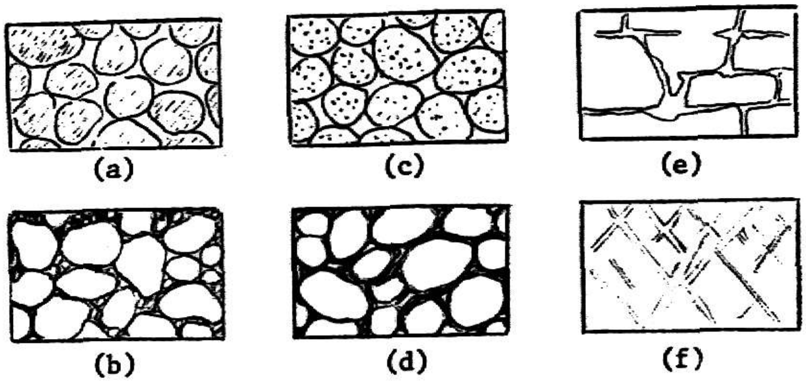
Many factors influence the acquisition cost of groundwater. Perhaps the most obvious is that of lift or depth of the groundwater. This factor imposes limits or constraints on groundwater extraction. As the lift increases the cost incurred also increases which has the potential of limiting groundwater extraction. If the depth to groundwater is excessive, extraction may not be practical except for very high-valued uses. Other factors affecting the cost of acquiring groundwater are: size of the initial investment required, expected life of the aquifer and the investment, available sources of power and the efficiency of the water producing unit. Many of these factors are influenced by the physical characteristics mentioned above.

The value of the acquired water is dependent on its above ground use. This value is in turn dependent on its efficiency as a productive input as well as the price of the resulting product and its value in nonproductive or consumptive uses.

It must be recognized that the above physical and economic constraints are quite general and somewhat incomplete because each area has its own unique problems and possible restrictions to groundwater development and, consequently, unique constraints on groundwater management. If the goal is to develop general groundwater management models the above physical and economic constraints constitute a sufficient foundation on which to build the analysis. If we are interested in the application of the general model to specific problem areas, it then becomes essential to have a comprehensive knowledge of the unique constraints of the area. Since it is quite impossible to discuss all the areas where groundwater management should be improved the following chapter will be devoted to the groundwater management problems of Kansas.

Figure III.

Types Of Interstices



Several types of interstices and the relation of rock texture to porosity. (a) Well-sorted sedimentary deposit having high porosity; (b) poorly sorted sedimentary deposit having low porosity; (c) well-sorted sedimentary deposits consisting of fragments of rock that are themselves porous, so that the deposit has a very high porosity; (d) well-sorted sedimentary deposit whose porosity has been diminished by the deposition of mineral matter in interstices; (e) rock rendered porous by solution; and (f) rock rendered porous by fracturing. (From Meinzer, 1959)

CHAPTER III

GROUNDWATER PROBLEMS OF KANSAS

Recognition of the Problem

Even if limited to the confines of one state, the problems of resource management are varied and numerous. As is typically the case, proper resource management is not considered essential until it is recognized that a shortage exists or that shortages will develop if present rates of use continue. The situation in Kansas is such that some areas have recognized the problem or potential problem since the impact of overdraft (withdrawals in excess of recharge) has been experienced for some time. Some water-users (primarily irrigators) have incorporated water-saving investments in their operations but a greater public awareness of the magnitude of the problem is needed.[1]

The discussion of Kansas groundwater problems will be limited to two areas of the state. The problem in both areas is basically the same--shortage or possible future shortages of groundwater--but the causes of this problem are completely different. The two selected problem areas will be considered in turn, first the western part and secondly the eastern part of the state.

Even within the confines of one area of one state it is difficult to generalize on one common groundwater problem. This is the case because there are variations in the amount of water in storage, depth to water and

---

[1]Kansas Water Resources Board, Irrigation in Kansas, (Topeka: State Printing Office, 1967), p. 2.

the dependence on these deposits. Due to the fact that most of the land in western Kansas can be irrigated and that most of the area overlies the Ogallala formation the basic problem, even though there is considerable local variations, is the same. At the present time the differences in the severity of the problem can be attributed to the degree of dependence on irrigation water and the fixed amount of water in storage.

The portion of western Kansas that we are concerned with includes essentially the western third of the state. This area is shown as the shaded area of figure IV, page 31. A large portion of this area of the state draws groundwater from the Ogallala formation which encompasses portions of six states.

General Characteristics of the Ogallala Formation

The general characteristics of the entire Ogallala formation are such that there is little, if any, groundwater inflow into the region that adds to the stock resource.[2] The only replenishing flow is from deep percolation--natural recharge. Due to the fact that the climate is semi-arid and that many parts of the aquifer possess physical barriers to recharge, the rate of natural recharge is very low. Some areas of this aquifer are considered completely closed to recharge.

The Ogallala aquifer also has a low transmission rate which adds to the management problem.[4] If an area of high water usage develops and

---

[2]Business Research Bureau Texas Technological College, West Texas Business Report, Vol. I, No. 8, (Lubbock, Texas: School of Business Administration, Texas Technological College, 1958), p. 2.

[3]U.S., Department of Agriculture, Agricultural Research, (Washington, D. C.: Government Printing Office, 1969), p. 10.

[4]Conover, op. cit., p. 3.

subsequently depletes the water deposits of the immediate area, the deficient area will not be replenished by rapid groundwater flows from the surrounding area. There are some isolated areas in the Texas High Plains overlying this formation that have essentially depleted their groundwater deposits while areas only a few miles away are virtually unaffected--experiencing very little if any decline in their groundwater table.[5] The result is that this area must view its groundwater extraction as coming primarily from a fixed total supply.

Western Kansas Groundwater Situation

Irrigation Incentives

As mentioned above, the area of western Kansas that we are concerned with includes essentially the western one-third of the state. The soil type and characteristics in this area are such that much of this area is considered suitable for irrigation. The shaded area on figure V, page 32, shows the maximum amount of land that could be irrigated. This figure does not consider the economic feasibility of irrigation or the availability of water but considers only the physical characteristics of the land itself. Out of 59,646,000 total acres in the state, 39,354,000 acres could be irrigated if the necessary water were available and proper management techniques were used.[6] As shown in figure V, essentially all of the land in the western third of the state could be irrigated.

The annual precipitation pattern, figure VI, page 33, and the general irrigated crop pattern permit the computation of average seasonal net irrigation requirements, figure VII, page 34. These irrigation requirements are the amounts that would be needed to produce maximum yields and do not necessarily indicate the most profitable per acre water applications.

---

[5] C. S. Conover, op. cit., p. 4.

[6] Irrigation in Kansas, op. cit., p. 3.

As was discussed in the previous chapter the saturated thickness of the aquifer helps determine the water-yielding capacity of the aquifer. As can be seen from figure VIII, page 35, the saturated thickness of the aquifers in southwest Kansas vary from 200 to 700 feet. Other areas in western Kansas are not as well endowed with groundwater. Saturated thickness in other areas of western Kansas varies from 0 to 200 feet.

Figure IX, page 36, shows that the depth to the saturated strata in western Kansas is generally less than 200 feet. This depth is not considered excessive and is not expected to be a significant factor in limiting the growth of irrigation units or the extraction per unit.

In addition to all of the above facts the value of an acre foot of water extracted for irrigation was in 1968 approximately $33 while the cost of acquiring an acre foot of irrigation water was considerably less.[7] All of these factors have had the effect of providing an environment favorable to increased groundwater extraction.

Growth of Groundwater Withdrawals

For the state as a whole irrigated acreage increased tenfold from 1940 to 1960.[8] A disproportionate amount of this increase has been in the western part of the state. Further, it has been estimated that irrigated acreage will double from the 1966 figure of 1,200,000 acres by 1980 and possibly double again by the year 2,000.[9]

---

[7]Kansas Water Resources Board, Economic Implications of Irrigation A Pilot Study, (Topeka: State Printing Office, 1968), p. 3.

[8]Irrigation In Kansas, op. cit., p. 5.

[9]Irrigation In Kansas, op. cit., p. 5.

The Limiting Factor

The factor that will eventually restrain further extraction is the low rate of recharge. For the state as a whole annual recharge varies from approximately one-fourth of one inch in portions of western Kansas to as much as six inches in portions of central and eastern Kansas.[10] This variation in annual recharge, shown in acre feet per year, is shown in figure X, page 37. Even though recharge in portions of western Kansas is small, it still exceeds recharge in the Texas and New Mexico portions of the Ogallala formation.

Considering two of the above factors together, the low rate of recharge and the growth of irrigated acres, one finds areas where there is a considerable excess of pumping over recharge, figure XI, page 38. Based on the projected growth of irrigated acres mentioned earlier, the area experiencing overdraft will be considerably larger by the year 2,000, figure XII, page 39. If this growth in water extraction is realized the eventual outcome will be depleted aquifers, (see figure XIII, page 40).

One of the main economic forces which in many situations tends to prevent further expansion of wells or limits withdrawals is absent in this case. This is the effect of increased lift. Due to the fact that the depth to groundwater is only 100 to 200 feet in most of the area, depth is not expected to be a limiting factor.[11] This is the case because even if the water level drops to the maximum possible level this is not expected to increase marginal costs to the point where water extraction for irrigation purposes is no longer feasible. The forces that might eventually limit the extraction of groundwater

---

[10] Ibid., p. 14.

[11] Ibid., p. 10.

in this area stem from the contingency value of the water remaining in the partially depleted aquifer or from the possible actions of the state regulatory agency. That is, the value of the remaining groundwater as a future source of water will increase as the groundwater supplies decrease. If this contingency factor causes the value of the groundwater to increase to levels greater than the value of a unit of water used in current production, it would be rational for the extractors as a group to discontinue groundwater mining. The other possible restraining force could be initiated by the chief engineer of the Division of Water Resources of the State Board of Agriculture. If further development is viewed as being sufficiently detrimental to the holders of existing rights the area could be closed to further development.

The situation in southwest Kansas seems to be such that depletion is not likely to stop unless controls are imposed by some regulatory agency.

Kansas Groundwater Law

Kansas has adopted the "prior appropriation" doctrine of groundwater law, which means that the groundwater is the property of the state and that the individual appropriates a right to use a specified quantity of water, provided the use is "beneficial". First in time is the first in right. In Kansas the appropriator must secure permission from the proper state agency (Division of Water Resources of the State Board of Agriculture) before he has the right to extract water for purposes other than domestic uses.[12] The chief engineer has the option of closing an area to further groundwater extraction. Such action can be taken, (1) if the proposed use will impair a use under an

---

[12] Kansas Statutes Annotated; Vol. VI, Section 82a-711, (Topeka: State Printing Office), p. 761.

existing water right, or (2) if the proposed use will prejudically and unreasonably affect the public interest.

In determining whether a proposed use will prejudicially and unreasonably affect the public interest, the chief engineer of the Division of Water Resources of the State Board of Agriculture shall consider:

> ". . .the area, safe yield and recharge rate of the appropriate water supply, the priority of existing claims of all persons to use the water of the appropriate water supply, the amount of each such claim to use water from the appropriate water supply, and all other matters pertaining to such questions."[13]

From the above it is clear that the chief engineer has both the power and obligation to regulate the extraction of groundwater if further extraction is not considered in the best interest.

Economic Impact of a Declining Water Level

The economic impact of a declining water level can be exhibited through several induced effects on the local economy. The declining water level could cause, (1) physical damage, (2) increased production costs and/or (3) extensive changes in production patterns. The actual result cannot be determined unless the severity of the decline and the resulting cost increases are known. Since the probability of physical damage is not known this feature will not be discussed.

Increased Production Costs

If the water level decline is such that it causes only moderate increases in production costs and still permits profitable irrigation with the same per acre water application and therefore generates the same total revenue as before the decline the results will not normally have serious

---

[13] Ibid., p. 761.

effects on the local economy. There are two possible exceptions where this is not the case. One exception which could cause adverse economic results, even with the same total revenue generated, is if the increased outlays for water extraction went for products produced by firms outside the region. For example, if the declining water level necessitated increased expenditure for power such as natural gas or electricity that is produced outside the region, this portion of aggregate expenditure would not contribute to local income. If the magnitude of these expenditures grow as the water level decline becomes more severe this could represent a substantial drain in local expenditures. In this case the declining water level, even though the same total revenue is generated, could cause adverse economic consequences to the region. Another situation that could produce a harmful regional impact could stem from a situation where the increased expenditure for water extraction is received by industries that have relatively low linkages and, therefore, low regional multiplier effects. In this case, even though the initial first-round regional expenditures remain constant, it is possible that a larger and larger proportion of total expenditure is received by an industry that is typically independent of other regional firms and possesses a much lower income generating potential. On the surface, however, there is no a priori reason to hypothesize that the industries receiving the increased extraction expenditures have this particular characteristic. To the extent, however, that this characteristic is present a declining water level could be detrimental to the region.

Extensive Production Changes

If the water level decline is significant enough to cause a reduction in per acre application or a complete readjustment to dryland farming the results can be expected to be detrimental to area income.

The magnitude of the decline in income is dependent on many factors. Some of these factors are:

(1) The difference in revenue that is generated by the dryland agricultural industry as opposed to the irrigation industry.

(2) The amount of resources, including human, unemployed due to the declining groundwater level and the resulting change in production.

(3) The size of the multiplier determining the ultimate impact of the initial decline in expenditures.

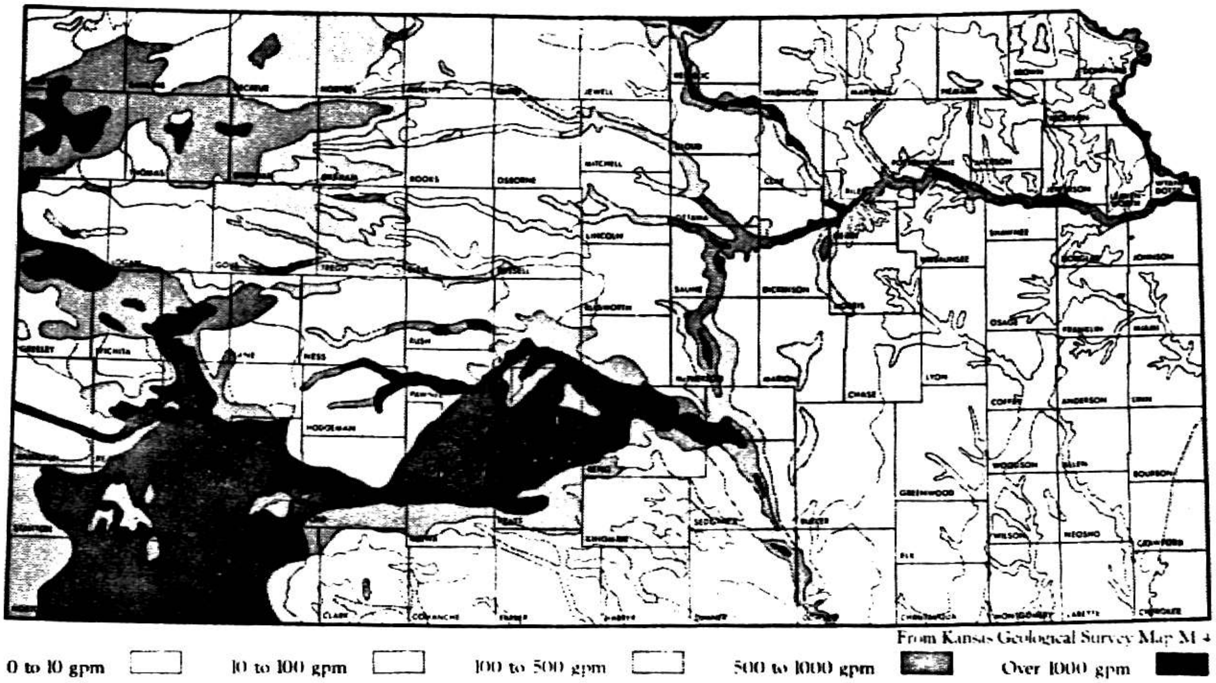
The approximate economic results of a declining water table can therefore, be determined only if the severity of the decline is known and knowledge of the structure of the local economy is available.

Eastern Kansas

The eastern third of Kansas also has groundwater problems, but, as mentioned earlier, they stem from completely different sources. In eastern Kansas some areas have extreme difficulty finding water bearing material in sufficient quantities to support even small domestic and livestock wells. This is not because the aquifer has been depleted through improper management but rather the subsurface material is such that water storage is not possible. A reexamination of figures IV, VIII and IX supports this view.

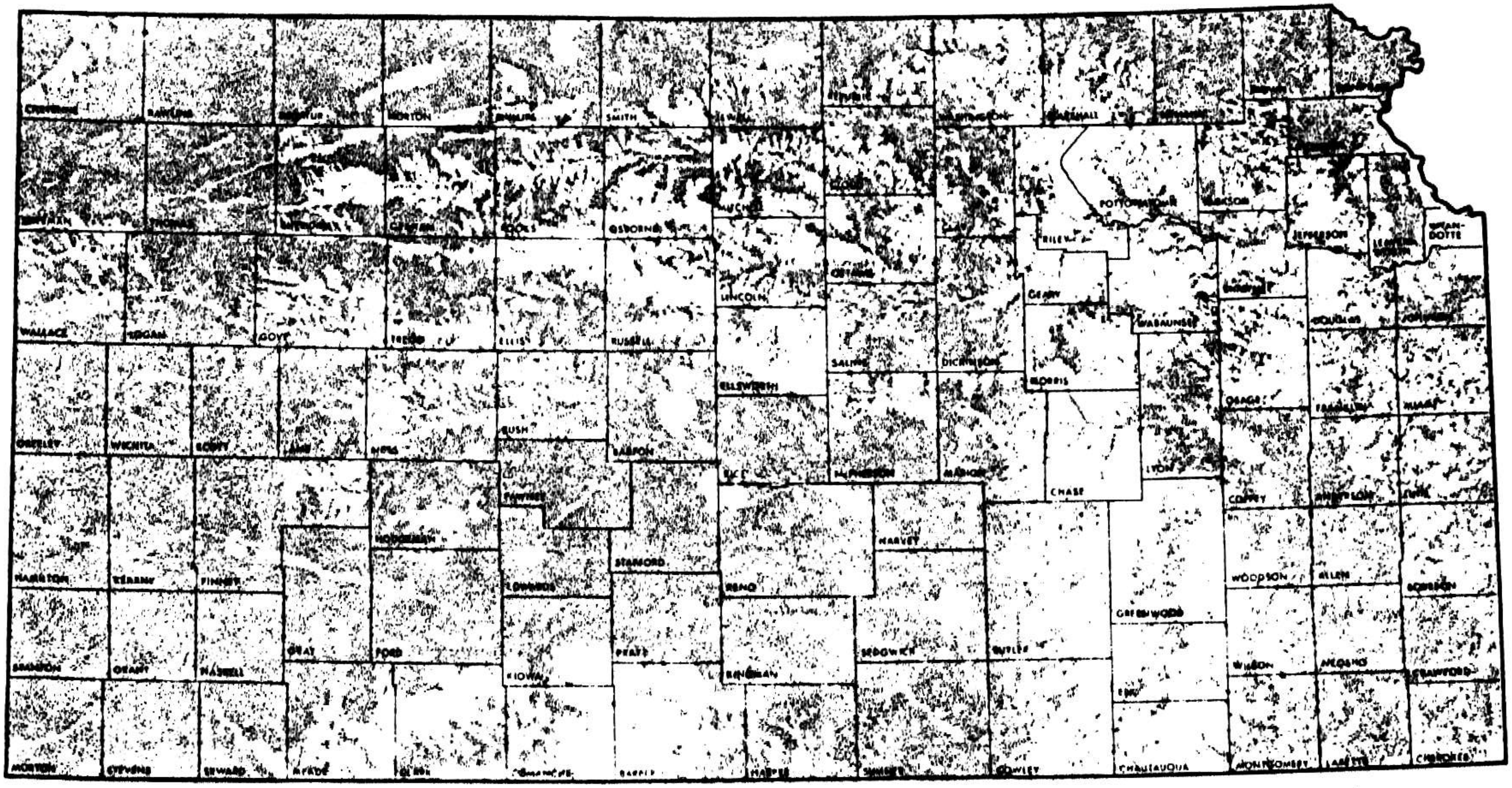
Another characteristic of eastern Kansas is that this area of the state receives much more precipitation than does the western part of the state. This precipitation is frequently in excess of the need at the particular time it is received. The excess water cannot be stored in subsurface storage areas so the only alternatives open are: to store it in surface reservoirs, let it flow out of the state unused, or to transport it to western Kansas to be used at that time or to store it in either surface reservoirs or in the depleted aquifers in this area by artificial recharge. The feasibility of the last of the above three alternatives has not yet been established.

Figure IV. Land Suitable for Irrigation Overlying Groundwater Areas Capable of Producing Yields of 100 Gallons Per Minute or More to Wells.



Source: Kansas Water Resources Board, Irrigation in Kansas, (Topeka: State Printing Office, 1967), p. 10.

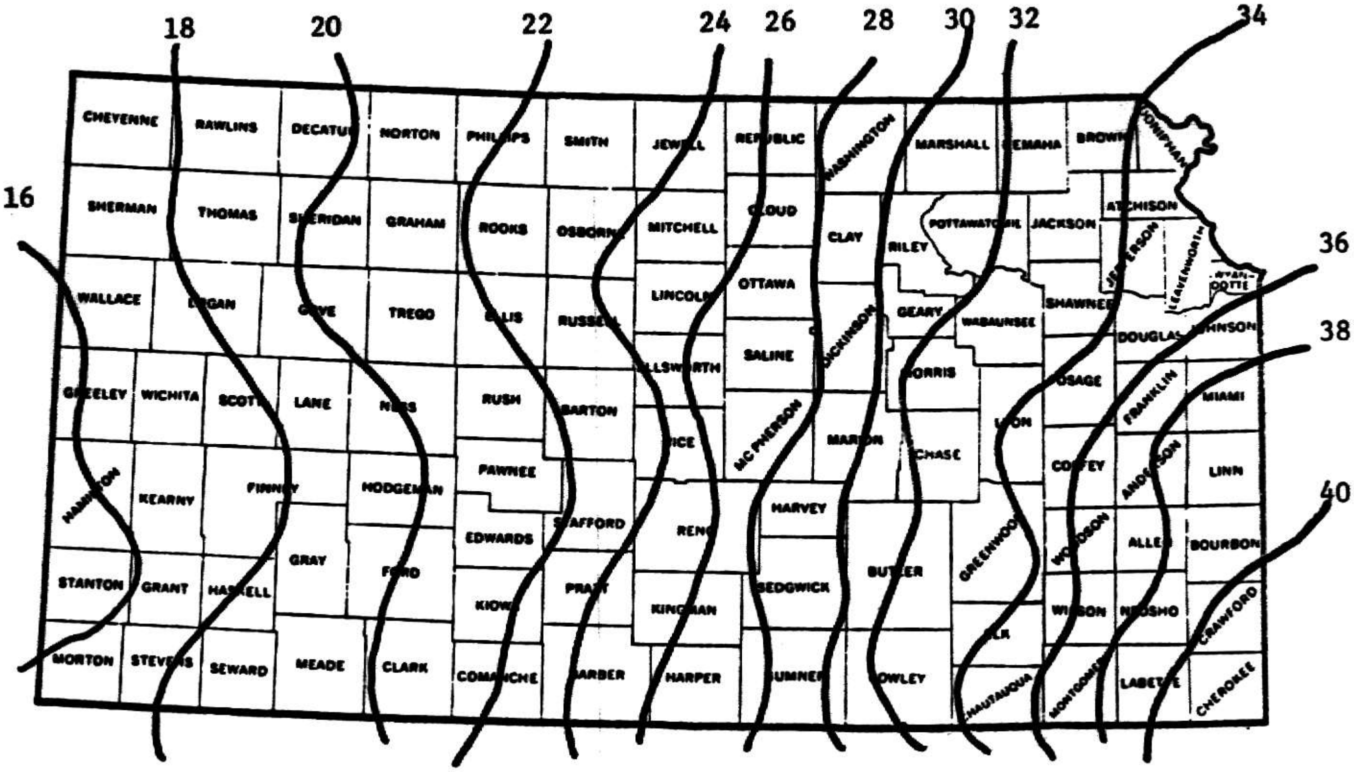
Figure V. Total Land Suitable for Irrigation



Shaded Area is Suitable for Irrigation.

Source: Kansas Water Resources Board, <u>Irrigation in Kansas</u>, (Topeka: State Printing Office, 1967), p. 15.

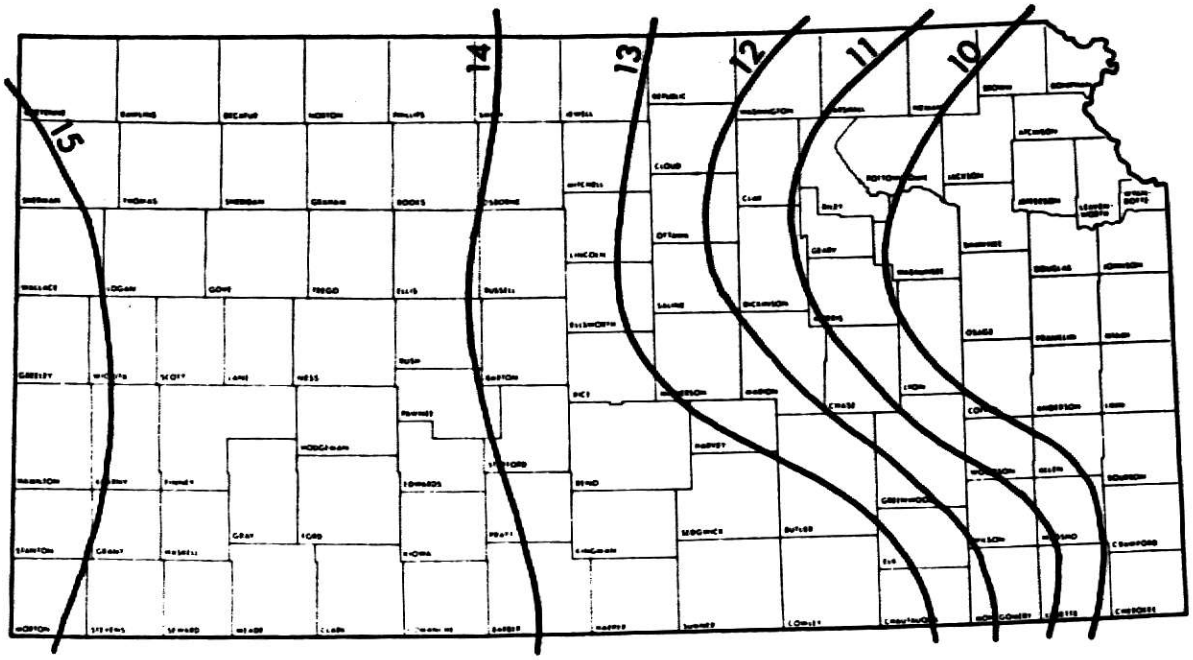
Figure VI. Map of Mean Annual Precipitation in Kansas 1921-1956



Lines Represent Areas of Equal Precipitation.

Source: Kansas Water Resources Board, Flood Frequency, (Topeka, Kansas); State Printing Office, (October, 1960), p. 6.

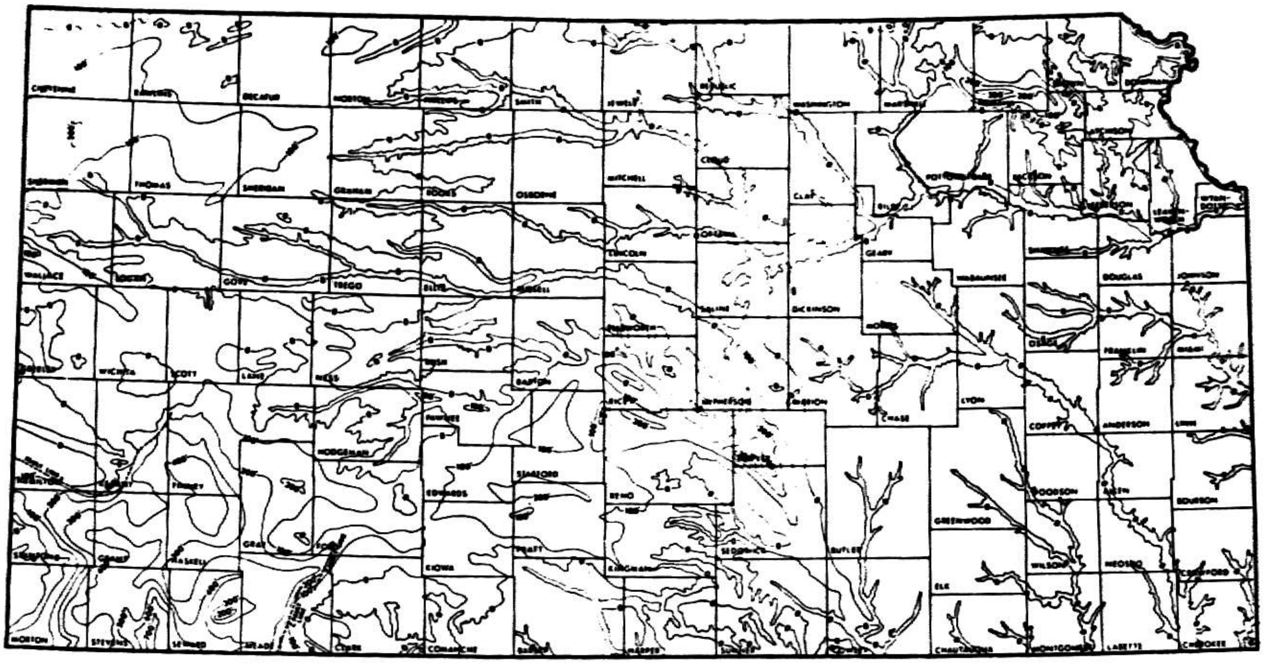
Figure VII. Net Irrigation Requirements.



Average Seasonal Net Irrigation Requirements Based on Recent General Irrigated Crop Patterns. Values in Inches

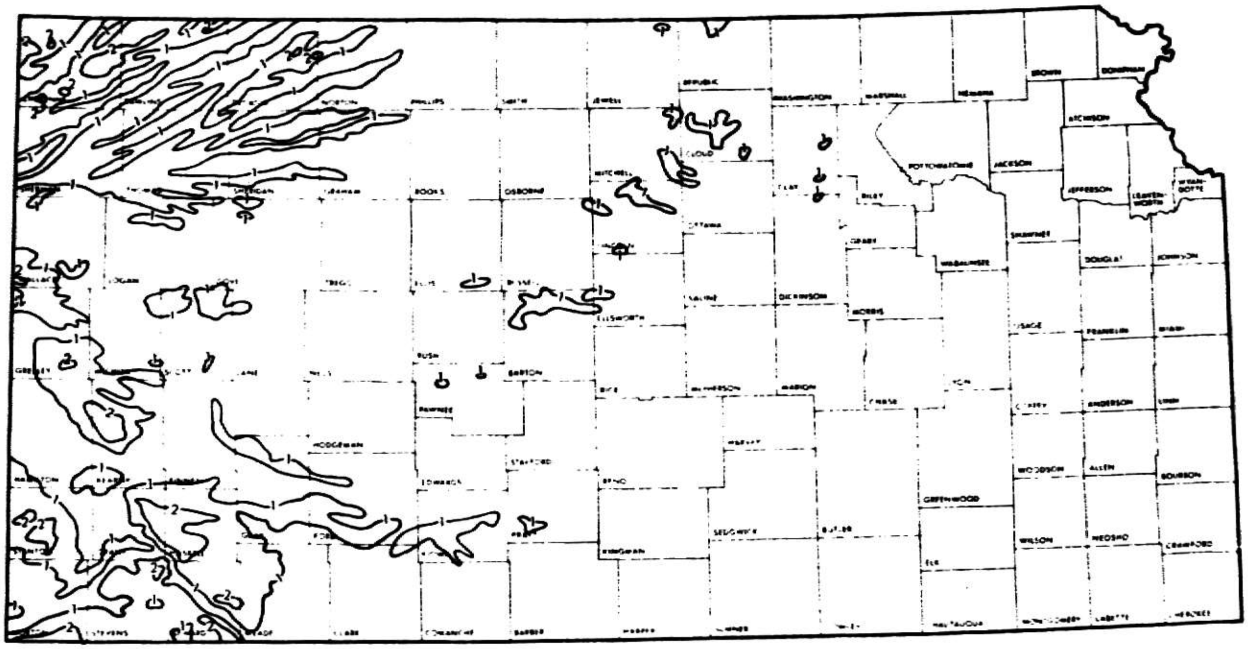
Source: Kansas Water Resources Board, Irrigation in Kansas, (Topeka: State Printing Office, 1967), p. 9.

Figure VIII. Saturated Thickness of the Unconsolidated Deposits.



Source: Kansas Water Resources Board, Irrigation in Kansas, (Topeka: State Printing Office, 1967), p. 12.

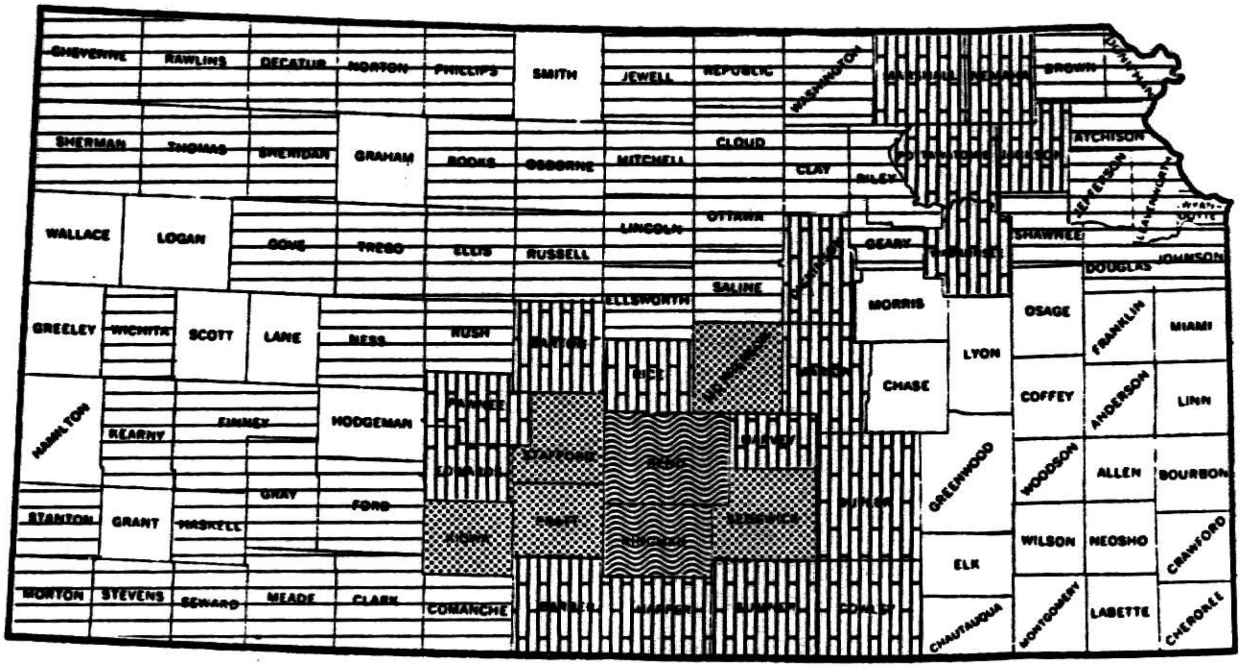
Figure IX. Depth to Water



Depth to Water. Values in Hundred of Feet.

Source: Kansas Water Resources Board, Irrigation in Kansas, (Topeka: State Printing Office, 1967), p. 11.

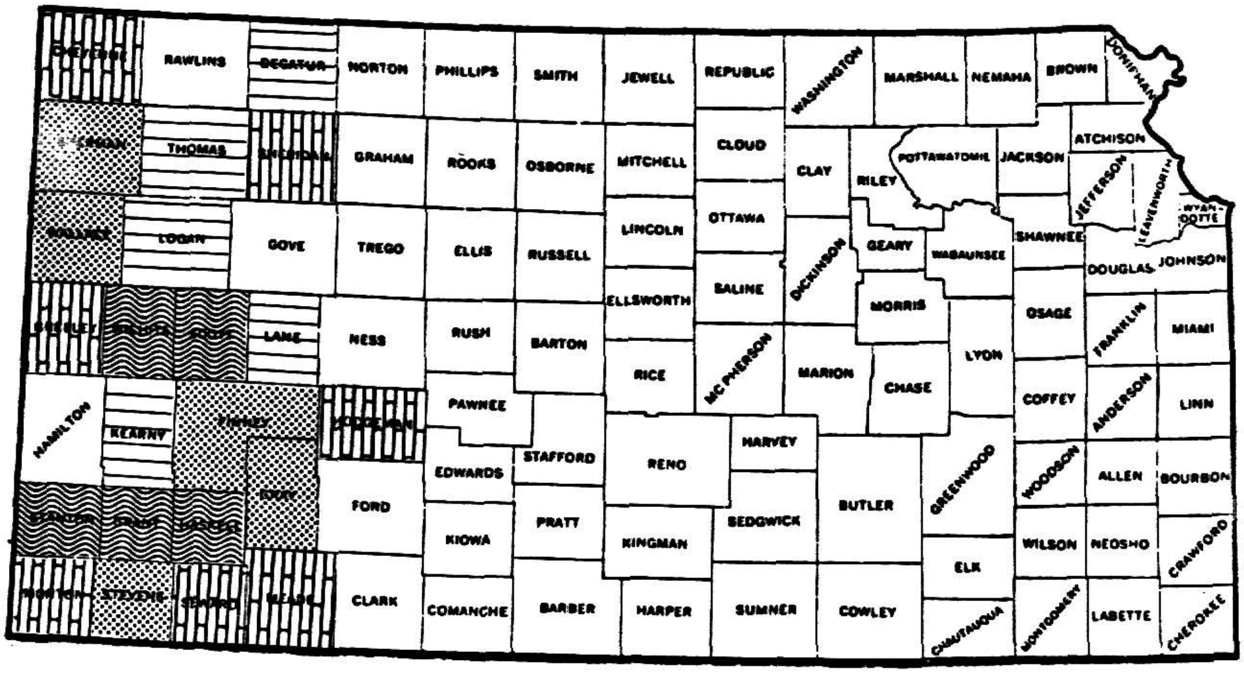
Figure X. Estimated Annual Natural Recharge to the Groundwater Reservoir.



0 to 9,999 Acre-Feet Per Year
10,000 to 49,999 Acre-Feet Per Year
50,000 to 99,999 Acre-Feet Per Year
Greater than 100,000 Acre-Feet Per Year

Source: Kansas Water Resources Board, Irrigation in Kansas, (Topeka: State Printing Office, 1967), p. 14.

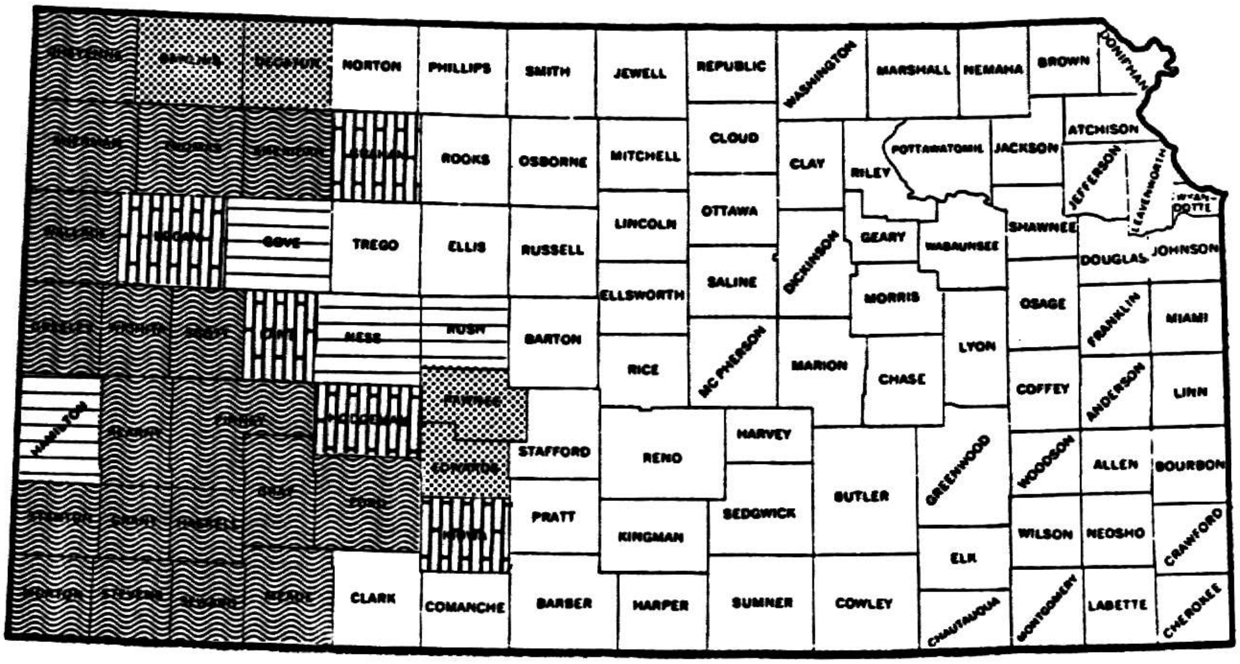
Figure XI. Estimated Excess of Pumpage Over Recharge in 1966.



0 to 9,999 Acre-Feet Per Year
10,000 to 49,999 Acre-Feet Per Year
50,000 50 99,999 Acre-Feet Per Year
Greater than 100,000 Acre-Feet Per Year

Source: Kansas Water Resources Board, Irrigation in Kansas, (Topeka: State Printing Office, 1967), p. 15.

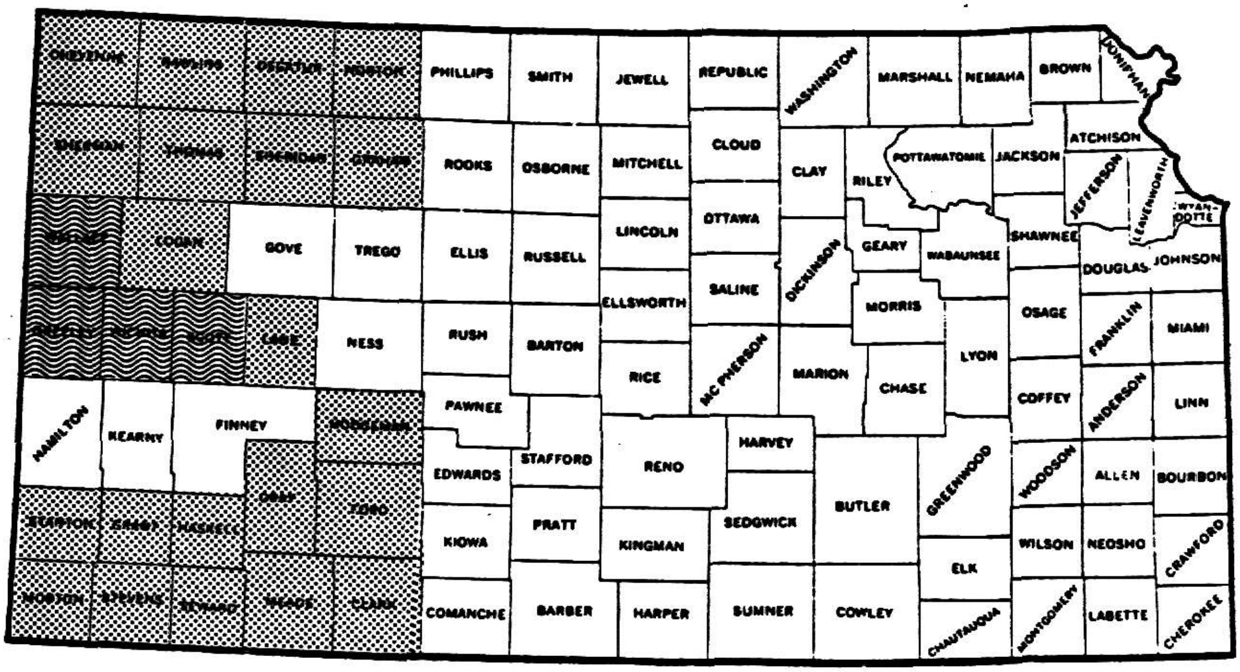
Figure XII. Estimated Excess of Pumpage Over Recharge in the Year 2000.



0 to 9,999 Acre-Feet Per Year
10,000 to 49,999 Acre-Feet Per Year
50,000 to 99,999 Acre-Feet Per Year
Greater than 100,000 Acre-Feet Per Year

Source: Kansas Water Resources Board, Irrigation in Kansas, (Topeka: State Printing Office, 1967), p. 15.

Figure XIII. Area of Potential Groundwater Depletion.



Where there is a possibility of groundwater reserves being essentially exhausted by the year 2000.

Where there is a possibility of groundwater reserves being essentially exhausted by the year 2050.

Source: Kansas Water Resources Board, Irrigation in Kansas, (Topeka: State Printing Office, 1967), p. 15.

CHAPTER IV

THE ECONOMICS OF GROUNDWATER MANAGEMENT

General Welfare Criteria of Resource Management

The previous chapters have concentrated on the importance of groundwater, the general physical characteristics of aquifers and a brief reference to the groundwater problems of Kansas. With this background it is now possible to delve into the economics of groundwater management.

The economics of groundwater management can be approached from the viewpoint that groundwater is a natural resource and, as such, the management considerations of natural resources in general are applicable to the groundwater management problem. A more restricted approach would be to consider only the management models that were designed specifically for a subset of natural resources--groundwater.

The general economic considerations are discussed first while specific resource management models are discussed in the latter part of the chapter. The resource management models to be considered include those that apply to exhaustible resources in general as well as those designed specifically for groundwater management.

An evaluation of how efficiently a natural resource is being utilized involves discussing two separate aspects of efficiency, i.e., the development of the resource and the use of the resource. The rate of exploitation and the allocation of a given resource (development and use) should proceed in a manner which will make the greatest possible contribution to national output--given the fixed supplies of the resource under consideration.

In a market economy the economic process has been left largely in the hands of private enterprise, with public regulation limited and designed to assist the market mechanism. In this context and based on the assumption of profit maximizing behavior on the part of resource owners, consumer satisfaction becomes the criteria for judging the performance of economic institutions. The resource price, determined by the market, determines the rate of exploitation or development as well as allocating the extracted resource among alternative uses.

The development of a natural resource involves a decision of whether the entrepreneur should allocate capital and labor to make the resource available as a productive input. The question of whether an entrepreneur should engage in the development of a natural resource can be approached from a benefit-cost framework. The development of a natural resource is therefore governed by the cost of capital, cost of extraction, the relative scarcity of the resource and the return per unit of the extracted resource.

If the present and future cost are less than the present and future benefits, both discounted by the appropriate rate, development is feasible since consumer satisfaction, measured by the market, is clearly greater with the investment than without. One must also consider not only the excess of benefits over costs but the ultimate decision of the feasibility of developing natural resources must also consider the return of the contemplated investment relative to the return that could be derived from other investments. Since there is only a finite amount of investment that an economy can make in a given time, the investments yielding the superior return must be selected over other inferior investments

The benefit-cost decision-rule, or guide to resource exploitation represents a rational approach from the stand point of society as a whole only if all present and future costs and benefits, both internal and external to the decision maker, have been considered.

The other features--use or allocation--as opposed to development, involves decisions on what type of output is the most desirable to be derived from the resource inputs. In economic terms the objective is to allocate resources among uses so that the marginal addition to income from the last input of the resource be equal in all uses. Designating X as the quantity of a limited resource and $Y_1, Y_2, \ldots Y_n$ as the value of the output from the use of X, then an allocation of X to produce the highest valued output will be when $\frac{\Delta Y_1}{\Delta X} = \frac{\Delta Y_2}{\Delta X} = \ldots \frac{\Delta Y_n}{\Delta X}$. Under the assumption of profit maximization by resource users the market will tend to bid the resource into its highest valued use so that the above equality will be achieved.

Before proceeding beyond this point it is expedient to make several observations. The first observation is that the models to be discussed herein consider only the rate of exploitation or development and do not deal with the question of optimal allocation of resources among uses. The models assume that the allocation of resources among uses is determined by the market forces and they therefore treat this as given and concentrate on the development aspect. This approach is deficient in the respect that efficiency encompasses both features, devlopment and allocation, and there is an inherent danger in treating the two as distinct and separable aspects of efficiency. This can be illustrated by the fact that estimates of the gains from greater efficiency and better allocation of water in New York

City could add as much to the city's total water supply as the costly Cannonsville supplemental water project but at a small fraction of the cost.[1] Ignoring the allocation aspect and concentrating exclusively on development can lead to costly mistakes.

The second observation pertains to the difficulties that can be encountered when the market is relied on to determine the optimal rate of resource extraction. The difficulties that arise can be attributed to unique characteristics that certain natural resources possess. These characteristics are commonality, regeneration, minimum depletable levels beyond which extraction cannot proceed, as well as a host of institutional constraints. It is essential that these features are recognized and brought into the analysis if a realistic groundwater management model is to be developed or evaluated.

The first of these features--commonality--is sufficient in itself to cast considerable doubt on the efficiency of the unrestricted market mechanism in determining the optimal rate of resource extraction. The reason for this failure is that the individual user, extracting from a common source, has no incentive to curb his rate of use because the units of resource saved are not earmarked for his own future use but instead may very well benefit <u>all</u> extractors, savers and nonsavers alike. Since rights to fugitive resources are normally obtained only by "capture", the extractors have an incentive to withdraw water at a rate greater than would be otherwise rational for fear some other extractor will capture the resource. As a consequence,

---

[1]Ian Burton and Robert W. Kates, ed., "Welfare, Economics, and Resource Development," <u>Readings in Resource Management and Conservation</u>, (Chicago: The University of Chicago Press, 1965), p. 285.

extractors act as though common property resources have zero marginal value (negative marginal value if they anticipate proration on the basis of use history). This means that the extractors act as if the increments of the resource extracted have a zero value and therefore, the use of these resources does not involve a present or future reduction in worth. As mentioned above if the extractors anticipate controls over the amount of the resource used, based on past use, the extractors may temporily remove resources at uneconomical rates so as to protect future extraction privileges. This results in the water user maximizing present returns without regard for the future which does not represent a rational way to plan or develop natural resources over time.

Other features which frequently are present and prevent the frequently used benefit-cost approach from being a viable and rational economic guide, stem from price and cost features commonly associated with natural resources. For example, the individual user, in determining his optimal extraction rate over time, considers his internal costs (such as investment amoritization, and capital costs) but frequently does not consider the existence of possible external costs and benefits associated with resource use. It is quite likely that a private oporator's cost and gain may represent only a part of the costs and gains of society as a whole. These costs may take the form of rehabilitation of the worker formerly employed in occupations dependent on the now exhausted resource, relocation costs or many other social costs.

Society's interest may also differ from private interest due to the fact that society is necessarily conceived as a permanant entity, while the individual is emphemeral and less likely to take so long a viewpoint when he has to compete in the short run. Society's lower valuation of the present over future therefore leads to a lower rate of current use as its optimum. There is still not complete agreement on the rate that should be used to discount future gains or losses. If present generations and society in general feel that they have an obligation to the continuance of society or a responsibility to posterity, the social rate of interest will be lower than the market rate of interest. This lower preference leads to a higher state of conservation as its optimum. This in fact might be one of the objections to the management models that follow. All of these models look at the resource management problem in a microeconomic framework and have therefore adopted the market rate of interest as the appropriate discount factor.

Other difficulties that are frequently encountered include situations where resource users are not required to pay the true cost of delivered resources. There are also cases where the prices of final products, that use natural resources as productive inputs, are not determined by the market system but are maintained at artificial levels. The result of under-priced resources or pricing of final products above their true social value is to encourage resource users to combine productive inputs in quantities in excess of what would be economically feasible if the units of the resources were correctly valued.[2]

The above limitations and failures of the market system have led to the development of management models which attempt to overcome one or more of these problems.

The resource management models that follow can be classified into three groups. The first model develops a unified theory of production for natural

---

[2]In a recent study by Jack Hirshleifer and James DeHaven the authors found that water supplies are often grossly misallocated among and between uses. Discriminating and subsidized pricing patterns were responsible for much of this waste. Large city users are charged prices less than the marginal cost of processing and delivering extra water to them. Large users therefore have no incentive to install recirculating devices to curtail water use, or to conserve water use in any way.

<u>Ibid.</u>, pp. 284-285.

resources in general. The second model establishes the concept of maximization of present value for the production of exhaustible resources. The third group of models pertain exclusively to groundwater management. Most of these models emphasize the convential management objective of maximization of present worth but present this objective in a variety of ways. There is also a great disparity in the scope of the models that follow. Some of the models merely emphasize the objective of maximizing present worth while others formulate sequential decision rules based on the current level of deposits of the resource or the rate of recharge.

Resource Management Models

Unified Theory of Production From Natural Resources

A recent contribution to resource management literature is the work of Vernon L. Smith.[3] The emphasis in this article is on providing a unified theory of production for a "common property" resource that is under the administration of a single agency or under control of centralized management. The model applies to the extraction of technologically diverse resources such as fish, timber, petroleum and minerals.

Essentially what is done in this model is to adapt the perfect competition model of free entry and exit in response to excessive profits to the production of renewable common property natural resources. This requires several additions to the competitive model.

The first major change is the recognition of the possible externality problem. Two types of externalities are accounted for by the addition of two additional parameters in the firm's cost functions. The first parameter

---

[3] Vernon L. Smith, "Economics of Production From Natural Resources," American Economic Review, Vol. LVIII (June, 1968), pp. 409-431.

that is added to the individual firm's cost function accounts for the possible externalities that arise as the number of firms in the extracting industry change. For example, the per unit extraction cost of the individual firm is likely to increase as the number of firms extracting from a common source increase. This factor is normally outside the firm's control but can be internalized by adding an additional parameter to each firm's cost function to account for what Smith calls crowding externality.

The second type of externality is brought about by resource population size. The competitive resource extractor has very little control over resource population size. As population size changes it can change the density of stocks and therefore affect costs. This effect on costs can also be internalized by adding the second parameter to the firm's cost function. The above is identified by Smith as a stock externality.

Since the decision to enter the extraction industry is based on the availability of excess profits any system that considers external costs as well as internal costs represents a significant improvement in resource management.

The second addition to the model accounts for the fact that we are dealing with a renewable natural resource. The resource growth is assumed to take the shape of an inverted "U" curve. The left end point, center point and right end point defining minimum self-sustaining population, largest sustainable net rate of growth and maximum self-sustaining population respectively. This assumption about the growth pattern of a renewable resource has implications for the optimal number of extracting firms. That is, extraction at a rapid rate--a rate faster than the growth of the resource--depletes the stock, reduces the growth of the resource, costs rise and ceteris paribus, discourages harvesting and the number of extracting firms.

In figure XIV, page 66, the two curves represent the size of the extraction industry and the growth of the resource. The notation in figure XIV is as follows: (I) represents homogeneous units of capital in the extracting industry, (K) is the number of homogeneous extracting firms, (X) is resource mass or population, ($\underline{X}$) is the maximum self-sustaining population. Curve I(X,K) = 0 represents points where the extracting industry is in equilibrium with alternative uses of capital in the economy. That is, the return to capital in the extracting industry equals the return in alternative uses. Curve F(X,K) = 0 represents points where the resource is in natural equilibrium--harvest equals replenishment.

Extraction at any point above the I(X,K) = 0 curve indicates that there are too many firms in the industry and the capital could earn a superior return if employed elsewhere. Points below the I(X,K) = 0 curve indicate excessive profits in the extraction industry and consequently an influx of new capital into the extraction industry can be expected. Likewise points above the F(X,K) =0 curve indicate points where extraction is greater than resource replenishment. This area of operation would tend to reduce the resource stock. Conversely, the resource stock would tend to rise at any point of operation below the F(X,K) = 0 curve. The arrows at points A,B,C,D and E indicate the expected change in investment in the extraction industry and the expected change in the resource stock.

Points P* and P** are two points in this particular illustration where both the resource and the extracting industry are in equilibrium. Smith states that the increased costs associated with extraction at a rate greater than replenishment almost guarantees an equilibrium point such as P** where both equilibrium conditions are satisfied.[4]

The practicability of the model can be questioned on the grounds that investment flows are not perfectly flexible or sufficiently sensitive to make the model operational.[5] The random nature of recharge, the indeterminacy of the boundaries and quantities of the stock resource, the social constraints present and the long term nature of investment, represent a considerable deviation from perfect competition where the absence of these factors would facilitate the flow of the desired amount of investment.

The "sole ownership" concept with the accompanying attempt to make private costs coincide with the true social cost by accounting for externalities does represent a significant improvement in resource management. This type of management is presently incorporated by areas or regions that have formed quasi public organizations, such as groundwater districts, for the purpose of developing resources. Other than this feature, the model offers little in the way of a direct application to the groundwater management problem.

Harold Hotelling's Maximum Mining Yield Concept

"The Economics of Exhaustible Resources" by Harold Hotelling published in 1931 is considered by many to be a classic in the area of resource management.[6] This pioneering, theoretical work applies exclusively to exhaustible resources such as mineral deposits and does not address itself to many of

---

[4]Ibid., p. 418.

[5]Willis W. Reed, The Political Economy of Colorado's Groundwater Development and Use, (unpublished Ph.D. dissertation, Colorado State University, June, 1970), p. 29.

[6]Harold Hotelling, "The Economics of Exhaustible Resources," Journal of Political Economy, Vol. XXXIX (April, 1931), pp. 137-175.

the particular problems characteristic of groundwater management.

Hotelling acknowledges that rapid exploitation and the resulting cheap products have given rise to the conservation movement while at the same time he recognizes that any rate of extraction of some natural endowments is considered by many to be excessive. The conservation movement also plays into the hands of those who find it in their self-interest to restrict output for the sake of higher prices. If on the other hand it is determined that the total supply of the resource is not to be preserved for future generations there is an optimal rate of extraction over time. Hotelling's objective is to develop a framework to explain the optimal rate of exploitation of a stock resource under several market structures--pure competition, monopoly and duopoly--in order to achieve the goal of maximizing the present value of all future profits.

The procedure used is to maximize the present value of all future profits. This, of course, necessitates discounting all future profits to their present value. The discount factor used is the prevailing rate of interest. The present value of all future profits is then maximized and the period of final exhaustion can be determined. This period of final exhaustion is reached when total quantity mined over time equals the total available supply of the resource. The period of time required to completely deplete the resource can be either finite or infinite depending on the particular demand function that is used to determine quantity mined.[7]

The emphasis of Hotelling's article is on purely exhaustible resources and consequently does not consider recharge which is characteristic of

---

[7] Ibid., p. 418.

most groundwater basins. Reference is made to the commonality problem but this is not brought into the analysis. This model is quite restrictive since it corresponds only to the concept of maximum mining yield. Nothing is incorporated into the model to account for reserve for contingencies or externalities. For these reasons, while the article is valuable from a theoretical standpoint it contributes little in the way of a practical solution to natural resource management problems.[8] Its basic argument, maximization of present value of all future profits may, however, be extended to include the salient features of groundwater management.[9]

Groundwater Management Models

Edward Renshaw's Approach

The first two models in this section deal with specific agricultural areas suffering from persistent overdraft problems. The examples and illustrations used in these articles are based on data from the Texas high plains and central Arizona respectively. The central theme or goal of both models is applicable, however, to any groundwater basin where overdraft is a problem.

Edward Renshaw approaches the groundwater management problem by

---

[8]Willis W. Reed, op. cit., p. 27.

[9]"The pioneering work of Hotelling, using the calculus of variations, has not been exploited for decision on temporal allocation of groundwater. Admittedly, mathematical solution of equations resulting from Hotelling's method is difficult; nevertheless, the method is feasible under simplifying assumptions that would give an approximate answer. Hotelling's work would have to be extended somewhat in order to cope with the flow component of groundwater, but this extension can be made with little difficulty."

Oscar R. Burt, "Economic Control of Groundwater Reserves," Journal of Farm Economics, Vol. XLVIII (August, 1966, p. 635.

emphasizing the value of water left in the groundwater reservoir.[10] He illustrates two general cases where the value of unpumped water in the aquifer is far greater than commonly thought. The first approach used by Renshaw deals with optimal mining in areas where annual recharge is negligible relative to withdrawals and the second case deals with the substitutability of groundwater for pumping inputs where recharge is not negligible.

The objective of Case 1 is to determine, not whether groundwater should be mined, but rather, what is the optimal rate to mine existing supplies. The assumptions that are made are:

1. The marginal productivity of water declines in a linear manner.
2. The long run total cost of pumping a given quantity of water is the same irrespective of the time at which the water is mined.
3. Due to the commonality problem the individual operator maximizes current income without regard for future income.

Renshaw demonstrates that a reduction in the per acre application of irrigation water will normally reduce income but a less than proportionate reduction can be expected. For example a 50 percent decrease in per acre application might result in a 25 percent reduction in income. The reduced per acre water application per unit of time from a stock pool extends the usable life of the aquifer and also, because of the less than proportional reduction in income, increases the total income derived from the stock resource. To determine whether, in fact, such a water conservation program is feasible the rate of return from such action must be calculated.

---

[10]Edward F. Renshaw, "The Management of Groundwater Reservoirs," Journal of Farm Economics, Vol. XLV (May, 1963), pp. 285-295.

Renshaw suggests that the return can be calculated by setting the present value of an annuity (an annuity with the same length as the expected length of the original groundwater stock) equal to the present value of a longer annuity, lengthened by the extended life of the aquifer resulting from the water savings and discounted by the proportional sacrifice in current income. The rate that equates the two annuities is the rate of return for conserving water.[11]

The goal in case one examined by Renshaw is to illustrate that water left in the reservoir has a greater value than commonly thought. He fails, however, to extend the argument to show how the analysis can lead to an optimal mining or extraction rate as specified in the heading he uses for case one--optimal mining. Essentially what is accomplished is to illustrate that in many cases the use of water in above ground low value uses is nonoptimal in the sense that it is worth more if retained in the ground.

The second approach used by Renshaw deals with regions that have significant recharge rates relative to withdrawal rates. The essential idea is that the water retained in the reservoir is a substitute for pumping inputs. That is, the marginal value of water retained in the ground is considered a substitute for pumping inputs because the withdrawal of a unit of water will depress the water table and thereby increase future pumping costs. Essentially the broad objective of case two is identical to that of case one--establishing a value for water retained in groundwater reservoirs. The only difference is that case two considers recharge to be significant and the cost of acquiring water not a constant but increasing as the depth to water increases.

The problem we are confronted with in case two is the same as before--

---

[11]Edward F. Renshaw, op. cit., p. 293.

assigning a meaningful value to the water retained in the ground. With the two additional assumptions--significant recharge and varying cost of acquiring water--the value of groundwater depends on three factors. The first is the cost of acquiring or lifting a unit of water one foot, denoted as C. The second factor is the amount of lift that can be saved by conserving a unit of water. The absolute savings in lift is considered to be inversely proportional to the amount of pore space that can be dewatered and is the reciprocal of specific yield of aquifer, denoted by 1/s. That is, withdrawal of an acre-foot of water will depress the average level of water table 1/s feet. The last factor to be considered is the amount of recharge, denoted as Y.

The savings that result from retaining water in the reservoir is the expression $C \cdot 1/s \cdot Y$. The annual savings is then capitalized by dividing by the appropriate interest rate. Again the conclusion that is suggested by Renshaw is the same as in case one--the value of the water retained in the ground is frequently greater than the value of water in above ground low value uses such as agriculture.

Table III, page 67, is a numerical example of Renshaw's case two. Table III presents the capitalized value of groundwater for various levels of specific yield and various rates of recharge. For this particular illustration the cost of pumping is assumed to be five cents per acre foot per foot of lift and a discount rate of five percent.

Renshaw generalizes and states that if annual recharge is three or more inches a year and overdraft is a problem, groundwater is without a doubt worth more left in the ground than in low value above ground uses.[12]

If recharge is not significant Y approaches zero and case two then is identical to case one.

---

[12] Edward F. Renshaw, <u>op. cit</u>., p. 293.

Renshaw concludes his discussion by recommending a price system over administrative and judicial regulation of water use in that it provides greater flexibility and tends to encourage a more efficient allocation of resources. Reference is also made to the need to look at water problems within the framework of an integrated surface and groundwater approach. Groundwater and surface water are both part of the total water supply and are not completely independent of each other. The approach to water management should, therefore, be to consider the entire problem and not treat surface and groundwater as separate and distinct entities.

Returns From a Forced Water Conservation Program, Formulated by Maurice Kelso

In an article by Maurice Kelso, based on the central Arizona situation, a similar approach to groundwater management is followed.[13] Kelso's goal is to calculate the basin-wide returns from groundwater management. This approach is similar to the Renshaw approach in that it involves a water savings program initiated by the water extracting group. The difference is that Renshaw demonstrates that the capitalized value of groundwater is greater than the individual extractor normally realizes while Kelso looks at the basin-wide returns from groundwater management.

The assumptions listed below are incorporated in the analysis.

1. There will be no change in:

   a. technology of crop production or pumping
   b. relationships among prices relevant to the analysis
   c. scale of farms

2. The water yielding efficiency of the aquifer will remain constant with depth.

---

[13] Maurice M. Kelso, "The Stock Resource Value of Water," Journal of Farm Economics, Vol. XLIII (December, 1961), pp. 1112-1128.

3. The only variable affecting net revenue with any one farming system is pumping costs related solely to water lift.

The first assumption removes the dynamics of time from the analysis while the last two assumptions, although unrealistic, simplify the analysis considerably.

With the above assumptions and based on agricultural data available for central Arizona, the actual breakeven point for lifting water in this particular region can be calculated in the following manner:

$$\frac{\text{Net Return Per Acre}}{\text{(Acre Feet of Water Per Acre Per Year)} \times \text{(Cost Per Acre Foot Per Foot of Lift)}}$$

This procedure determines the depth at which it will be no longer feasible to lift this quantity of water per acre given the cost of lift and the net return per acre. The numerical illustration used by Kelso incorporates the following assumptions: \$100 net return per acre, 5.5 acre feet of water per acre per year and a pumping cost of 4¢ per foot per foot of lift. This example produces a breakeven point for this particular basin of 455 feet. Further, knowing the present depth to water and the decline per year enables one to determine the point in time when the breakeven point will be reached.

The above is illustrated by figure XV, page 68. Line A depicts the net rent for 5 1/2 acre feet per acre per year, net revenue of \$100 to pay for the water, 183 feet to the groundwater level in 1960 and 4¢ per acre foot per foot of lift. This example produces a water cost of \$40 per acre. With a net return per acre of \$100 and a water cost of \$40 the net water rent per acre is \$60 in the initial time period. As the depth to water increases and application per acre remains constant the breakeven point is reached in 42 years, that is, when the cost of water completely exhausts the net water rent per acre.

Line B is the net rent line if water application is reduced by 1/3 after it becomes economically rational for the individual operators to voluntarily reduce their per acre application. This is the case because at point W the net revenue per acre is the same irrespective of whether 3 2/3 or 5 1/2 acre feet are applied. Beyond point W it is feasible to apply 3 2/3 acre feet because the reduced pumping costs more than make up the difference in net revenue. This voluntary action increases the life of the aquifer 21 years. The gain from such voluntary action is represented by the area T, X, Y, in figure II.

Line C is the net revenue line that would be generated by applying 3 2/3 acre feet per acre per year beginning in the initial time period, 1960. Such a program if initiated in the beginning time period (1960) would prolong the life of the reservoir another 13 years to a total of 76 years.

To determine whether it is feasible for the basin-wide planning group to embark on the forced water savings program in the initial time period, the sacrifice UVW must be compared to the gain WXYZ in figure XV, page 68.

Kelso suggests that the discount rate may be applied in one of two ways. The first method is to select the rate which management feels is the appropiate rate and then apply it to the gain and loss respectively. If the discounted gain exceeds the present value of the sacrifice the water savings program should be instituted.

The alternative would be to determine the rate of discount which would equate the present value of the two areas. If this rate is in excess of what is considered "acceptable," the conservation program should again be initiated.

The article also discusses the possibility that even though the water rationing program might not be feasible for the irrigators, because the return is unacceptably low, the entire community may find it desirable to enter into the decision making process and influence the irrigators to undertake the program. While it is certainly true that net income in agriculture will decline as the water level falls, due to the increased expenditures for a unit of water, aggregate expenditures may remain constant. This increased expenditure for water still represents local spending. These outlays will be for different things but there is no reason to believe this spending will have more or less power to generate aggregate personal income in the community. The result is that there may be no decline in aggregate local personal income, resulting from a declining water table, until the operators reduce per acre application or until it is no longer feasible to irrigate and production ceases, either of which would reduce local aggregate expenditures.

The data used by Kelso suggests that even if the community forced a water savings program on the operators and reduced water application by 1/3, thereby extending the life of the aquifer 13 additional years, the present value of the income gained would not equal the income sacrificed from year zero to year 24 except at a discount rate of 1 3/4 percent or lower.

Kelso briefly examines the conditions under which the irrigators and/or community might find it profitable to curtail water extraction from the stock source and promote partial reliance on imported water. This would exert two influences. One, it would directly reduce pumping costs per acre which would become more significant as the water level falls and, two, it would also extend the portion of the agricultural net revenue stream that is dependent on the stock water source.

It is suggested that the value and therefore the price of the imported water depends on numerous factors and probably cannot be computed for the community as a whole. It is clear, however, that if the price of the flow water is below the total rent accruing to the flow water then additional pumping costs can be met and the breakeven point for groundwater extraction is lowered. In this case the imported water would subsidize further extraction of stock water. If the reverse is true--a price greater than total rent is charged for the flow water--the breakeven point of groundwater extraction is raised.

Groundwater as a Production Input Substitute

Another approach to groundwater management is that taken by Oscar Burt. Burt has published several articles dealing with groundwater management; however, the essential points can be gleaned from the August 17, 1966, manuscript.[14] This article incorporates much of his previous work and is primarily expository, using intuitive economic reasoning reasoning and geometry. It has the advantage of being relatively simple and concise. The analysis that follows bears a strong conceptual similarity to that of Renshaw's case two because the water retained in the reservoir is considered a substitute input. The model is, however, presented in a different framework and is much more comprehensive than the Renshaw Model.

The objective of the analysis is to arrive at an optimal decision rule and determine the equilibrium storage of the aquifer under various conditions. Equilibrium storage in this context means that if water stocks are above equilibrium the rate of use would exceed recharge or, conversely, if storage is below equilibrium, the rate of use would be less than recharge. The desired level, equilibrium, is brought about by increased pumping costs as groundwater stocks are depleted and by the increased value of water reserves as a contingency to uncertain future supply. It is quite unlikely that the equilibrium storage level will be near full capacity of the aquifer since delayed produc-

---

[14]Oscar R. Burt, "Temporal Allocation of Groundwater," Water Resources Research, Vol. III, (1967), pp. 45-56.

tion always has an associated cost reflected by the interest rate. An optimal policy of temporal allocation balances off the urgency of immediate production against (1) diminishing returns with respect to water use in a given period; (2) increased pumping cost brought about by depletion of stocks; and (3) the insurance value of stocks against uncertainty.

It is assumed that recharge is a constant (not subject to random variation), and pumping depth ultimately limits economic utilization of groundwater, as contrasted to physical exhaustion.

Burt incorporates the following assumptions in the analysis.

1. Recharge is assumed to be constant.

2. Pumping depth limits economic utilization of groundwater.

3. Pumping a given quantity of groundwater from storage will not create local overdrafts relative to basin-wide stocks of water.

4. Net output--any appropriately defined economic measure of production per time--for the basin remains constant through time.

5. Net output is a function of withdrawals of groundwater per period and groundwater stocks, denoted by $G(x,s)$, where s is groundwater stocks and x is withdrawals.

6. All other variables are specified at their most economic levels, i.e., land, labor and capital are assumed to be at optimal levels in relation to any specific storage level and rate of use for water.

As in Renshaw's case two, net output is a function of stocks, s, and withdrawals, x. At any fixed net output the rate of use x and s can be thought of as substitute inputs. An increment of x obviously contributes to current production while an increment to s reduces present and future pumping costs and is thought of as a substitute input in this context.

Each input has an opportunity cost associated with it. Water used in current production has an opportunity cost as a source of supply to the stock of groundwater. This potential increment to storage would reduce present <u>and</u> future pumping costs or make a contribution each year in the future. If it adds one dollar to the first year's net output the present value of its entire contribution is 1/r where r is the interest rate or discount factor. An increment to direct or present production, X, makes its entire contribution immediately and has a present value equal to one. The price ratio S to X in an opportunity cost sense is r when the two inputs are considered substitutes in producing a fixed net ouput perpetually. Figure XVI, page 69, illustrates the input substitution concept described above.

In figure XVI with X on the vertical axis and S on the horizontal axis a constant net output for various levels of X and S is depicted by curve 00'. The curves lying above 00' and convex to the origin are also iso-net-output curves implying higher levels of output. These iso-net-output curves are convex to the origin if there exists diminishing marginal rate of substitution of S for X throughout the entire range of S. The iso-net-output curves are negatively sloped if marginal net output is positive with respect to both X and S.

The ratio of the opportunity costs of X and S is the interest rate (with net ouput held constant) and is represented by AA' which has a negative slope of -r.

As mentioned above figure XVI illustrates both the iso-net-output and the opportunity cost concept. This figure is a perfect analogy of the least cost method of production concept frequently employed in microeconomic analysis. The iso-net-output curve, labled 00' is analogous to the isoquant concept while the AA' curve is analogous to the budget line. In microeconomic analysis the least cost method of production is found by connecting the points where the slope of the isoquant is equal to the slope of the budget line. If we apply the same process to figure XVI, i.e.; connect the points where the slope of the iso-net-output is equal to the slope of the opportunity cost curve, the result is curve BC. Curve BC is analogous to the expansion path concept employed in microeconomics and traces out the points of efficient allocation for the appropriately defined net output function G(x,s) and the discount rate r.

Equilibrium storage is given by the point on curve BC where the rate of use x equals the rate of recharge. Figure sixteen, thereby provides a method of finding equilibrium storage, which is determined by (1) the net output function, G(x,s) used in constructing the iso-net-output curves; (2) the interest rate; and (3) the recharge rate to groundwater stocks. BC can therefore be interpreted as the equilibrium storage relation for various rates of recharge measured on the vertical axis.

The curve BC can be used as an approximately optimal decision rule for any quantity of groundwater. It is conditional for from figure sixteen we can determine the amount to withdraw for current production given any quantity of groundwater in stock at the beginning of the period. The decision rule is approximate, even with the assumption of constant recharge and constant net output, except at equilibrium because both stocks and rate of use will be changing from year to year unless at equilibrium.

The effect of various changes can also be illustrated with the use of figure sixteen. For example the influence of the interest rate on optimal rate of use and equilibrium storage can be easily depicted. An increase in the interest rate makes AA' steeper which shifts BC upward and to the left. This shift results in a greater utilization of x given a specific storage level. For a given recharge rate a higher interest rate decreases the equilibrium storage level.

The slope of the iso-net-output curve--00'--is given by the following ratio MNO_s/MNO_x. A decrease in x due to decreased product prices, or increasd factor prices increases the slope and shifts the tangency points to the right implying a lower rate of use for a given storage level and a higher equilibrium stock for a given recharge rate.

Other changes, such as improved pumping technology and the resulting decrease in pumping costs increases MNO_x and decreases MNO_s. These changes reduce the ratio (MNO_x/MNO_s) and shift BC to the left which implies higher rate of use in relation to storage and lower equilibrium for storage.

Thus far the decision rule has been analyzed with the rate of use as a function of groundwater storage. This could be transformed into a decision rule that specifies rate of use as a function of time for any initial stock of groundwater. If initially stocks are S_0 and rate of recharge is W and the decision rule is applied to determine the initial rate of use, (X_0 in the first period) storage in the second period is $S_0 + W - X_0$ which can be denoted as S_1. Applying the decision rule to S_1 the rate of use of groundwater in this period, X, can be determined from figure XVI. The general recursive relation for storage at year T is ($S_t = S_{t-1} + W - X_{t-1}$). Once the storage level is determined the optimum rate of use of groundwater can be determined from figure XVI. Repeated application of the decision rule yields the sequence of rate of use of $X_0, X_1, \ldots X_t$.

Optimal Groundwater Mining

The final model is a mathematical formulation by Domenico, Anderson and Case.[15] The objective of the model is to formulate mathematical expressions

[15] P. A. Domenico, D. V. Anderson, and C. M. Case, "Optimal Groundwater Mining," Water Resources Research, Vol. IV, No. 2, (April, 1968), pp. 247-255.

for several management concepts and to arrive at an expression for optimal groundwater depletion.

The decision rule formulated is that groundwater mining is desirable as long as the annual net revenue derived from mining exceeds the capitalized annual loss in value recharge.

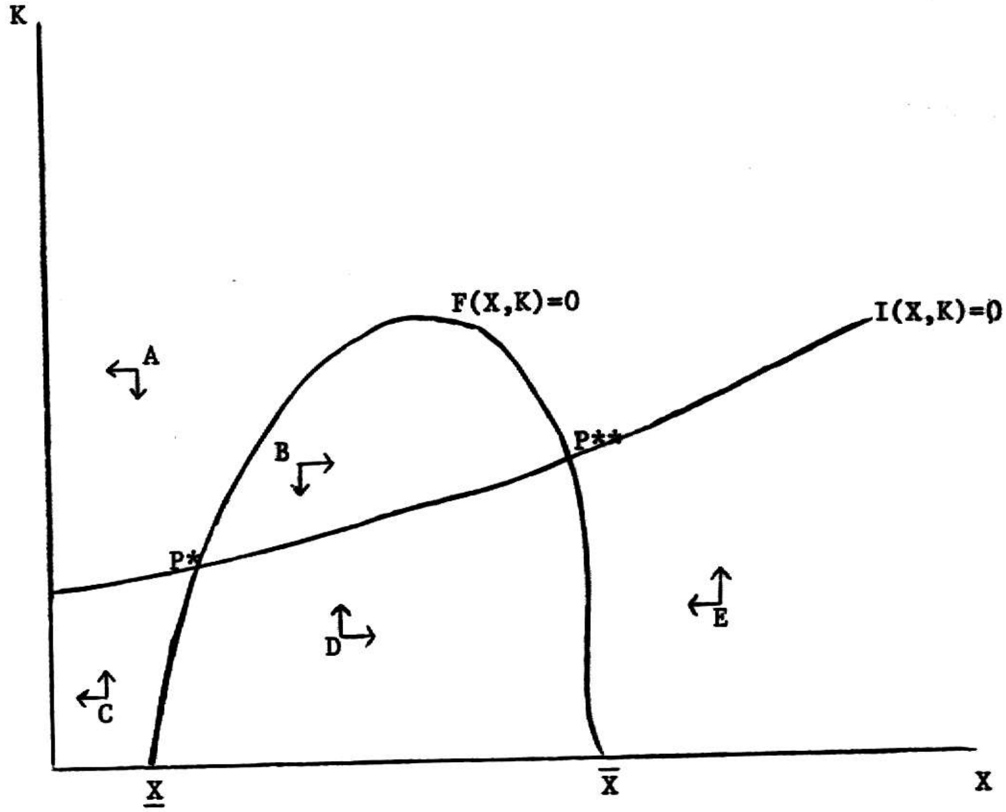
This can be illustrated by figure XVII, page 70. This figure is based on a particular example with arbitrary values chosen for recharge, marginal cost per foot of lift, interest rate and other necessary factors. The concept, however, applies to any example. Curve A, figure XVII, represents the net annual receipts from mining. Curve B is the capitalized annual loss in value of recharge due to mining. The height of A and B respectively is the net receipts from mining for any particular year and capitalized annual loss in value of recharge due to mining.

At any point to the left of T' the gain from mining exceeds the losses and it is profitable to continue to extract the resource because the contribution to net revenue is greater than the capitalized loss in value of recharge. At T' the gain equals the loss while to the right of T' the capitalized loss in value of the flow exceeds the gain.

Since the information required to construct figure XVII is readily available for many groundwater basins this simple condition can be easily applied to many problem areas. It is realized that such a fixed mining yield is only approximate and is realistic for the short run. The condition or test for optimality will need revision in subsequent periods as factors such as the discount factor change.

The remaining chapter will be a summary of this study and the conclusions that were made after completing the study. Special reference will again be made to the Kansas situation.

Figure XIV. Equilibria Between the Resource Mass and Its Environment and Equilibria Between the Extracting Industry and Alternative Uses of Capital in the Economy.



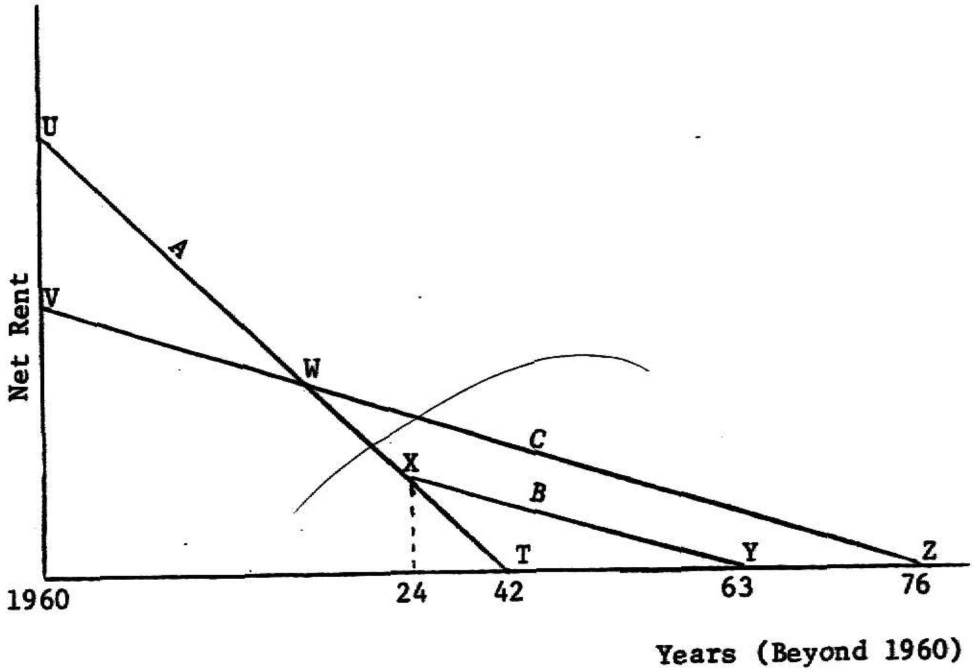
Source: Vernon L. Smith, "Economics of Production From Natural Resources," American Economic Review, Vol. LVIII (June, 1968).

TABLE III. CAPITALIZED VALUE OF GROUNDWATER

Safe Yield Y Acre-Feet Per-Acre Per Year	Specific Yields (s) In Percent 40	20 Dollars	10	6.7
0	0	0	0	0
0.25	0.62	1.25	2.25	3.75
0.50	1.25	2.50	5.00	7.50
0.75	1.87	3.75	7.50	11.25
1	2.50	5.00	10.00	15.00
1.50	3.75	7.50	15.00	22.50
2	5.00	10.00	20.00	30.00

Source: Edward F. Renshaw, "The Management of Groundwater Reservoirs," Journal of Farm Economics, Vol. XLV (May, 1963).

Figure XV. Streams of Net Rent Per Acre for Groundwater With Different Amounts of Water Applied Per Acre



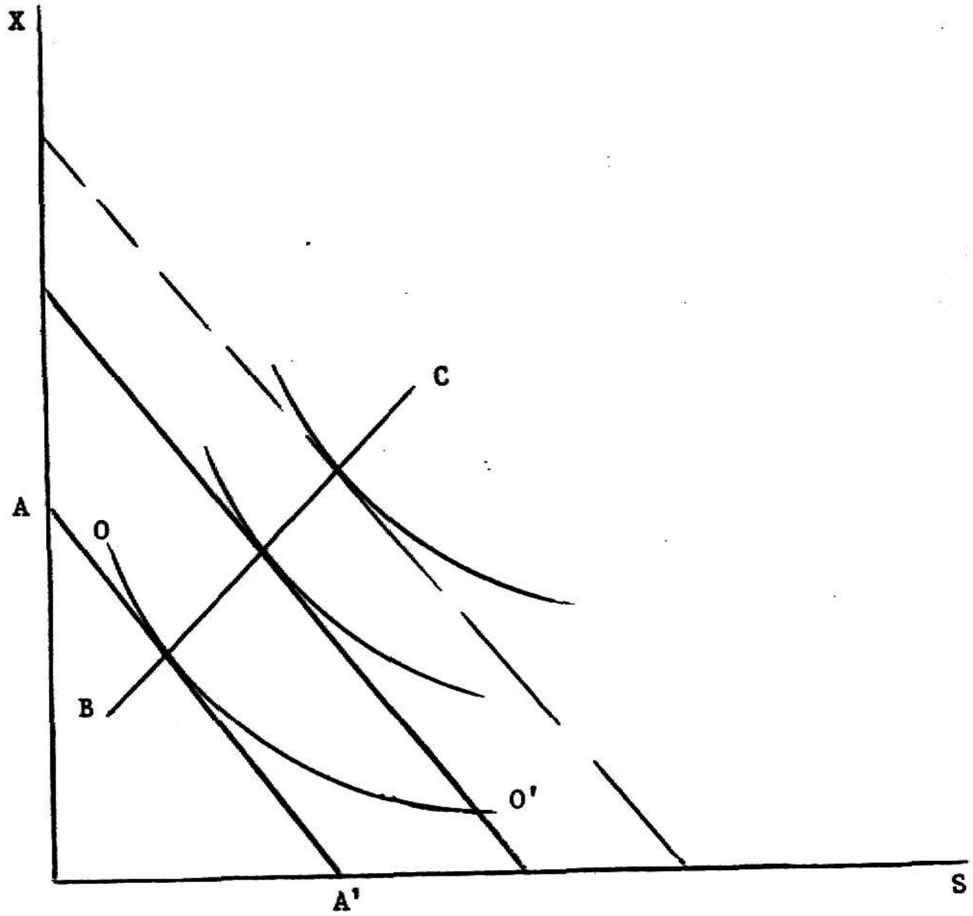
Line A: 5 1/2 acre-feet per Acre--decline 6 1/2 feet per year.

Line B: 3 2/3 acre-feet per Acre--decline 4 1/3 feet per year.

Line C: 3 2/3 acre-feet per Acre--decline 4 1/3 feet per year.

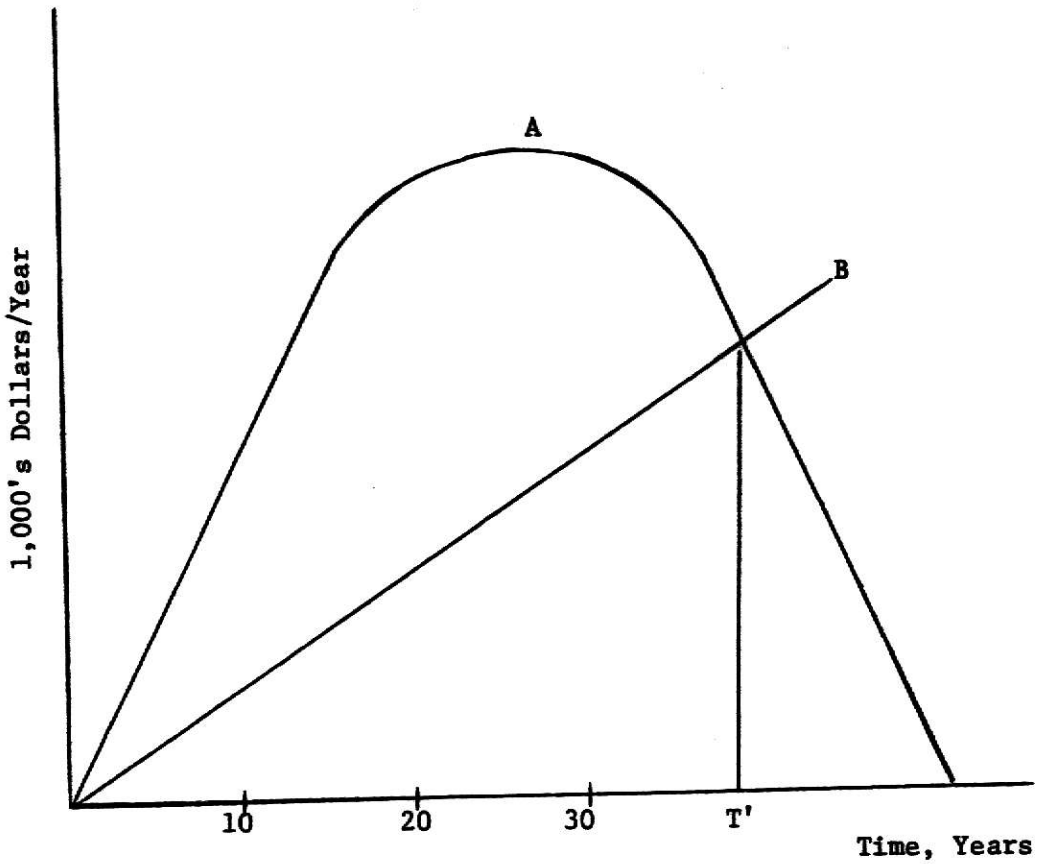
Source: Maurice M. Kelso, "The Stock Resource Value of Water," Journal of Farm Economics, Vol. XLIII (December, 1961).

Figure XVI. Iso-Net-Output map and Decision Rule



Source: Oscar R. Burt, "Temporal Allocation of Groundwater," Water Resources Research, Vol. III, (1967).

Figure XVII. Plot of Net Annual Receipts From Mining and Capitalized Annual Loss in Value of Recharge.



Source: P. A. Domenico, D. V. Anderson, and C. M. Case, "Optimal Groundwater Mining," Water Resources Research, Vol. IV, No. 2, (April, 1968)

CHAPTER V

SUMMARY AND CONCLUSIONS

The Value of Groundwater Management Models

"The value of a model is directly related to the significance of the questions it is intended to answer and the quality of the answer it gives."[1] If the above is a reasonable criteria by which to judge the models in the preceding chapter the value of the groundwater models cannot be questioned. Groundwater management is indeed a significant economic topic because as pointed out earlier many industries and local economies are totally dependent on the extraction of this resource. Chapter I clearly points out the importance of this resource as well as clearly indicating a growing dependence on the extraction of this resource.

In addition to the significance of the groundwater management question, all of the models succeed in providing quality answers. The models are by necessity somewhat general and are not intended to be completely applicable to every groundwater problem area. In general terms, however, it seems that the models have a common objective or answer to the management problem. That is, all of the models in one way or another emphasize the value of the water retained in the ground. Whether the groundwater is viewed as a pumping input substitute or merely a future production input the objective is to illustrate to the regulatory agency or to the extractors themselves that there are factors

---

[1]Kalman J. Cohen and Richard M. Cyert, Theory of the Firm, (Englewood Cliffs, New Jersey: Prentice Hall, Inc., 1965), p. 20.

to be considered other than water's value or use in current production. If these groups consider this fact--the value of water in future time periods--the objective of the models has been achieved and a satisfactory answer to the management problem is provided. This is not to say that all of the management questions have been satisfactorily answered. For example, the question of how much weight should be given to current production relative to future production--that is, the size of the discount factor--has not and cannot be resolved by this type of management model. If, however, extractors approach the groundwater management problem from any one of the rational approaches provided by any of the models, this would represent a significant improvement over the frequently used objective of maximizing present returns without regard for the future.

Limitations of the Models as a Practical Management Tool

Even though the overall objective and approach of the groundwater management models is satisfactory, there are several limitations that must be recognized. All of the following limitations have been discussed prior to this point but they still merit additional discussion.

The first two limitations of the models are that they do not satisfactorily account for the externality and commonality problem. The individual extractor will always have the incentive to maximize his returns without regard for society as a whole unless he is forced to consider externalities. Likewise he has the incentive to maximize present returns without regard for the future because of the commonality feature. How can the individual extractor view water retained in the ground as a pumping input substitute, or as a future production input when he has no assurance that it will not be "captured" by other extractors.

The only way these adverse incentives can be removed is through centralized ownership or control. Most of the models recognize this feature but Kelso and Smith are the only authors that explicitly incorporate this feature into their analysis. Kelso's model seems to be superior to all others from the standpoint of a practical approach to groundwater management.

Besides the question of commonality and externalities there is one other major deficiency in the approach taken by the models. This deficiency is not a problem inherent in the models themselves but instead is encountered because of the common tendency of separating the aspects of economic efficiency. The models discuss various aspects of the optimal rate of exploitation of natural resources but fail to take into account the potential gain from greater efficiency and better allocation. The point is not that one feature is more or less important than the other, but, is instead concerned with the wisdom of treating them as completely independent of each other. The optimal rate of extraction of groundwater would not be the pressing question that it is in many irrigation areas if more efficient irrigation methods were used. For example, in Kansas the average irrigator operates at approximately 50 percent efficiency with respect to water application.[2] In New York City only 25 percent of all water users are metered.[3] This means the marginal cost of water to the non-metered users is zero.

The two aspects of efficiency should be approached jointly, optimal rate of extraction from the natural resource and efficient use and allocation of the amount extracted. A more balanced approach would at least temporarily ease the problem in many areas of excessive overdraft.

---

[2]Op. cit., Irrigation in Kansas, p. 2.

[3]Op. cit., Ian Burton, p. 285

The Models as Applicable to the Kansas Situation

As has been mentioned earlier the situation in western Kansas is such that the declining water level is not expected to significantly affect the marginal cost of acquiring water. The amount of recharge is also quite low and cannot be realistically considered a pumping input substitute. On the other hand considerable gain could be made from organizing a basin wide or regional agency to enforce efficiency requirements as well as regulating per acre water applications or total extraction. One hypothesis is that such an agency could prolong the life of the remaining water deposits as well as increase the total income derived from these deposits. This approach again implies a preference for the Kelso Model.

If irrigation is permitted to expand, uncontrolled by any agency, complete depletion is imminent. The exact economic results of depletion are impossible to predict. It could result in the abandonment of existing capital, producing a modern day version of the "ghost town" of the past or elaborate supplemental water projects might be undertaken in an attempt to save the area economy.

The exact economic results depend on the available production substitutes, the speed of adjustment to these substitutes, the amount of resources unemployed and many, many other factors. It is quite unrealistic, however, to think that the loss of a productive input such as water could result in anything but a significant economic loss to the area and to the state as a whole.

In an attempt to avoid or postpone the adverse economic consequences mentioned above it is essential that the individual extractor be provided the incentives to extract and utilize groundwater efficiently--that is, consider the future value of water when determining his extraction rate and to use efficient water saving techniques in applying the water.

BIBLIOGRAPHY

Books

Burton, Ian and Kates, Robert W. (ed.). "Welfare, Economics and Resource Development." Reading In Resource Management and Conservation. Chicago: The University of Chicago Press, 1965.

Campbell, Thomas H. and Sylvester, Robert O. (ed.). Public Policy Issues In Resource Management. Seattle, Washington: The University of Washington Press, 1968.

Ciriacy-Wantrup, S. V. Resource Conservation: Economics and Policies. Berkeley: The University of California Press, 1963.

Cohen, Kalman J. and Cyert, Richard M. Theory of The Firm. Englewood Cliffs, New Jersey: Prentice Hall, Inc., 1965.

Hirshleifer, Jack; DeHaven, James C.; and Milliman, Jerome J. Water Supply: Economics, Technology and Policy. Chicago: The University of Chicago Press, 1960.

Kansas Statutes Annotated, Vol. VI, Section 82a-711. Topeka, Kansas: State Printing Office, 1963

Kansas Water Resources Board. Irrigation In Kansas. Topeka, Kansas: State Printing Office, 1967.

Kneese, Allen V. and Smith C. (ed.) Water Research. Baltimore, Maryland: The John Hopkins Press, 1965.

Todd, David Keith. Groundwater Hydrology. New York City: John Wiley and Sons, 1959.

Ward, R. C. Principles of Hydrology. New York City: McGraw-Hill Publishing Company, 1967.

Walton, William C. Groundwater Resource Evaluation. New York City: McGraw-Hill Book Company, 1970.

Periodicals

Burt, Oscar R. "Economic Control of Groundwater Reserves." Journal of Farm Economics, Vol. XLCIII, August 1966.

Burt, Oscar R. "Temporal Allocation of Groundwater." Water Resources Research, Vol. III, 1967.

Domenico, P. A.; Anderson, D. V. and Case, C. M. "Optimal Groundwater Mining." Water Resources Research, Vol. IV, April, 1968.

Hotelling, Harold. "The Economics of Exhaustible Resources." Journal of Political Economy, Vol. XXXIX, April, 1931.

Kelso, Maurice M. "The Stock Resource Value of Water." Journal of Farm Economics, Vol. XLIII, December, 1961.

Renshaw, Edward F. "The Management of Groundwater Reservoirs." Journal of Farm Economics, Vol. XLV, May, 1963.

Smith, Vernon L. "Economics of Production From Naturan Resources." American Economic Review, Vol. LVIII, June, 1968.

Texas Technological College. West Texas Business Report, Vol. I, No. 8. Lubbock, Texas: School of Business Administration, Texas Technological College, 1958.

U.S., Department of Agriculture, Agricultural Research. Washington D. C.: Government Printing Office, 1969.

Bulletins, Reports and Other Sources

Conover, G. S. U.S., Department of the Interior, Geological Survey Circular No. 442. Groundwater Resources--Development and Management. Washington, D. C.: Government Printing Office, 1961.

Kansas Water Resources Board. Economic Implication of Irrigation, A Pilot Study. Topeks, Kansas: State Printing Office, 1968.

Meyer, Gerald and Wyrick, G. G. U.S., Department of the Interior, Geological Survey Circular No. 533. Regional Trends in Water-Well Drilling in the United States. Washington, D. C.: Government Printing Office, 1966.

Nace, R. L. U.S., Department of the Interior, Geological Survey Circular No. 415. Water Management Agricultural and Groundwater Supplies. Washington, D. C.: Government Printing Office, 1961.

Reed, Willis W. The Political Economy of Colorado's Groundwater Development Use. Unpublished Ph. D. dissertation, Colorado State University, Fort Collins, Colorado, 1970.

Thomas, Harold E. "Management of Groundwater Resources." Proceedings of the National Symposium on Groundwater Hydrology. Urbana, Illinois: PDQ Printing Service, 1967.

THE ECONOMICS OF GROUNDWATER MANAGEMENT WITH SPECIAL EMPHASIS ON THE HIGH PLAINS REGION OF WESTERN KANSAS

by

DAVID L. JORDENING

B.A., Kearney State Teachers College, 1964

AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF ARTS

Department of Economics

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1972

ABSTRACT

The increasing tendency of relying on groundwater reservoirs as a source of water supply has resulted in overdraft in many areas. Such practices raise economic questions concerning whether groundwater reservoirs should be depleted and the optimal rate of depletion.

Several groundwater management models have been developed to assist in answering some of the economic questions concerning groundwater extraction. Six resource management models are presented in this report. These include the models developed by Hotelling, Smith, Renshaw, Kelso, Burt and a mathematical formulation by Domenico, Anderson and Case.

The emphasis in Smith's model is to provide a unified theory of production for renewable common property resources. The desired rate of extraction in this particular model occurs when the return earned by extracting resources--an extraction rate which equals resource growth--is equal to the return to capital in alternative uses in the economy.

Hotelling's model on the other hand deals with purely exhaustible resources. The objective is to determine the rate of extraction so as to make the present value of all future profits a maximum. This optimal rate of extraction and the period of final exhaustion depend on the market structure and the demand function used.

Renshaw's work is divided into two distinct situations. Case one deals with areas where recharge is negligible and the groundwater is considered purely a stock resource. Case two is devoted to areas where recharge is significant. In case one Renshaw assumes that the marginal product of water declines

in a linear manner. If this is the case, the total income derived from a fixed quantity of water over several time periods may be maximized by restricting the water application in each period, thereby maintaining the marginal product in each period at a relatively high level. In case two by Renshaw groundwater is viewed as a pumping input substitute. The rationale behind this approach is that water retained in the ground raises the water level of the aquifer and thereby reduces the future marginal cost of acquiring water. In many cases the value of water retained in the reservoir exceeds its value in above ground uses.

Kelso's approach is similar to Renshaw's case one in that a water conservation program results in a less than proportional decline in total income. A water conservation program may thereby increase the benefits derived from a stock resource. Kelso also extends the analysis to consider the benefits that could be derived from a basin-wide conservation program. The basin-wide program is an attempt to internalize many of the externalities frequently associated with groundwater extraction.

The model by Burt is an extension of Renshaw's case two in that it assumes that current output is a function of current groundwater withdrawals and groundwater stocks. Groundwater contributes to output through withdrawal use and as a pumping input substitute. The model uses this relationship to arrive at an optimal rate of use for any quantity of water in stock.

The final model is a mathematical formulation that presents many management concepts in mathematical terms. The decision rule developed is that it is profitable to mine groundwater as long as the annual net revenue derived from the use of groundwater from storage plus the capitalized annual net value derived from the use of recharge exceeds the capitalized annual loss in the net value of recharge due to increased pumping costs.

The models that consider recharge as a pumping input substitute are not applicable to the High Plains area of western Kansas because recharge in this particular area is believed to be an insignificant proportion of the stock. Of the remaining models--Kelso's, Smith's, Hotelling's and Renshaw's case one--the most useful one as a practical management tool is that developed by Kelso. This model discusses many of the complexities inherent in groundwater extraction in the High plains area.