BIBLIOGRAPHIC DATA SHEET	1. CONTROL NUMBER PN-AAH-500	2. SUBJECT CLASSIFICATION (695) AP10-0000-0000

3. TITLE AND SUBTITLE (240)

The impact of groundwater development in arid lands: a literature review and annotated bibliography

4. PERSONAL AUTHORS (100)

Keith, S. J.

5. CORPORATE AUTHORS (101)

Ariz. Univ. Office of Arid Lands Studies

6. DOCUMENT DATE (110)	7. NUMBER OF PAGES (120)	8. ARC NUMBER (170)
1977	149p.	Ø16.3391Ø4.K28

9. REFERENCE ORGANIZATION (130)

Ariz.

10. SUPPLEMENTARY NOTES (500)

(In Arid lands resource information paper no. 10)

11. ABSTRACT (950)

12. DESCRIPTORS (920)

Arid land
Ground water
Environmental factors
Hydrogeology
Bibliographies
Economic aspects
Socioeconomic development

13. PROJECT NUMBER (150)

931015900

14. CONTRACT NO.(140)	15. CONTRACT TYPE (140)
AID/ta-G-1111	211(d)

16. TYPE OF DOCUMENT (160)

AID 590-7 (10-79)

PN-AAH-500

Arid Lands Resource Information Paper No. 10

THE IMPACT OF GROUNDWATER DEVELOPMENT IN ARID LANDS:

A Literature Review and Annotated Bibliography

by

Susan Jo Keith

The University of Arizona
OFFICE OF ARID LANDS STUDIES
Tucson, Arizona 85721

1977

ADDITIONAL PUBLICATIONS ON ARID LANDS

Office of Arid Lands Studies

Seventy-Five Years of Arid Lands Research at the University of Arizona, A Selective Bibliography, 1891-1965

Arid Lands Abstracts, no. 3 (1972)-no. 8 (1976)

Jojoba and Its Uses, An International Conference, 1972

Arid Lands Resource Information Papers, no. 1 (1972)-no. 10 (1977)

An International Conference on the Utilization of Guayule, 1975

Application of Technology in Developing Countries (1977)

Desertification: A World Bibliography (1976)

Desertification: Process, Problems, Perspectives (1976)

Arid Lands Newsletter, no. 1, 1975- to date

University of Arizona Press (*=OALS authors):

*Deserts of the World

*Arid Lands in Perspective

*Food, Fiber and the Arid Lands

Coastal Deserts, Their Natural and Human Environments

Polar Deserts and Modern Man

*Arid Lands Research Institutions: A World Directory, Revised edition, 1977

The work upon which this publication is based
was supported in part by funds provided by

The U.S.Department of the Interior/Office of Water Research and Technology

as authorized by
The Water Resources Research Act of 1964, as amended

Windmill and Stock-Watering Tank,
Semiarid grassland of southeastern Arizona

- Photo by S. J. Keith

CONTENTS

		Page
	Foreword	iv
	Preface	v
	Acknowledgments	vi
	Abstract	vii
I.	GROUNDWATER AND ARID LANDS	1
	1. Introduction	1
	2. Groundwater in arid lands	2
	3. The effect of pumping on an aquifer	4
II.	PHYSICAL ENVIRONMENTAL IMPACTS	7
	1. Introduction	7
	2. Impacts due to the use of groundwater	7
	a. Irrigation use	7
	b. Livestock use	9
	3. Impacts due to the response of the aquifer to groundwater pumping	10
	a. Spring flow	10
	b. Vegetation	11
	c. Streamflow	11
	d. Groundwater flow	12
	e. Drainage	15
	f. Groundwater quality	16
	i. Inland aquifers	16
	ii. Coastal aquifers	17
	a) Economic impacts	19
	b) Legal and political aspects	19
	g. Topography	20
	i. Subsidence	20
	ii. Earth fissures and faults	21
	iii. Geomorphic impact	22
	iv. Economic impact	26
	Eloy-Picacho area, Arizona	26
	Santa Clara Valley, California	27
	Houston-Galveston area, Texas	27
	v. Legal aspects	29
	4. Summary	29
III.	SOCIOECONOMIC IMPACTS OF GROUNDWATER DEVELOPMENT	30
	1. Introduction	30
	2. Health impacts	30
	3. Cultural impacts: Groundwater development and nomadic pastoralism	33
	a. Groundwater development and the Papago Indians	34
	Papago culture Pre-1900	35
	Post-1900 Papago culture	36
	Summary	39

		Page
	4. Economic impacts: Groundwater development and irrigated agriculture	39
	a. Economic impact of the initial development of groundwater in developing regions	39
	i. Groundwater as a catalyst in economic development: Pakistan	40
	b. Economic impact of a diminishing groundwater resource	47
IV.	AN OVERVIEW OF THE LITERATURE	55
V.	SOME FURTHER CONSIDERATIONS	56
	1. The physical setting	56
	2. Technology	56
	a. Technological change	56
	b. Appropriate technology	57
	3. Cultural-institutional aspects	59
	a. Developing countries	59
	b. Developed countries	60
VI.	SUMMARY AND CONCLUSIONS	62
	SUPPLEMENTARY REFERENCES	64
	BIBLIOGRAPHY	71
	Author index	130
	Keyword index	133

ILLUSTRATIONS

Figures:

1.1.	Cone of depression in X-section	5
1.2.	Cone of depression in plan view	5
1.3.	Aquifer under undisturbed conditions	5
1.4.	Pumped aquifer	5
1.5.	Idealized hydrograph of well in arid area	6
1.6.	Idealized hydrograph of well in humid area	6
2.1.	Degradation of groundwater from irrigation	8
2.2.	Spread of desertification through development of wells	9
	A. Original situation, end of dry season 1	9
	B. After well-digging project . . . End of dry season 2	9
2.3.	A: An effluent stream	11
	B: An influent stream	12
2.4.	Groundwater elevations and direction of flow in an area in southern Arizona	13

2.5. San Joaquin Valley: 14
A. Flow conditions in 1900 14
B. Flow conditions in 1966 14
2.6. Hydraulic conditions in an unconfined aquifer in continuity with the ocean 18
2.7. Hydraulic conditions in a confined aquifer in continuity with the ocean 18
2.8. Profiles of land subsidence and artesian head decline 20
2.9. Profiles of subsidence through time in an area in the San Joaquin Valley 21
2.10. Land subsidence, 1959-1962, Arvin-Maricopa area, San Joaquin Valley 22
2.11. Air photo of the Picacho Fault 23
2.12. Gully in Eloy-Picacho subsidence area 24
2.13. Looking downstream, gully in Eloy-Picacho subsidence area 24
2.14. Fissure which has intercepted a dirt road 25
2.15. Fissure showing adjacent earth slumping and wasting 25
2.16. Fissure showing dendritic drainage developing up-gradient 25
2.17. Subsidence in the Eloy-Picacho area of central Arizona 26
2.18. Approximately 3,000 square miles affected by land surface subsidence in Texas 28
2.19. Subsidence of the surface in the Houston-Baytown area, 1943-1973 28

3.1. Map of Arizona showing location of Papago Indian Reservation 34
3.2. Map of Pakistan 41
3.3. Estimate of private tubewells in Pakistan 42
3.4. Aggregate marginal demand curves for water for several types of users 48
3.5. Composite aggregate marginal demand curve for water for several types of users 48
3.6. Total personal income from all sources, Arizona, 1929-1970, in dollars of current purchasing power 50
3.7. Water use in Arizona 1936-1968 51
3.8. Percentage of personal income by broad source, Arizona, 1929-1970 51
3.9. Personal income by broad source, Arizona, 1929-1970, in dollars of constant purchasing power (1957-1959=100) 52

Tables:

2.1. Changes in geochemical type of water from 1964-1970 due to groundwater pumping in an area in the Punjab, Pakistan 16
2.2. Changes in water quality usability and dilution requirements from 1963-1970, due to groundwater pumping in an area of the Punjab, Pakistan 17

3.1. Water-related diseases 31
3.2. Number of Papago ranch and grazing locations since prior to 1850 37
3.3. Estimated numbers of livestock 38
3.4. Availability of irrigation water, by source, Pakistan, 1960-1969/70 (maf) 43
3.5. Cropping patterns and cropping intensities of tubewell and nontubewell farmers, 1967 43
3.6. Yields per acre, with and without tubewells 44
3.7. Size of holding and fertilizer use of tubewell and nontubewell farmers, 1963/64, Pakistan 45
3.8. Land and labor inputs, tubewell and nontubewell farms 45
3.9. Net farm income with and without tubewells, by size of farm, Pakistan 46
3.10. Changing structure of the Arizona economy related to water diversions and pumpage 53

5.1. Comparison of the benefits of two tubewell technology alternatives for installation in Bangladesh 58

FOREWORD

The Arid Lands Resource Information Paper presented here, the eighth prepared for the Water Resources Scientific Information Center (WRSIC), was supported in part by the U. S. Department of the Interior, Office of Water Research and Technology Grant No. 14-31-0001-5254, to the University of Arizona, Office of Arid Lands Studies, Patricia Paylore, Principal Investigator; and in part by the U. S. Agency for International Development as a contribution from its 211(d) institutional grant to the University of Arizona. [Two other Papers, Nos. 5 (Jojoba) and 7 (Guayule) in the series, were funded by another Federal agency.]

I wish once more to thank the National Science Foundation for its early funding of the development of the computer program which now handles so successfully the Arid Lands Information System (ALIS). The extensive bibliography accompanying this Paper was produced by ALIS, and includes over one hundred references prepared by the Office of Arid Lands Studies originally under previous OWRT/WRSIC grants. These, and others where users are referred to SWRA [Selected Water Resources Abstracts] in lieu of abstracts, are taken from RECON, ERDA's Oak Ridge-based information system.

While I appreciate the support of OWRT/WRSIC of the Office of Arid Lands Studies, University of Arizona, as a U. S. Center of Competence in water-related problems of arid lands, neither the U. S. Department of the Interior nor the University of Arizona is responsible for the views expressed herein.

Patricia Paylore
Assistant Director
Office of Arid Lands Studies
Tucson, Arizona 85721

September 27, 1977

PREFACE

The scientific mind, in being totally scientific, is being unscientific ...
The scientist atomizes, someone must synthesize
The scientist withdraws, someone must draw together
The scientist particularizes, someone must universalize
The scientist dehumanizes, someone must humanize
The scientist turns his back on the as yet, and perhaps eternally, unverifiable
And someone must face it

-Fowles (as quoted in Wiener, 1972)

Interdisciplinary research is always a gamble, and for a topic such as this one cannot help feeling the odds are against him. In this paper depth has been sacrificed to scope for good reason. Our water problems are not simply problems of physical scarcity or quality, or of retrieval, storage, and distribution. Our water problems, and our methods of solving them, are related to every aspect of our physical and cultural being, from the environment in which we function, to our cultural institutions, to our own individual personal behavior. As such, there is a necessity to view water development with a systems-like approach, to begin to try to decipher the connecting thread between water development and environmental and cultural change in the web of life. While specialized research is an extremely important aspect in this, perhaps just as important is synthetic research which attempts to tie things together.

It is to this end, with this philosophy, that this paper has been written: to point out that there is more than water in the well.

Susan Jo Keith

Tucson, Arizona
September 1, 1977

ACKNOWLEDGMENTS

There are a number of persons I should like to thank for assistance in the preparation of this Paper as it appears before you: Bill Daniels provided some of the photography. On the topic of earth fissures, Michael Carpenter was helpful with information, many references, and, along with James Boling, a field trip crucial to my understanding of this phenomenon. The section on cultural impacts benefited from an early draft review by Frank Putnam and by Elizabeth Evans, who also provided references on the Papago Indians.

Dr. Stanley N. Davis, Head, University of Arizona Department of Hydrology and Water Resources, and Dr. K. James DeCook, Associate Hydrologist, Water Resources Research Center, University of Arizona, who each took time out from busy schedules to read and comment on various parts of the Paper, have my grateful thanks.

Of the staff of the Office of Arid Lands Studies, University of Arizona, I wish to thank its Director, Dr. Jack D. Johnson, particularly, as well as Mr. J. Richard Greenwell, and also Ms. Mary Ann Stone for assistance in the preparation of tables and figures for reproduction.

sjk 9/1/77

ABSTRACT

SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

1. Report No.
2. [illegible]
3. Accession No. **W**

4. Title
Impact of Groundwater Development in Arid Lands: A Literature Review and Annotated Bibliography

5. Report Date
6. [illegible]
8. Performing Organization Report No. [illegible]

7. Author(s)
Susan Jo Keith

10. Project No.

9. Organization
University of Arizona, Tucson, Office of Arid Lands Studies

11. Contract/Grant No.
OWRT No. 14-31-0001-5254

12. Sponsoring Organization [illegible]
13. Type of Report and Period Covered [illegible]

15. Supplementary Notes
Arid Lands Resource Information Paper, No. 10. 1977. 139 p.
34 Figs., 13 Tabs., 318 Refs.

16. Abstract

As groundwater comes increasingly under development, it is imperative, for economic, ecological, and political reasons, to anticipate the impact of its development. This paper reviews the literature on this impact in arid lands in terms of two general categories: physical environment impacts and socio-economic impacts. Two case studies are presented: one focuses on the impact of groundwater development on the Papago Indians, illustrating the cultural and subsequent environmental changes occurring when an assured groundwater supply is developed within an area of previous water scarcity inhabited by a semi-nomadic people; the second, through a discussion of groundwater development in Pakistan, demonstrates the role groundwater development can play in the economic development process in developing arid countries. The point is made that the impact of groundwater development is not simply the result of the withdrawal of water. Technology, through its growth and appropriateness, and our institutions influence very much the type and magnitude of the impact of groundwater development. It is through an understanding of these roles that desirable impacts can be promoted and undesirable impacts mitigated.

(Keith-Arizona)

17a. Descriptors *Groundwater, *Water resources development, *Land subsidence, *Arizona, Wells, Springs, Streamflow, Pumping, Environmental effects, Social aspects, Salinity, Water quality, Subsidence, Saline water intrusion, Vegetation, Economic impact, Arid lands, Technology, Water management (applied), Bibliographies, Agriculture

17b. Identifiers *Pakistan, Tubewells, Papago Indians, Industrial linkages, Institutional aspects, Developing countries, Economic development, Appropriate technology

17c. COWRR Field & Group 06G

18. Availability
19. Security Class. (Report)
20. Security Class. (Page)
21. No. of Pages
22. Price

Send To:
WATER RESOURCES SCIENTIFIC INFORMATION CENTER
U.S. DEPARTMENT OF THE INTERIOR
WASHINGTON, D.C. 20240

Abstractor Susan Jo Keith
Institution University of Arizona

WRSIC 102 (REV JUNE 1971)
GPO 899-837

THE IMPACT OF GROUNDWATER DEVELOPMENT IN ARID LANDS:

A Literature Review and Annotated Bibliography

I: GROUNDWATER AND ARID LANDS

Water, especially groundwater, is the key to life in semi-arid and arid zones.
-Schoeller, 1959*

Groundwater is the key to any development effort in the Sahara.
-Ambroggi, 1966*

Hydrogeology ... should be the starting point for development of arid zones.
-Pallas, 1972*

1. Introduction

Groundwater. At any one point in time it constitutes ninety seven percent of the fluid fresh water available to man (Universal Oil Products, 1975*) and makes up approximately 30 percent of stream flow (Barry, 1969*). It is generally a superior source of supply for the following reasons: 1) it is commonly free of pathogenic organisms and needs no treatment for domestic or industrial uses, 2) it usually has a constant temperature, 3) turbidity and color are usually absent, 4) chemical composition is commonly constant, 5) radiochemical and biological contamination is usually difficult, 6) it is less vulnerable to drought conditions, and 7) it is available in many areas lacking dependable surface water supplies (Davis and DeWiest, 1966*).

In the Arid zone[1] these last two points make groundwater a particularly important resource, some would say the most important. Until around the beginning of the 20th century or so, most groundwater developed in the Arid zone was from near-surface aquifers, or at natural discharge points, such as the oases in the Sahara. Technology used to develop this water supply was ingenious and simple: Human labor dug the holes or galleries, in the case of qanats. The energy used to extract the water was either gravity, as in qanats, or human and animal. Sometimes no energy source was necessary if the aquifer was under enough pressure to force water to or above the land surface when tapped.

Technological advances, the result of the Industrial Revolution, combined with a growing need to be able to withdraw groundwater, first for dewatering of mining operations, then for domestic and municipal use (due to increasing pollution of surface water sources and the recognition of the polluted water disease link), eventually culminated in the development of a much more efficient and effective well-drilling technology, more powerful and economic pumps, and an energy source and system to fuel them (Kazmann, 1972*).[2]

Perhaps no other technology has had such influence on the character and extent of the development of the Arid zone as modern groundwater technology has had. Suddenly vast new subsurface water resources became available that heretofore had been beyond the reach of more primitive technologies. Suddenly adaptive behavior no longer was so necessary to survival in the Arid zone. Suddenly a technology was available capable of altering both the physical and socioeconomic processes in Arid lands.

---

* References marked with an asterisk are listed in the Supplementary References section. All others are listed in the Bibliography.

[1] A capitalized "Arid" refers to the zone as a whole which includes the semiarid, arid, and extremely arid regions. References to the "arid" subarea will be designated by the uncapitalized term.

[2] Green (1973) provides an excellent discussion of the evolution of modern groundwater development technology and its impact on the development of the High Plains of west Texas.

The impact of this groundwater development in Arid lands is the topic of this paper. Other than the element of human curiosity, there are a number of rational and practical reasons for wanting to know what this impact might be, for wanting to understand the relationship between groundwater development, society, and the environment. For one reason, groundwater in Arid lands will come under development increasingly because of increased water demands resulting from three factors:

First, there is the sheer increase in numbers of people and animals in the Arid zone. Population growth rates are often highest in the Arid regions of both developing and developed nations (see Mann, 1969*; Beaumont, 1976; Mann and Malhotra, 1976*).

Second, with respect to the developing nations, there is the huge latent water demand implicit in the economic development process. As standards of living rise, so does per capita water consumption. The Sahelian nomad's daily use of a few gallons of water is in marked contrast to the 220 gallons per day per capita (gpd/capita) used by the citizen of Phoenix, Arizona. Indeed, per capita water consumption may be an even more telling index of development than those traditionally used.

But by far the greatest increase in water demand will come from the extractive demands being placed on the Arid zone for food, fiber, and energy. Food and fiber cannot be produced in the Arid zone without huge amounts of water. Irrigated agriculture is the largest consumer of water even in the highly industrialized nations. For example, 90 percent of the water used in the arid western U.S. goes to irrigation (Ruttan, 1965*). The exploitation of nonrenewable energy sources requires large volumes of water at the same time that it causes degradation of water supplies (Bowden, 1975). Even solar energy has its hydrologic drawbacks. Regions of greatest solar power availability are usually those areas with limited water supplies, a deficiency considered critical in terms of both quantity and quality of water (Packus and Brown, 1976*).

The increasing development of desert aquifers will be accompanied by increasing environmental changes induced by this development. It seems important, therefore, to anticipate these changes in order to manage the development of the aquifer in an ecologically, economically, and politically sound manner.

There is another reason for wanting to know the impact of groundwater development in Arid lands. Particularly in developing nations, groundwater development is often undertaken as a tool of economic development. How effective a tool is it? How does groundwater development contribute to the well-being of peoples in an Arid region? What happens when it is gone? Answers to these questions can only aid the decision maker in his allocation of scarce resources.

So there are good reasons for wanting to know what the impact of groundwater development is in Arid lands. It becomes more and more imperative that intelligent decisions are made regarding our water supplies, decisions that cannot be made in the absence of information on how they will affect the environmental and socioeconomic processes. It is hoped that this paper and the accompanying bibliography will serve as a brief introduction to the topic and the literature on the impact of groundwater development on Arid lands for both the layman and the specialist, and in some way contribute to an understanding of the relationship between groundwater, society, and the environment.

2. Groundwater in Arid Lands[3]

The Arid zone covers approximately 36 percent of the Earth's land surface, and may be broken into three different regions according to moisture scarcity: semiarid, arid, and extremely arid.[4] The semiarid region encompasses approximately 8,202,000 square miles, or some 45 percent of the Arid zone; the arid, with 8,418,000 square miles, and the extremely arid, with 2,244,000 square miles, occupy the rest, or about 55 percent (Walton, 1969*). Some 60 countries are affected by the Arid zone, approximately half the countries of the world (Batisse, 1969*), though only 13 percent of the world's population is estimated to live in this zone. Of this 13 percent, 72 percent live in the semiarid regions (Amiran, 1966*).

---

[3] Readers interested further in this topic are referred to Schoeller (1959*), International Association of Scientific Hydrology (1961*), Maxey (1968), Simpson (1968), and Davis (1974).

[4] See adaptation of Meigs' maps delineating "World Distribution of Arid and Semi-Arid Homoclimates," in McGinnies, Goldman, and Paylore, 1968*.

The Arid zone is distinguished above all by the uncertainty, variability, and scarcity of rainfall. These factors coupled with the very high evapotranspiration rates make this an area of extreme moisture deficiency. In the semiarid region, there is often enough rainfall for a risky dryland farming or ranching operation. In the arid and extremely arid regions there is not even enough rainfall for that. Unless blessed by the occurrence of an exotic river, such as the Nile, the occupation and utilization of these areas is restricted to places where groundwater can be developed or has surfaced as springs.

Groundwater is indeed an extremely important resource in all the Arid zone — many think the most important. In Tunisia, 75 percent of the population depends upon it; in Morocco, 95 percent; in Saudi Arabia, 100 percent; in Israel, 70 percent (United Nations Water Resources Development Centre, 1960). The southwestern U.S., western Australia, Iran, Iraq, Pakistan, India, central Asia, and northern Africa also depend heavily upon groundwater (Ibid.).

There are several aspects about groundwater, however, that limit its potential impact in Arid lands:

First, groundwater does not occur everywhere and anywhere beneath the surface. It selectively accumulates in environments geologically and hydrologically favorable (see Davis and DeWiest, 1966*, for further discussion). Though this is a trivial fact to professionals in the field of groundwater, it is emphasized here to dispel any notion the uninitiated might have that all one has to do is construct a well to gain access to groundwater.

When groundwater is found, the amount of water available for human use is limited by the aquifer characteristics, recharge, and water quality. The yield from properly constructed wells will vary from one aquifer to the next according to the physical characteristics of the aquifer. The time span over which this yield can be sustained will vary with the areal extent and volume of the aquifer and the recharge rate. Thus some aquifers are capable of sustaining large-scale development over a long time span, such as would be required for irrigation agriculture or heavy municipal use, while others are capable only of small-scale development for human or stock watering use.

Recharge of Arid zone aquifers is a topic of considerable concern. Its meagerness and variability are what give rise not only to the designation of groundwater in arid lands as a finite resource but also to the pessimism toward its development. A general rule of thumb in arid areas is that recharge is usually less than five percent of rainfall. Significant amounts of recharge are associated only with extremely high precipitation events that may occur only once every ten(s) to a hundred years (Nace, 1964*).

In some areas today, the arid and extremely arid regions particularly, there is virtually no recharge. Groundwater found in these areas is often, as Nace (1969) has put it, "a legacy of the past" when a more humid climate prevailed. Carbon 14 dating techniques, used to date these groundwaters, indicate a major recharge period 20,000 years ago. In the Negev, where rainfall is less than 2.5 cm/yr, dated groundwater yielded an age of 20,000 years (Valery, 1972); in the Great Artesian Basin in Australia, 20,000 years (Nace, 1969); and in Arabia, 20,400 to 24,760 years (Thatcher, Rubin, and Brown, 1961*). The latter authors attribute this to the high rainfall associated with the climax of the Wisconsin glacial stage at about 20,000 years ago.

The final limiting factor to the amount of groundwater available for human use in Arid lands is water quality. Nace (1960*) estimated the total worldwide recoverable groundwater resources in the upper 790 meters to be 4.2×10^6 cubic kilometers. [5] Simpson (1968) postulates that ten percent of this is stored under the Arid zone, an estimate he feels is conservative in terms of actual quantity but not in terms of usable quality. Davis (1974) states that in deserts "water quality is probably a more severe limitation than the scarcity of water itself." Groundwater tends to be more saline here than elsewhere for the following reasons:

---

[5] It is interesting to note that Nace's more recent (1969) estimate is 7.0×10^6 cubic kilometers, and is for the upper 1,000 meters. One can speculate why the depth for estimated recoverable groundwater resources jumped from 790 to 1,000 meters, and why the increase in groundwater was more than linear — an increase in our technological efficiency, and/or an extension of our geographical knowledge of the occurrence of groundwater?

1) Evapotranspiration exceeds precipitation, so soluble salts originally in rain will tend to be concentrated by evaporation at the land surface. Occasional heavy rain will redissolve these salts, and runoff will carry the water and salts to points of groundwater recharge.

2) Dry fallout, which is almost ubiquitous in deserts, contains easily soluble salts. Precipitation which eventually becomes groundwater recharge will dissolve significant amounts of these salts.

3) Deserts favor the preservation of natural beds of gypsum, halite, and other evaporite deposits which will contribute dissolved material to water from infrequent storms.

4) Slow water movement in deserts will mean that flushing of connate saline water will also be very slow. Thus, some of the salinity in desert aquifers may be related to ancient saline water originally deposited with the sediments.

-Davis (1974), p. 20

Thus the discovery of large volumes of water in underground storage in Arid lands should only give rise to reserved expectations of its production potential, for the amount of recoverable water will be limited by the aquifer's physical characteristics and recharge, and the amount of usable water will be limited by the water quality.

These factors affecting the availability of groundwater in Arid lands have been introduced here because they are one part of the package of variables that determine the type and magnitude of the impact that groundwater development will have in a region.

3. The Effect of Pumping on an Aquifer

An understanding of the nature of the impacts of groundwater development in Arid lands begins with an understanding of how the physical system of an aquifer is affected by pumping from wells. Theis' (1940) paper provides much of the basis for the following discussion.

Hydrogeologists generally feel that under natural conditions (no significant well development), aquifers are in a state of approximate dynamic equilibrium, that is, recharge to the aquifer equals discharge from the aquifer, and over a given time span fluctuations in water level balance each other out. When wells are introduced into this previously stable system, the equilibrium is disrupted by an increase in discharge through the wells. The aquifer tries to adjust to this disturbance, attempting to establish a new equilibrium, by increasing its recharge, decreasing its discharge, and/or by a loss of water in storage.

The cone of depression is the mechanism through which these actions take place and is so called because of the cone-like geometry of the water level configuration around a pumped well (see Figs. 1.1 and 1.2). It is "a pirating agent created by the well to procure water for it, first robbing the aquifer of stored water and finally robbing surface water or areas of transpiration in the localities of natural recharge or natural discharge " (Theis, 1938). It deepens and broadens through time (at rates dependent upon the pumping rate and the aquifer's physical characteristics) with continued pumping which means that the depth to groundwater at any given point in the area of influence will increase through time as will the area under influence (Figs. 1.3 and 1.4) at decreasing rates, until a new equilibrium is established.

Until the cone intersects areas of recharge and discharge, the water pumped from the well is taken from water in storage in the aquifer, and recharge and discharge rates are unaffected. When discharge sites (springs, streams) are reached by the cone, discharge declines or ceases as potential discharge water is diverted toward the pumping center by the steeper hydraulic gradient created by the cone. The effect of the cone of depression on recharge rates will depend on the recharge condition in the recharge area.

Two possible conditions can exist in the recharge area which will determine how much water is recharged to the aquifer from the surface through rainfall or stream flow infiltration. In the first case, the potential recharge rate may be so high as to exceed the rate that water can flow laterally through the aquifer. In this case, the aquifer is full and no space is available to accept recharge at a rate in excess of that of the movement of water through the aquifer, and a condition of rejected recharge exists. This in turn runs off as streamflow, swamps, or lakes. The second condition is the

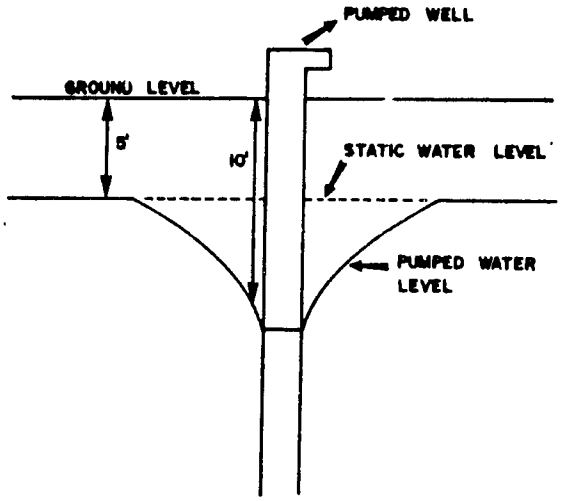


Fig. 1.1. Cone of depression in X-section

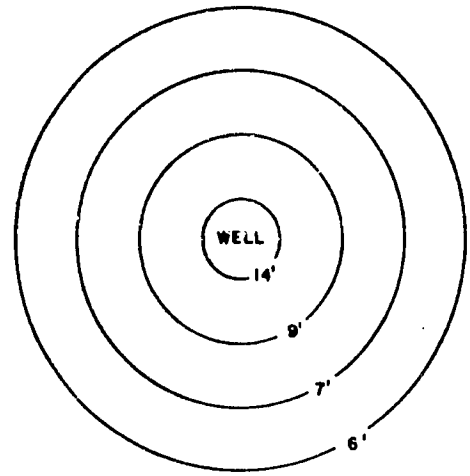


Fig. 1.2. Cone of depression in plan view; contours are equal depths to water

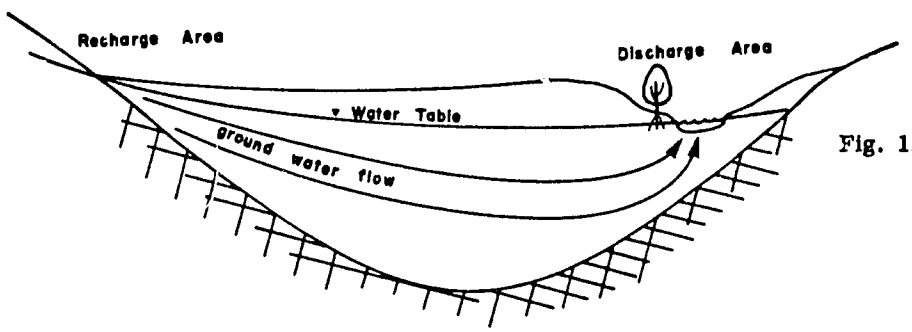


Fig. 1.3. Aquifer under undisturbed conditions

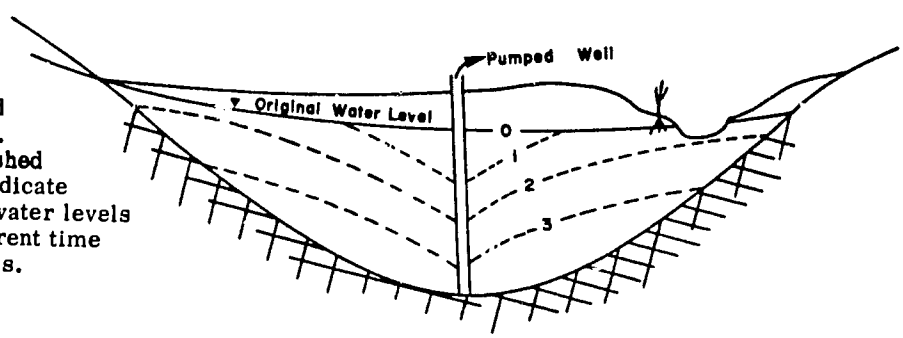


Fig. 1.4. Pumped aquifer. The dashed lines indicate groundwater levels at different time intervals.

one more common to Arid lands, where the recharge rate is lower than the rate at which the aquifer can transmit water. Here the amount of water recharged is determined by the amount of water available for recharge through rainfall and runoff, and by the rate at which it can move downward through the soil or stream channel to the water level. The faster this rate is, the less water lost to evaporation, and the more recharged. Thus, in more humid areas, recharge rates (up to a certain point) can be increased to make up for well discharge, whereas in arid areas they cannot.

The implications of this are obvious. In humid areas, where conditions of rejected recharge often exist, an aquifer will be more successful in attempting to establish a new equilibrium (and thus stabilize water levels) after the initial disruption of well construction (Fig. 1.6). Arid zone aquifers lack the option of increasing recharge and make up for the water discharged by wells by even-

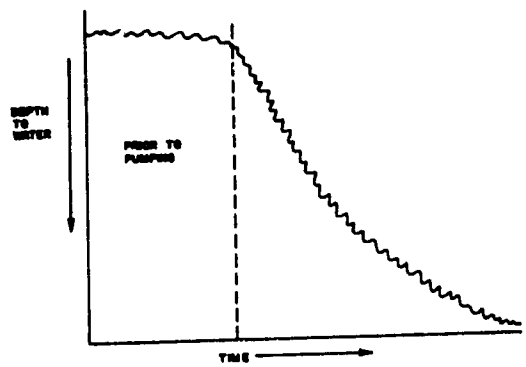


Fig. 1.5. Idealized hydrograph of well in arid area

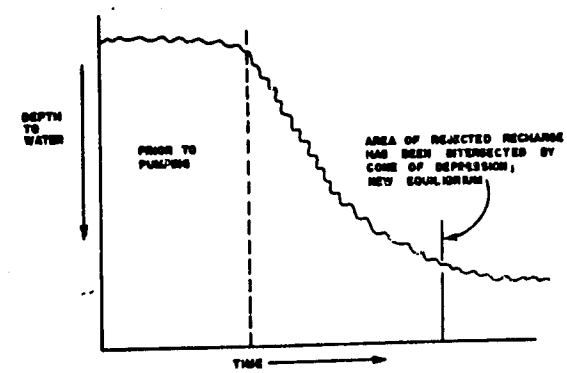


Fig. 1.6. Idealized hydrograph of well in humid area

tual decline of natural discharge and, most of all, by withdrawal of water from storage. Continuing water level declines are the immediate consequence for the individual well owner (Fig. 1.5). On a broader scale, changes in surface and subsurface flow systems, vegetation, topography, water quality — to name a few — due to pumping of an aquifer are occurring in subtle and not-so-subtle ways, the topic of the next chapter.

II : PHYSICAL ENVIRONMENTAL IMPACTS

Water resource development projects are purposefully conceived and designed to achieve major environmental changes.
-Dee et al, 1973

Because the entire hydrological system is so directly interconnected, we must be able to measure the effect of the actions we take on specific parts of the overall system. Unfortunately, although we know a great deal about certain of the critical elements of the system, we are quite ignorant in other crucially important areas ... So it is that years after an action is taken, effects occur that were not foreseen and that are often more important than the advantages offered by the development itself.
-Abel Wolman, as quoted in Wiener, 1972*

1. Introduction

Groundwater development in Arid lands is undertaken to create a microenvironment in which man is more able to live, both biologically and economically. In the process, major environmental changes can and do take place, both locally and regionally. Because most of the groundwater that is developed is used for irrigation, the most obvious environmental change is the "blooming of the desert": the creation of carpets of emerald-green cropland that glitter like jewels in the dry heat of dusty desert basins. But other changes are taking place also, on the surface and beneath, where, at least initially, they are unseen and unsuspected. These changes can be grouped into two general categories: those that occur due to the type of use to which the groundwater is put, and those that occur due to the response of the aquifer to pumping. This chapter reviews briefly the literature on these changes and their socioeconomic impacts.

2. Impacts Due to the Use of Groundwater

These are the physical changes in the environment due to the application and utilization of groundwater. Unlike the impacts discussed in the following section, which are directly due to physical changes in the aquifer as a result of pumping, these impacts are due to cultural decisions and behavior. As such, many of these impacts are not necessarily the result of groundwater development, but could occur regardless of the source of water. This paper concentrates on the examples which happened as a result of groundwater development.

In Arid lands, particularly in the developing nations, most groundwater is developed for one of two reasons: irrigation or livestock watering. The impacts on the environment of the use of groundwater in Arid lands for these two purposes are discussed in the following sections.

2. a) Irrigation use

By far, most of the groundwater developed in the Arid zone is used for irrigation. In Texas Arizona, New Mexico, Utah, and Colorado, 90 percent or more of the groundwater pumped is used for irrigated agriculture (Turner, 1974*). In the developing countries where industrial use of groundwater is nearly nil, the percentage of groundwater used for growing crops is probably even greater.

The major environmental problems associated with irrigation in Arid lands, regardless of the source of water, are, first, salinity, then waterlogging. A considerable volume of literature exists on the topic of these irrigation problems in Arid lands, for example Casey's (1972*) literature review

and bibliography contains 986 references on salinity alone. A more technical textbook approach to salinity, waterlogging, and drainage can be found in FAO/UNESCO (1973*).

With respect to groundwater alone, the major problem facing its use in irrigation is salinity. The reasons for the salinization of soils and groundwaters are identified by Burdon (1971) as: a) initial high salinities and temperatures of groundwater, b) high evaporation, c) lack of drainage, d) recirculation of groundwater, and e) operation in closed basins.

Groundwater commonly has a high salinity in Arid lands (for reasons discussed in Section I, "Groundwater in Arid Lands") and when it is withdrawn from beneath the surface and exposed to the high evaporation rates characteristic of Arid areas its salinity increases as fresh water molecules evaporate and salts are left behind. Because the amount of water applied to crops is seldom enough to carry away as much salt as is introduced, many of these salts accumulate in the soil, eventually threatening the productivity of the crops. The salinity problem in irrigated agriculture is the result of a number of complex interacting factors such as the type of soil, the salinity of the water applied, the composition of the salts in the water, the type of crop grown, and the irrigation procedures used (Gindler and Holburt, 1969).

The problem of salinization exists even with fresh groundwater. For instance, a well yielding 20/liters/sec of fresh water can produce greater than 600 metric tons/yr of salts (Ambroggi, 1966*). Salinization of soils due to the application of groundwater in the arid New Valley of Egypt has resulted in the loss of agricultural productivity of approximately 30 percent of the land initially brought under production, and has also caused the destruction of walls and house foundations (Meckelein, 1976).

Those salts that do not remain in the soil are flushed back down into the groundwater reservoir when infiltration and percolation of water downward is greater than the drop of the groundwater level due to pumping. In this type situation, a cycling of groundwater is set up with a progressive increase in groundwater salinity that will ultimately destroy its utility unless significant amounts of water are being recharged from fresh water sources. Fig. 2.1 illustrates this process of increased salinization of groundwater through recycling. In Pakistan, this process is felt to threaten the future use of groundwater (Malmberg, 1975; Mundorff et al, 1976). But in other areas, such as in some of the intensely developed groundwater basins in southern Arizona, where water levels have been dropping rapidly for a number of years, it is hard to identify whether any significant increase in salinity is taking place due to recirculation of groundwater.

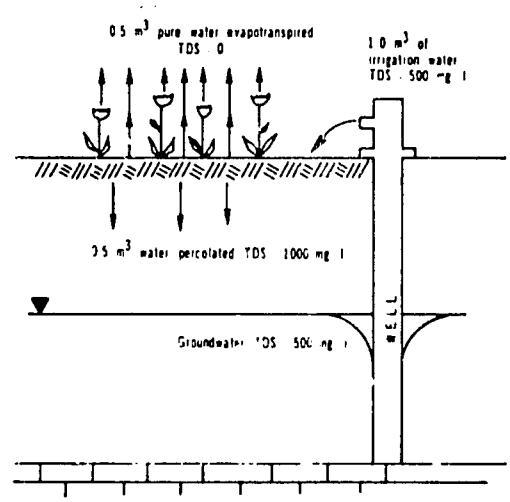


Fig. 2.1. The degradation of ground water from irrigation. -Helweg (1977)

Davis (1974) points out another problem associated with the application of groundwater for irrigation. Where certain geologic conditions exist that impede or prevent the percolation of the irrigation water back into the groundwater zone, irrigation water accumulates as perched water bodies in previously dry zones. If these zones are near enough to the surface, problems of waterlogging and salinity resulting from a near-surface groundwater level (see section on drainage, p. 15) can occur, which, again, results in the loss of agricultural productivity of the land.

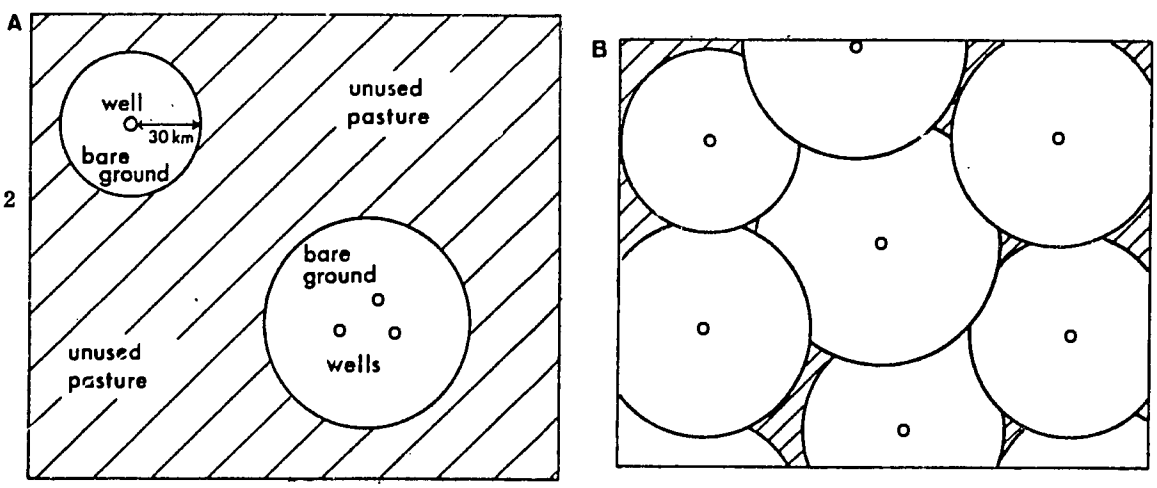
When irrigated land is abandoned for the above or other reasons, land degradation occurs as the soil, left without any vegetative growth to hold it in place, is subject to both wind and water erosion. This contributes not only to the air pollution but also poses a serious hazard. In the central Arizona area, dust derived from abandoned irrigated lands has been responsible for several highway deaths (Matlock, 1976).

2.b) Livestock use

In one form or another pastoral nomadism historically has been one of the most successful and is the most widespread pattern of occupance in the semiarid zone. It continues today on a much smaller scale, particularly in the developing countries. Groundwater development for the use of pastoral nomads' livestock has received a good deal of attention in recent years, being held partially responsible as it has for the "desertification" process of the semiarid zone.[6]

Generally the sequence of events that explains the role in desertification of the development of groundwater for livestock use in areas of pastoral nomadism is as follows: Prior to the development of groundwater by modern technology, the movement of nomadic herdsmen was keyed to the availability of water and food for grazing. Thus the amount of time spent in any one area, and the number of animals herded, was limited by the seasonal variability of water and food. When this seasonal variability of water was eliminated, the nomad's response was to increase the herd size to beyond that previously limited by a lack of water,[7] and to stay longer, or even permanently at one well site. Food then became the limiting factor and severe overgrazing followed. The destruction of vegetation and the compaction of soil that ensued set off a self-enhancing geomorphic response[8] — a desertification process — that can only be termed as undesirable: a loss of topsoil, and thus greater dust pollution; less infiltration of rainfall and thus less recharge to near-surface aquifer systems; more rainfall runoff and thus more erosion, higher flashier flood peak flows, and increased sediment yield; and sedimentation in the downstream direction. Fig. 2.2A and B show how the area of desertification can spread with the development of wells.

Fig. 2.2



A. Original situation. End of dry season 1. Herd size limited by dry season pasture. Small population can live on pastoral economy.
B. After well-digging project, but no change in traditional herding. End of dry season 2. Large-scale erosion. Larger total subsistence herd, and more people can live there until a situation when grazing is finished in a drought year. Then the system collapses. -Rapp (1974*)

[6]See Paylore (1976*) for further discussion and references.

[7]Widstrand (1975*) discusses this response from an economic standpoint.

[8]See Bull (1976*) for a framework from which to analyze the fluvial response to vegetation changes in the watershed.

Many investigators report this cultural and consequent environmental response to the provision of a stable water supply to pastoral nomadic cultures in areas previously characterized by uncertain and variable water supplies: Rapp (1974*), Sterling (1974*), Caldwell (1975*), and Scheiber (1974*) in the Sahel; Talbot (1972) in Masailand, East Africa; Swidler (1972*) in Pakistan; and Heady (1972) in Saudi Arabia, for example. The economic consequences can only be surmised. The problem is further discussed, with emphasis on the cultural response, under the section on Cultural Impact.

3. Impacts Due to the Response of the Aquifer to Groundwater Pumping

The procurement of water for a well, via the cone of depression, imposes changes in the aquifer that have a chemical, surficial, or subsurface expression. Impacts such as these can occur in any type of climate where groundwater withdrawal is relatively large. Arid areas are more prone to these impacts because there is more of a dependence on groundwater (because rainfall and surface water are lacking) and because there is usually no rejected recharge to make up in part for well discharge. Thus water is taken from storage in the aquifer and captured at natural discharge areas, the consequences of which are discussed in the following section.

3. a) Spring flow

Historically springs have played a very important role in the use of the arid zones, particularly the arid and extremely arid. In the Sahara, springs provided the only permanent dwelling places, oases, in millions of square miles of dry desolate expanses, and also made possible the caravan routes of trade between the Mediterranean and interior Africa. Here, as elsewhere in the arid world, their historic, economic, recreational, strategic, and esthetic value has been in great contrast with their surroundings.

The importance of springs has diminished somewhat, particularly in the developed countries where the technology to exploit and carry water in large volumes is available. Groundwater development technology, while it has led to a diminishing dependence on spring flow, has also led to its decline by capturing water for the well or pumping center that would otherwise have been discharged as a spring.

There is little literature devoted to the discussion of the topic of groundwater development and spring flow decline per se. Most references to the topic are only two or three sentences long and of a qualitative nature, and are not included here. Brune's (1975) paper on springs in Texas provides one of the few relatively lengthy discussions. Measurements made of spring flow in Texas beginning in the late 1800s show a dramatic and alarming decline in flow, many times to the point of drying up completely, particularly in the semiarid area of west Texas. Brune has no qualms about attributing this part of the historical decline to the development of groundwater which began in the late 1800s and rapidly expanded after World War II.

Some feeling for the economic and legal impact of this decline can be gleaned from Brune's history of the Comanche Springs at Fort Stockton in Pecos County. For thousands of years these large springs, which had a total discharge of 66 cfs in 1899, had served the Comanche and other Indians in the area. In 1859 when Camp Stockton was established, the spring flow was used as its supply. In 1904 it was used to power a gin. From 1875 on, the springs were the basis for an irrigation district which watered 6,200 acres of cropland. By 1947 heavy pumping by adjoining landowners of the aquifer supplying the springs was beginning to take its toll on the flow. In 1954, although the irrigation district sought an injunction to restrain pumping which interfered with the spring flow, the injunction was denied and in March 1961 the springs ceased to flow.

Brune's prognosis for future spring flow in Texas is not optimistic, although recently some concern has been shown for the preservation of these springs for their historic, recreational, and esthetic value.

Elsewhere, where aquifers have a history of pumping, the story is the same. Springs in the Tucson, Arizona area were used by the Papago Indians for irrigation of small fields (Hackenberg, 1974*) until groundwater pumping and arroyo cutting dried them up around the beginning of the twentieth century. In northern Israel, the Na'Aman spring which yielded an average of 43 mcm/yr (million cubic meters/year) during the period 1950-1954, dried up during the summer months of 1959 and 1960 due to extremely low rainfall and pumping that averaged 25 mcm/yr (Mandel and Mero, 1961).

3. b) Vegetation

Vegetation changes associated with a decline in groundwater levels are most often inadvertent, but sometimes purposefully designed. Many people recommend the development of groundwater as a means of preventing its loss through spring flow and streamflow (when it is of no great economic value),[9] being especially adamant about recovering groundwater that would have left the system through transpiration from uneconomic vegetation. Phreatophytes, in particular, have provoked the ire of hydrologists by the amount of water that is "wasted" by them. In the western United States Davis and DeWiest (1966*) put this figure at 25 maf/yr (30 x 10^9 cubic meters). Conover (1961) estimates that for the seven million acres of phreatophytes in California, Arizona, New Mexico, Nevada, Utah, and Colorado, 10-12 maf/yr is lost, a figure approximately equivalent to the flow of the only major source of surface water supply for the area — the Colorado River!

Bryan (1928) appears to be the first to observe and document the changes in plant association with changes in groundwater levels. He notes that the flats of sacaton grass and swampy areas of the tule (bulrushes) which used to cover many of the valley floors in the southwestern United States (and indicated a near-surface groundwater level) were being replaced by dense thickets of phreatophytes, the only vegetation capable of sending its roots to deeper and deeper groundwater levels as they declined from rather complex causes involving arroyo cutting[10] and possibly groundwater development. Since then in many areas, the San Xavier Mission south of Tucson (Matlock, 1976) and the Casa Grande National Monument (Judd, Laughlin, and Guenther, 1971) in central Arizona, for example, groundwater has been lowered beyond the reach of even the phreatophytes, and stark dead mesquite bosques replace former vistas of lush green.

The deliberate clearing of phreatophyte growth to reduce groundwater loss through transpiration raises interesting legal, ecological, and psychological issues. Legally, who has the right to groundwater saved when a farmer undertakes a phreatophyte control project? Martin and Erickson (1976) address this question but only with respect to the right the surface flow phreatophyte clearing would have saved, and found that the phreatophyte clearer, a junior water appropriator, was not entitled to the extra water. The senior water appropriator, a downstream user, was.

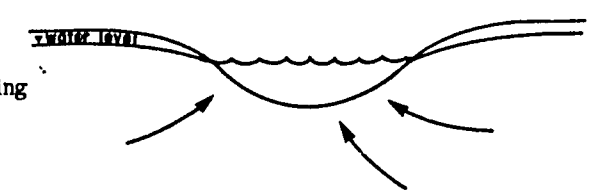
Ecological issues arise in the environmentally-conscious industrialized nations as phreatophyte stands provide a mini-environment that allows many types of plant and animal life to flourish that otherwise could not. But while it is an environment of great ecological value, to residents of the Arid zone its greatest value is psychological. It is not unlikely that the rancher would protest the hydrologist's recommendation to get rid of the only patch of green in hundreds or thousands of square kilometers.

3. c) Streamflow

Closely related to the above two topics is that of the impact of groundwater development on streamflow. There is a fair amount of literature available on this topic with a history of analytical techniques to compute their relationship that dates back to the 1930s (Theis, 1935; Glover and Balmer, 1954; Conover, 1954*; Bittinger, 1964; Jenkins, 1968; and Walton, 1970, for example) indicating a substantial interest in the topic and also the point in time that the less desirable effects of groundwater pumping began surfacing.

For groundwater pumping to affect streamflow, the two must be in hydraulic contact. When they are in contact, two different conditions are possible. When the groundwater level is above the stream level, the stream is being fed by groundwater; it is called an effluent stream (Fig. 2.3A). When the groundwater level is below the stream, an influent stream exists, one which is losing water to groundwater (Fig. 2.3B).

Fig. 2.3A: An effluent stream: Groundwater level is above stream level and is discharging into stream



[9] Ambroggi (1966*) articulates this philosophy.

[10] See Cooke and Reeves (1976*).

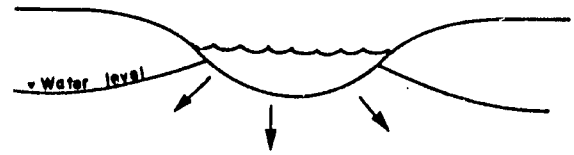


Fig. 2.3B. An influent stream: Groundwater level is below stream and in hydraulic contact. Recharge is occuring through stream channel

Groundwater pumping will affect an effluent streamflow in two ways: It can intercept groundwater which otherwise would have been discharged into the stream even before the cone of depression has extended into the discharge area; and, when the cone does extend to the stream, it will lower the water level and eventually convert the stream from an effluent to an influent state (Davis, 1972).

A pumped well will affect an influent stream only if the cone of depression reaches the stream under conditions where the water table otherwise would be in hydraulic contact with it. The cone, by steepening the gradient, will increase the flow from the stream to the groundwater supply, up to a certain point (Ibid.).

In both conditions the end point is the same: a decrease or total diminishment of streamflow. This has happened quite commonly in parts of the southwestern U. S. where groundwater has a long history of extensive development: southern California, Arizona, and New Mexico.

The same ecological and psychological issues associated with the vegetation changes due to groundwater development are applicable to the decline of streamflow for the two are intimately related. The body of literature relating to legal aspects of pumpage and streamflow decline is much more extensive, for depletion of streamflow is of much greater economic importance than the death of vegetation. Here the basic question is what legal rights do downstream surface water users have to water that is intercepted upstream by induced infiltration to groundwater that formerly reached them as surface flow. The legal rights of an individual in such a case vary depending on the groundwater and surface water codes of the state of residence, for both are often treated legally as unrelated entities (see Chalmers, 1974, and Castleberry, 1975), and the nature of the hydraulic contact between the groundwater and the surface water. Davis (1972) gives a very comprehensive summary of court cases in the U. S. that involve groundwater pumping and streamflow depletion.

Martin and Erickson (1976) also discuss this topic in a more limited case-specific manner. While acknowledging that rules vary from state to state, "... the general rule is that a senior surface appropriator ... is entitled to require junior well owners to stop or curtail their pumping of groundwater tributary to the river if the senior appropriator is not receiving his water."

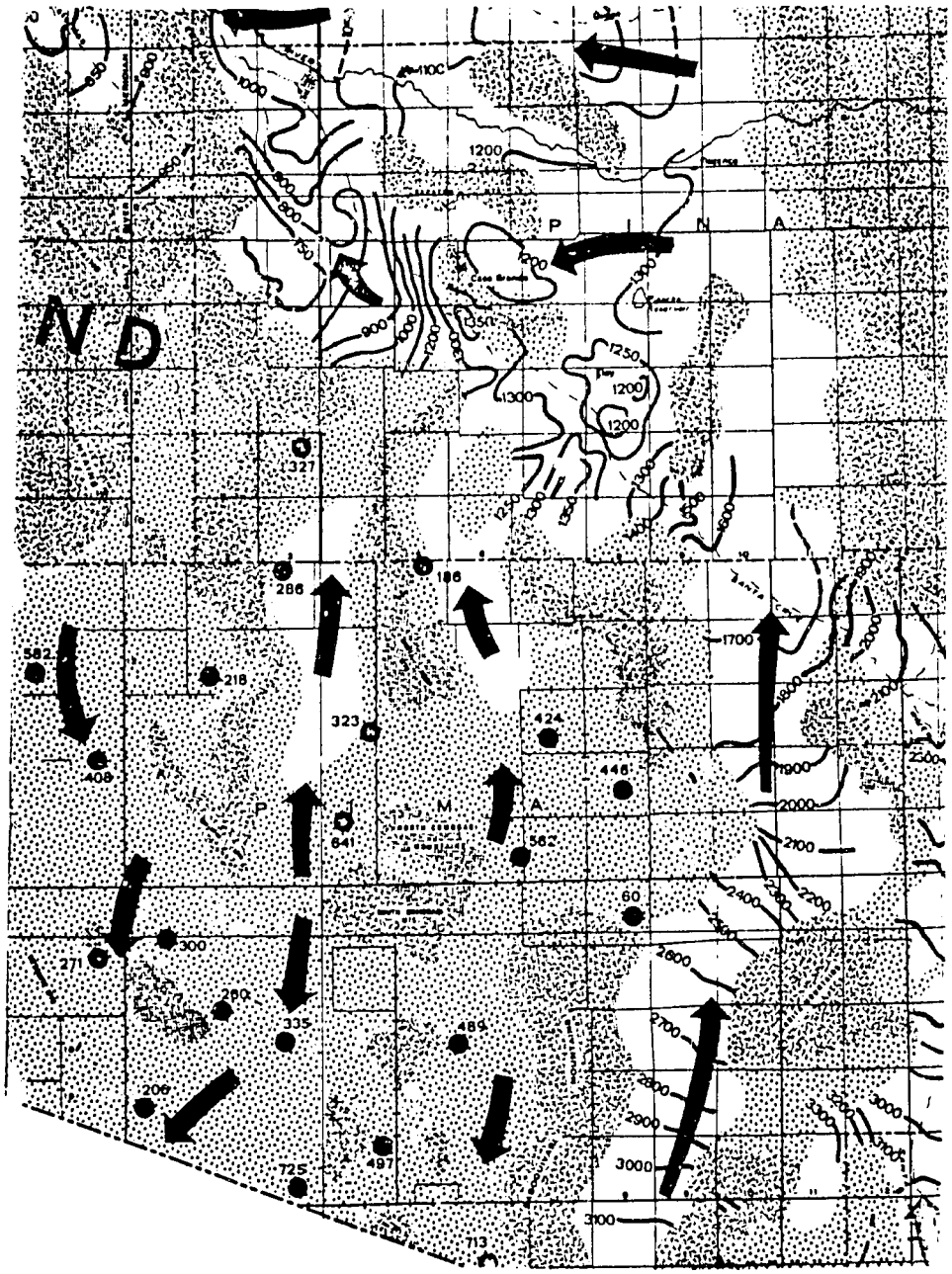
A decline in groundwater quality is an additional point of concern when pumping induces infiltration of chemically polluted stream water. While bacterial pollutants can be filtered out to some extent by sand and gravel, chemical pollutants pose much greater threats to groundwater quality because of the ease with which dissolved chemicals travel through alluvium. There is little published field data to document the degree of this threat (Rahn, 1968).

3. d) Groundwater flow

The most intuitively obvious but visually subtle impact of groundwater development, inseparable from all the impacts due to the response to an aquifer to pumping, is the change in groundwater flow regime. It is often hard to determine the magnitude of the changes in groundwater flow patterns because to do this requires a knowledge of conditions prior to development. In some areas, Tunisia for example, this means going back some 2,000 years (Thomas and Butcher, 1961). Establishing these initial pre-pumping conditions is nevertheless an extremely important part in trying to evaluate future impacts.

Changes in groundwater flow are made via the cone of depression through the steep hydraulic gradient it creates, capturing groundwater that under a gentler hydraulic gradient previously would have flowed elsewhere, discharging as streamflow, springs, vegetation transpiration, or underflow into the next basin. Fig. 2.4 shows the groundwater flow patterns and elevations in a portion of southern Arizona just to the west and northwest of Tucson. The two areas of interest on this figure are the unshaded areas of the Altar-Brawley Wash aquifer system, and the Santa Cruz aquifer system. The Altar-Brawley Wash aquifer begins in the southern portion of the map and flows northward between the Baboquivari, Sierrita,

Fig. 2.4. Groundwater elevations and direction of flow in an area in Southern Arizona
-Arizona Water Commission (1975*)



POTENTIAL WELL PRODUCTION
IN GALLONS PER MINUTE

50 to more than 2,500.

10 to 500.

0 to 10.

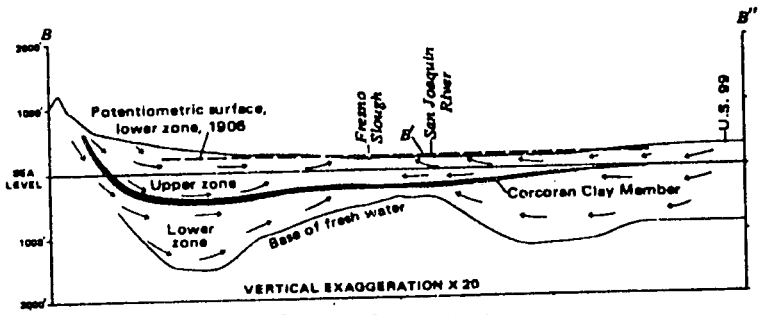
2550 — Water surface elevation contour in feet above mean sea level. Dashed where inferred.

Indicates direction of groundwater flow.

218 — Depth to water in feet below land surface. "d" indicates well dry at indicated depth.

and Tucson mountains to the Santa Cruz. It is a good example of groundwater flow in an undeveloped aquifer. The flow direction is parallel to the main valley stream drainage and the groundwater elevations are perpendicular to it. In contrast is the aquifer system along the Santa Cruz River. Prior to its extensive development the pattern of groundwater flow and surface elevation probably would have looked much like the present Altar-Brawley Wash aquifer system. Instead, what we see now are localized groundwater level highs and lows indicative of the areas of heavy pumping.

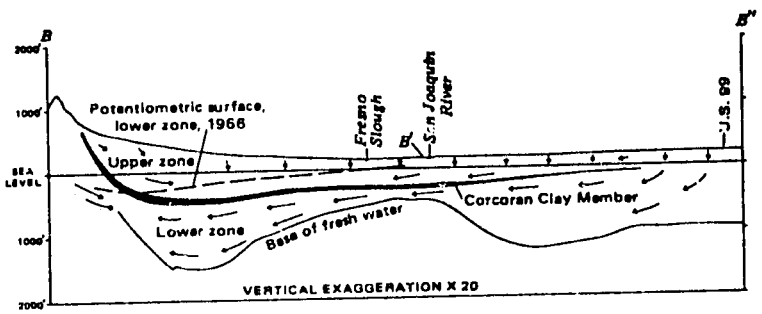
Bull and Miller (1975) provide a good illustration and analysis of changes in groundwater flow due to large-scale agricultural development in the San Joaquin Valley between 1900 and 1966. Fig. 2.5A shows the situation in 1906 prior to large scale groundwater development. There are two important things to note here: first, the position of the lower aquifer's potentiometric surface is above the land surface as much as 20 feet in much of the area. This means that wells drilled into that lower zone, i.e. beneath the Corcoran Clay member, in that area would have been flowing with a head sufficient to raise a column of water up to 20 feet. Second, water in the upper zone, a water table aquifer, was discharging into the Fresno Slough and San Joaquin River which means these were flowing streams.



A. Flow conditions in 1900

Fig. 2.5

-From U.S. Geological Survey, Professional Paper 437-E: "Changes in the Hydrologic Environment Conducive to Subsidence," p. E33



B. Flow conditions in 1966

The situation is considerably different in Fig. 2.5B which shows flow conditions in 1966. The lower aquifer's potentiometric surface is now below sea level in most of the region. Indeed, the last report of a flowing well was in the winter of 1925-1926, by which time 170 wells had tapped the confined system. The large-scale agricultural development of the west side is indicated by the degree of lowering of the potentiometric surface there and by its reversal of gradient since 1906 from east to west. The upper zone water table aquifer no longer discharges into the Fresno Slough or the San Joaquin River and we can assume neither is no longer flowing, or they are now influent rather than effluent streams. Irrigation is now providing recharge to the upper aquifer.

The legal, ecological and psychological aspects of changes in groundwater flow that lead to declines in stream and spring flow, as well as destruction of vegetation, have been discussed in the previous sections. The legal, political, and economic impacts of changes in groundwater flow that lead to declining water levels and pressure heads and reduced well capacities remain to be discussed. The economic aspect of a diminishing groundwater resource and declining water levels will be discussed in depth in a later chapter.

The legal and political issues of changes in groundwater flow systems are truly the most intriguing, controversial, and perhaps unanswerable issues that will face the managers of groundwater in the future. Already these changes have set neighbor against neighbor as water levels, pressure heads, and well capacities have declined. Chalmers (1974) reviews the basic legal framework against which these questions are cast for the southwestern United States, and the United Nations Department of Economic and Social Affairs (1972*) does it on a more general level for the world. Martin and Erickson (1976) discuss specific court cases that illustrate general water law trends for the western U. S.

But the basic philosophical question remains to be answered: What determines an individual's or nation's right to groundwater? The point in time that they began development? The amount of property they own? Their power? Their need? The flow conditions of the aquifer prior to development?

The potential international conflicts that will arise as aquifers that are shared by two or more countries become more intensely developed necessitate addressing ourselves to these questions now. Groundwater development along both sides of the border between Arizona, the U. S., and Mexico particularly in the Yuma, Arizona, area [11], has already indicated a need for the development of some sort of framework from which to proceed. In recognition of this problem, Minute No. 242, approved in 1973 by the United States and Mexico, has proclaimed:

> ... With the objective of avoiding future problems, the United States and Mexico shall consult with each other prior to undertaking any new development of either the surface or the groundwater resources, or undertaking substantial modifications of present developments, in its own territory in the border area that might adversely affect the other country.

And:

> ... Pending the conclusion by the Governments of the United States and Mexico of a comprehensive agreement on groundwater in the border areas, each country shall limit pumping of the groundwaters in its territory within five miles (eight kilometers) of the Arizona-Sonora boundary near San Luis to 160,000 acre-feet (197,358,000 cubic meters) annually.

To meet its obligations under Minute No. 242, the U. S. Congress passed the Colorado River Basin Salinity and Control Act. Title I of the Act provides, among other things, for the establishment of a protective and regulatory groundwater pumping program for the Yuma area at an expected cost of $1.4 million (Rhinehart, 1977*). Solutions to international water problems will not come cheaply nor will they come without a good understanding of the physical parameters and the philosophical considerations.

As yet, no body of literature exists on this topic but research has begun (Michael Bradley and K. James De Cook, oral communication), and interest is growing as it should, for these problems on an international scale promise to crop up more and more in the future as water-short nations scramble to capture one of their more precious resources.

3. e) Drainage

Related to the topic of changes in groundwater flow due to pumping is the topic of groundwater pumping purposefully to lower groundwater levels for alleviation of drainage problems. When groundwater rises to a level even with the surface of the land or just below it, the problem of waterlogging occurs. Because plant roots are deprived of their normal supply of air by the presence of water and are thus unable to grow, the land becomes useless for agricultural production. When the water level lies just a few feet below the surface, capillary action coupled with the intense heat and dryness of the air in Arid areas results in excessive water evaporation. When the water evaporates, the dissolved salts present in the groundwater are left behind to concentrate in the soil giving rise to the problem of salinity. Since most agricultural crops have a limited salt tolerance, the land becomes useless when this salt concentration is surpassed.

---

[11] Holburt (1975*) summarizes the history of the international surface water and groundwater problem here.

The twin problems of waterlogging and salinity can occur due to natural causes, but more commonly they have been the result of surface water irrigation where seepage through unlined canals and infiltration of irrigation water recharges the aquifer, causing water levels to rise. Lowering the water table through pumping from wells is one way of approaching the problem. Indeed, the initiation of groundwater development in some areas, the Salt River Valley in Arizona, for example (Skibitzke el al, 1961), has been in response to waterlogging problems caused by surface water irrigation.

The technique of groundwater development to alleviate the problems of waterlogging and salinity appears to be successful in a number of areas. Hargreaves (1972) reported that the Modesto Irrigation District in California formerly had 45,000 acres (18,000 hectares) under a system of gravity drainage which, when replaced by groundwater pumping, resulted in considerable economic benefits. The annual costs of the drainage system were $148,700; pumping for both irrigation and drainage accomplished the drainage with an annual profit of $158,900.

In the 1950s and 1960s drainage wells were installed in eastern Yuma Valley and in the 1960s in South Gila Valley in southern Arizona to alleviate drainage problems caused by a rise in groundwater from irrigation from surface water sources (Olmstead, Loeltz, and Irelan, 1973*).

In Pakistan, by the late 1950s, waterlogging and salinity had affected roughly five million acres — about 18 percent of the gross area in the Indus Plain and 22 percent of the canal-irrigated cultivated area — and the area of severe problems was increasing at a rate of from 50,000 to 100,000 acres per year. Groundwater development by the public and private sectors, beginning in the late 1950s has been notably successful in land reclamation of waterlogged areas (Mundorff et al, 1976; Malmberg, 1975).

There is some controversy over whether groundwater pumping is the most effective efficient method to relieve waterlogging (for instance, see Dorfman, Revelle, and Thomas, 1965; and Mohammad, 1965A). The latter says that pumping of groundwater is "completely inefficient for drainage alone" and that as a method it can only be used when the water pumped is used for some other purpose, such as irrigation or to satisfy downstream water rights. Indeed, this is what we have seen in the three examples mentioned above: in the Modesto Irrigation District and in Pakistan where water pumped is used for irrigation, and in the Yuma Valley where it is transported to Mexico via canal as part of its legal allotment of surface water from the United States.

3. f). Groundwater Quality

i. Inland aquifers

Groundwater pumping commonly induces water quality changes through the lateral and vertical migration and mixing of groundwater from lenses of different chemical quality within the aquifer (Greenman, Swarzenski, and Bennett, 1967). In the Punjab region of Pakistan, large-scale groundwater development has resulted in a more "chemically homogeneous groundwater body" (Malmberg, 1975) by changing the rate and direction of flow, inducing infiltration from canals, and mixing indigenous waters of different chemical quality (Mundorff et al, 1976). Table 2.1 depicts the water quality changes from 1964 to 1970 in one particular region in the Punjab after groundwater development had begun. Mundorff

Table 2.1: Changes in geochemical type of water from 1964-1970 due to groundwater pumping in an area in the Punjab, Pakistan. -Mundorff et al, 1976

Geochemical type of water	Number of tubewells producing each type of water			
	1964	1966	1968	1970
Calcium bicarbonate	14	21	7	5
Magnesium bicarbonate	39	18	24	17
Sodium bicarbonate	62	80	87	94
Magnesium sulphate	1	--	--	--
Sodium sulphate	9	5	7	6
Calcium chloride	1	1	1	1
Magnesium chloride	2	--	2	--
Sodium chloride	10	13	10	15
Total	138	138	138	138

et al (Ibid.) point out that pumping has induced a marked reduction in the volume of calcium and magnesium bicarbonate type waters since 1964, whereas in the same period it has induced an increase in the sodium bicarbonate type water. The number of wells yielding sodium chloride type waters has also increased somewhat.

Table 2.2 shows the water quality changes occurring in another area in the Punjab due to pumping with respect to the usability of the groundwater without dilution. Between 1963 and 1970, the number of wells yielding water of quality usable without dilution declined by 36, and the number of wells yielding water of hazardous quality rose by 10.

Table 2.2: Changes in water quality usability and dilution requirements from 1963-1970 due to groundwater pumping in an area of the Punjab, Pakistan. -Mundorf et al, 1976

	1963	1969-70
Number of wells yielding water of quality usable without dilution	337	301
Number of wells yielding water of marginal quality requiring 1:1 dilution with high-quality canal water	406	432
Number of wells yielding water of hazardous quality requiring greater canal-water dilution and also chemical soil amendments	336	346
Total	1,079	1,079

The water quality changes in response to pumping are usually for the worse, from a human standpoint, as wells tap the fresher parts of the aquifer and pumping induces flow from areas that are often unusable due to poor quality. The occurrence of saline and brackish water lenses within the aquifer is common in Arid areas, and the changes in quality due to pumping are often severe enough to threaten the productivity of the land the water is used to irrigate, as it has in some areas in New Mexico (Hood, 1963; Hennighausen, 1970), and to prohibit further use of wells, as has happened in some aquifers in Iran (Williams, 1977).

ii. Coastal aquifers

Sea water intrusion into coastal aquifers due to groundwater pumping is a problem common to coastal aquifers in any climatic region. In the Arid zone some of these areas so afflicted include the coast of southern California (Moore and Snyder, 1967; Bookman, 1968; California Department of Water Resources, 1972), the northwestern coast of mainland Mexico (Matlock, Fogel, and Busch, 1966), the coastal plain of Israel (Kahana, 1966*; Schmorak, 1967), the area in northern Iran along the Caspian Sea (Williams, 1977), and Dakar, Senegal (Major, Kirshen, and Lengyel, 1974*).

Two conditions are necessary for sea water intrusion (Moore and Snyder, 1967): the aquifer must be in hydraulic contact with the ocean, and the normal seaward gradient of the groundwater must be flattened or reversed to a landward gradient. This second condition occurs when water levels in the aquifer are lowered to or below the sea level by excessive groundwater pumping, making the pressure head of the sea water greater than that of the fresh water. Figs. 2.6 and 2.7 show schematically the intrusion of sea water under very simple, idealized water table (unconfined) and artesian (confined) aquifer conditions respectively.

The extent and rate of sea water intrusion will depend upon the characteristics of the aquifer recharge, the physical and geographical characteristics of the aquifer, and the rates and spatial distribution of the groundwater pumping (Kashef, 1973). As sea water intrudes, it roughly takes the shape of a wedge with the top edge sloping landward. Fresh water, being lighter than sea water, floats on top. Their interface is not sharp but rather a graded boundary as there is little mixing or diffusing of the two bodies of water.

The deterioration of coastal aquifers through sea water intrusion can be expressed primarily through the change in the chloride ion content. Fresh water aquifers have a chloride ion content of less

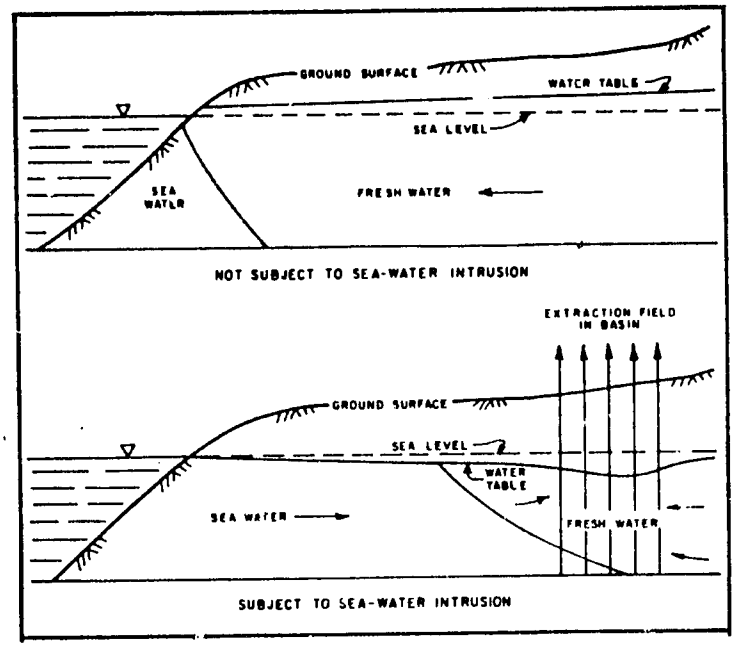


Fig. 2.6 HYDRAULIC CONDITIONS IN AN UNCONFINED AQUIFER IN CONTINUITY WITH THE OCEAN

-California Department of Water Resources (1972), Bulletin 63-6: "Sea-water intrusion: Morro Bay Area, San Luis Obispo County"

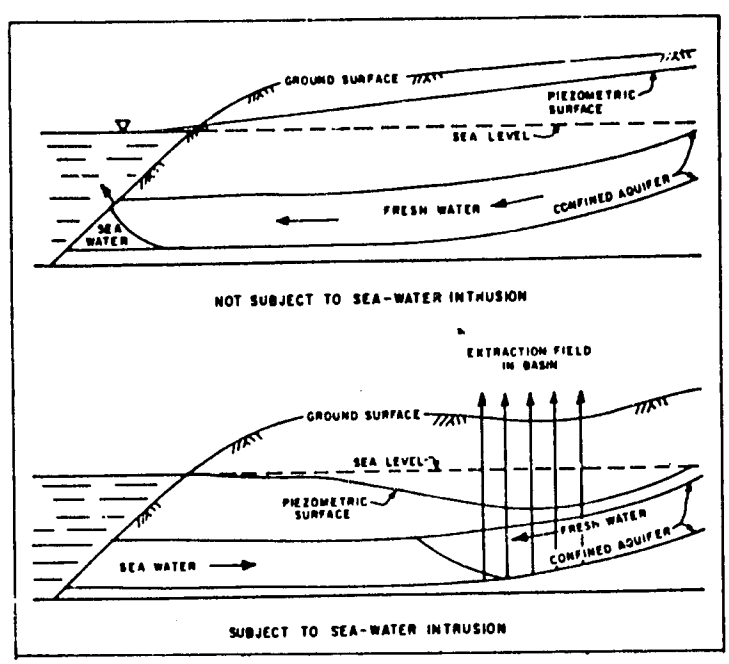


Fig. 2.7 HYDRAULIC CONDITIONS IN A CONFINED AQUIFER IN CONTINUITY WITH THE OCEAN

than 100 parts per million (ppm). As the chloride content increases beyond 100 ppm , the utility of the water decreases. Sea water commonly has 19,000 ppm of cnloride. Because there is little mixing and diffusing of the sea water and the fresh water, once the wedge hits a well, the quality of the water pumped will deteriorate rapidly, often within a period of a few weeks or even days. Tests in southern California have shown a change in pumped water chloride content from a normal 100 ppm to over 1,000 ppm within a single growing season (Moore and Snyder, 1967).

Literature on the problem in California, where sea water has intruded 13 major and minor groundwater basins (Bookman, 1968) illustrates its extent. Here the most serious intrusion has occurred in the West Coast Basin in Los Angeles County and the coastal area of Orange County where pumping has lowered water levels along 39 miles of coastline to as much as 100 feet below sea level less than four miles inland (Ibid.). In Los Angeles County alone, over 80 percent of the water levels in the principal aquifers underlying the 470 square mile coastal plain area are below sea level, and the volume of sea water intrusion is estimated to be 700,000 acre feet (Milne, 1968). In the Salinas Valley sea water intrusion grew from 6,000 af/yr in 1945 to 12,000 af/yr in 1954; by 1966, 8,000 acres of vegetable-producing land overlying the 180-foot aquifer, and 500 acres of vegetable-producing land overlying the 400-foot aquifer had been rendered useless because of groundwater quality deterioration due to sea water intrusion (Moore and Snyder, 1967, 1969). In the Oxnard Basin, Ventura County, sea water was advancing at a rate of 1,200 ft/yr during the early 1960s. By 1965 it had affected 4,900 acres in the Port Hueneme area and 5,700 acres in the Point Mugu area. This represented a degradation of 255,000/af of groundwater in storage and a loss of usable storage capacity of 169,000/af for the Oxnard basin as a whole (Gindler and Holburt, 1969).

Interestingly enough, whereas in California sea water intrusion has been regarded as a truly undesirable impact of groundwater withdrawal, in Israel the inducement of just a small amount of sea water intrusion is seen as a management tool to increase the amount of recoverable groundwater (Kahana, 1966*). By reversing or flattening the normal seaward gradient of groundwater, that which otherwise would have discharged into the ocean can be captured apparently in a quantity that would be larger than that lost through deterioration of water quality.

ii, a) Economic impact

There have been no detailed economic impact studies of sea water intrusion, but there are a few papers that treat the topic somewhat empirically and also theoretically. The basic questions are asked by Gindler and Holburt (1969): "What would be the impact on the economy to the valley if the intrusion problem is not solved? What is the average annual cost of solving the problem?" In trying to answer these questions with respect to the Oxnard Valley in California, they note that while the second question is rather easily answered, the first answer is not so readily obtained. For instance, the cost of solving the problem in the Oxnard Valley would be about $128,000/yr, the cost of a fresh water canal that would provide 16,000 af/yr at an average of $8/af. With respect to the first question, they note that the 500 acres of artichoke-producing land taken out of production due to deterioration of groundwater quality had an average gross income of $300,500.

Gindler and Holburt (1969) suggest another way to approach the problem by determining the value lost as the aquifer no longer can function, due to water quality deterioration, as a water supply, a distribution unit, a storage unit, and an emergency supply. Applying this to the Oxnard Basin, where the average annual dependable groundwater supply is 46,000/af, they found that as a water supply, if the 46,000/af/yr were lost, the economic loss would be $690,000/yr (groundwater being conservatively estimated to be worth $15/af); as a distribution unit, an expenditure of millions of dollars would be required to provide surface distribution facilities to areas now served by groundwater, plus operation and maintenance fees; as a storage unit, were the aquifer to be replaced by surface water reservoirs to control an annual supply of 46,000/af, the cost would be greater than $9 million; and as an emergency supply, it would be difficult to assign a value.

Gindler and Holburt (1969), Moore and Snyder (1967), and Ditwiler (1969) propose several theoretical economic frameworks from which to analyze the problem.

ii, b) Legal and Political Aspects

Legal and political responses to the problem of sea water intrusion due to groundwater pumping vary from country to country. In the Hermosillo, Mexico, area, where in 1964 the groundwater elevation at the center of pumping stood at 56 feet below sea level, the Mexican government decreed pumpage be reduced over a period of four years to counteract sea water intrusion (Matlock, Fogel, and Busch, 1966). The island of Malta forbids pumping of groundwater when there is evidence that salinity is increasing dangerously (Finkel, 1973).

In California, the Porter-Dolwig Ground Water Basin Protection Law, passed in 1961, declares

> ... that the people of the State have a primary interest in the correction and prevention of irreparable damage to, or impaired use of, the ground water basins of this State caused by critical conditions of overdraft, depletion, sea water intrusion or degraded water quality.
>
> The Legislature finds and declares that the greater portion of the water used in this State is stored, regulated, distributed and furnished by its ground water basins, and that such basins are subject to critical conditions of overdraft, depletion, sea water intrusion and degraded water quality causing great detriment to the peace, health, safety and welfare of the people of the State.

It also authorized the California Department of Water Resources to initiate or participate in studies for construction of projects deemed necessary to accomplish the purposes of the act.

The legal and political courses followed by different groundwater basins in California are detailed by Gindler and Holburt (1969) and Bookman (1968).

3. g) Topography

i. Subsidence

Subsidence, lowering of the land surface due to groundwater withdrawal, is one of the more extensively-documented impacts of groundwater resources development. It afflicts many parts of the world: London, England; Honshu, Japan; Mexico City, Mexico; and, in the U. S., the Houston-Galveston, Texas area; the Eloy-Picacho area in central Arizona; the Las Vegas Valley, Nevada; and the Santa Clara and San Joaquin valleys in California (Poland and Davis, 1969). Although subsidence can be caused by a number of other factors such as withdrawal of oil and gas, hydrocompaction of moisture-deficient deposits above the water table, oxidation of organic soils, and tectonism (Lofgren, 1975), excessive groundwater pumpage is one of the major causes of recorded subsidence in the last 50 years, and the following discussion, therefore, refers solely to subsidence from this cause.

Groundwater withdrawal subsidence of the land surface is the result of subsurface compaction of water-yielding deposits due to an increase in effective loading stress caused by a water level decline (Lofgren, 1975). But subsidence does not occur wherever or whenever groundwater is pumped. It is a phenomenon restricted to a specific geologic environment and certain hydrologic conditions. Geologically, subsidence occurs only in late Cenozoic, unconsolidated to semi-consolidated alluvial and lacustrine deposits. Typically the deposit is characterized by an average porosity of 40 percent, an average specific gravity of the grains of 2.7, and, at least in subsiding areas of Texas, central Arizona, central California, and Mexico City, montmorillonite as the dominant clay mineral comprising 60-80 percent of the clay mineral assemblage (Poland, 1969A).

Hydrologically, there must be a net decline in the water table level or artesian head before subsidence will take place. The amount of decline necessary to induce subsidence and the time lag between decline and subsidence varies in time and space with the chemical and physical properties of the deposit, the magnitude and history of the stress, and possibly the type and rate of stress applied (Lofgren and Klausing, 1969). The relationship between water level change, compaction, and subsidence through time and space is illustrated in Figure 2.8.

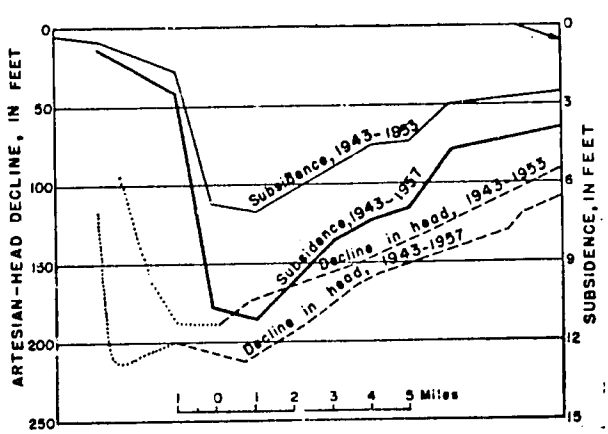


Fig. 2.8: Profiles of land subsidence and artesian head decline (Poland and Davis, 1969). Reprinted from Reviews in Engineering Geology, vol. 2, p. 248, by permission of the Geological Society of America.

Topographically, subsidence occurs in a fairly uniform fashion with a gradually declining rate as one migrates away from the center of heaviest water withdrawl (McCauley and Gum, 1972), producing a bowl-shaped geometry as seen in Figs. 2.9 and 2.10.

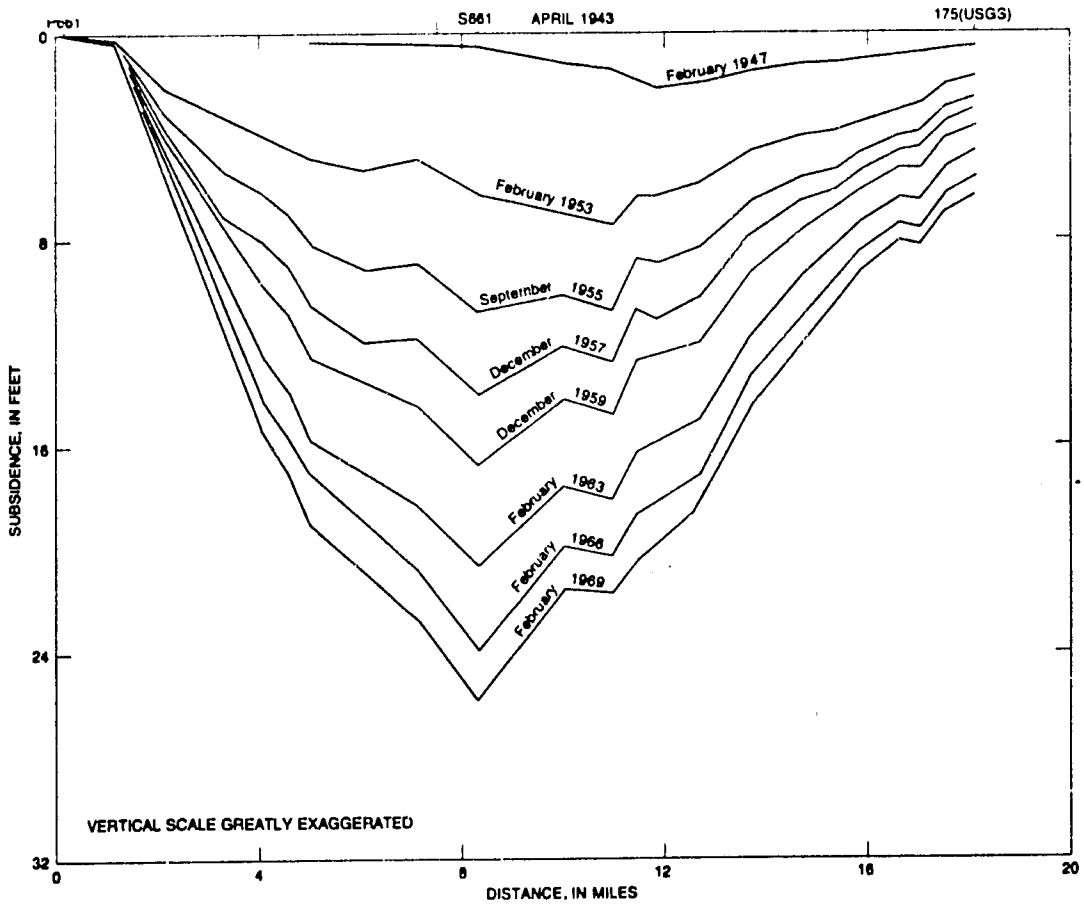


Fig. 2.9: Profiles of subsidence through time in an area in the San Joaquin Valley, California (Poland et al, 1975)

The areal extents, volumes, depth, and rates of subsidence can be documented where precise levelling data are available through a time span. Thus the quantitative understanding of subsidence is limited to areas where topographic surveys have been made over a given time span. The San Joaquin Valley, California, is the site of one of the more intensively studied subsiding areas in the world. By 1970 more than 5,200 square miles had subsided, representing a volume of 15.6 million acre feet (maf); maximum subsidence exceeded 28 feet and the maximum subsidence rate recorded was 1.8 ft/yr (Poland et al, 1975). These are extreme values but demonstrate the magnitude of the physical change that can be imposed on the landscape due to groundwater withdrawal.

ii. Earth Fissures and Faults

Earth fissures are long narrow linear features, usually initially less than 2.5 cm wide and as much as 1.6 m long, which exhibit horizontal separation but no vertical or laterial movement (Schumann and Poland, 1969). Faults are fractures in the Earth's surface along which there has been lateral and/or vertical movement. Both appear to be related either directly or indirectly to subsidence and water level decline [12], but the relationship is not yet understood. Fissures in particular are becoming more numerous

[12] Both have other more common causes, notably tectonism.

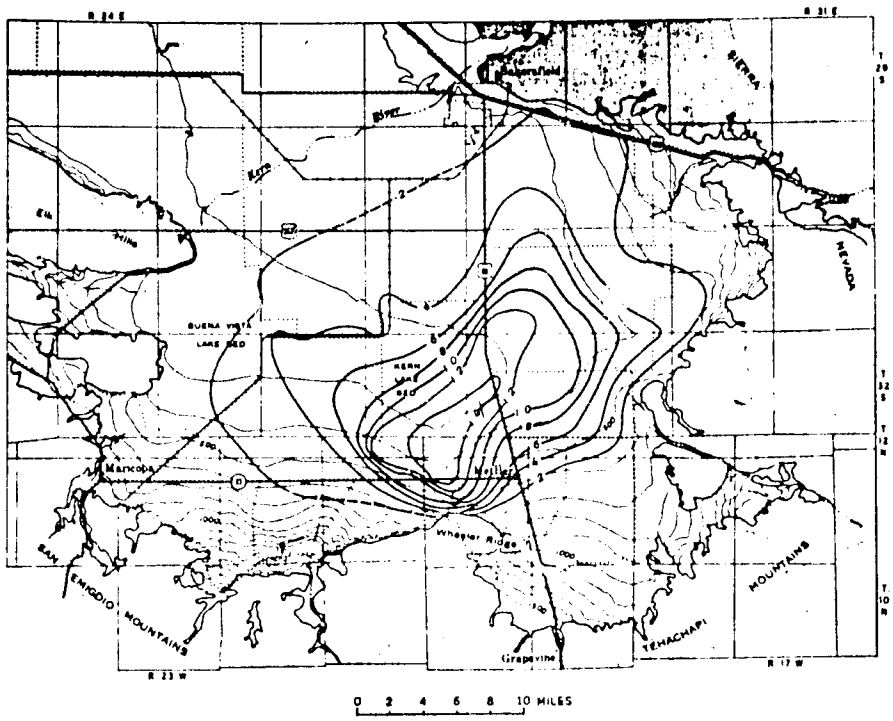


Fig. 2.10: Land subsidence, 1959-1962, in Arvin-Maricopa area of San Joaquin Valley, California. Heavy contours are line of equal subsidence, in feet; shaded areas are deformed rocks bordering the valley (Poland and Davis, 1969). Reprinted from Reviews in Engineering Geology, vol. 2, p. 256, by permission of the Geological Society of America.

and widespread in subsiding areas: more than 75 in central Arizona and 33 in the Las Vegas Valley of Nevada have been reported[13]. They are spectacular features from the air (Fig. 2.11) and the ground (Figs. 2.14-2.16).

Just as dramatic but not nearly so numerous are faults due to groundwater withdrawal. One such fault, the Picacho fault in the Eloy-Picacho area of central Arizona (Fig. 2.11), exhibits .5 m of offset over a distance of 11 km. [14]

iii. Geomorphic Impact

The principal environmental effect of subsidence is to change the gradients of the streams flowing through the area and thus the erosion and sedimentation regimes. Upstream from the affected area the drainage system responds to the fall in local base level caused by subsidence by increasing its gradient, which in turn results in an increased ability to erode and to transport more and larger particles. Entrenchment of the stream channel may occur. Downstream the gradients tend to flatten, reducing the channel's ability to transport water and sediment. The net result of these two factors is an increased deposition of sediments and a decreased ability to conduct flood flows in the affected area and downstream (Roll, 1967).

Earth fissuring and faulting due to groundwater withdrawal also bring about a geomorphic response primarily in the form of gullys. When newly formed fissures transect drainageways, lower base levels are established at the point of intersection which promotes more rapid erosion and gullying upstream (Kam, 1965), as illustrated in Figs. 2.12, 2.13, and 2.16. Gullys may also form upstream from a fissure even where no drainageway previously existed (Fig. 2.16).

---

[13] T. Holzer, Seminar at the University of Arizona, Department of Hydrology, Sept. 29, 1976.

[14] Ibid.

Fig. 2.11. Air photo of the Picacho Fault and some earth cracks (fissures) in the Eloy-Picacho subsidence area, central Arizona. The Picacho Fault is the vegetated linear running from the upper right corner of the picture to the lower left corner. Note the evidence of repair where it crosses Interstate 10.

-Photo courtesy Arizona Department of Transportation, Photogrammetry and Mapping Division

Fig. 2.12

Looking up a gully created when an earth crack opened up during a storm on July 23, 1976, in the Eloy-Picacho subsidence area in Arizona. Photo taken Nov. 20, 1976 from the surface of the old drainage.

-Photo by Bill Daniels

Fig. 2.13

Looking downstream from gully shown in Fig. 2.12, above. Earth crack runs left to right across picture. The original stream channel is preserved in the downstream breached section, just to the right of the man standing.

-Photo by Bill Daniels

Fig. 2.14. Fissure which has intercepted a dirt road.

-Photo by S. J. Keith

Fig. 2.15. Fissure runs top-bottom of picture. Note earth slumping and wasting left of fissure.

-Photo by S.J.Keith

Fig. 2.16.

Fissure runs from middle of lower border of picture to middle of right border. Note dendritic drainage developing up-gradient from crack.

-Photo by S.J.Keith

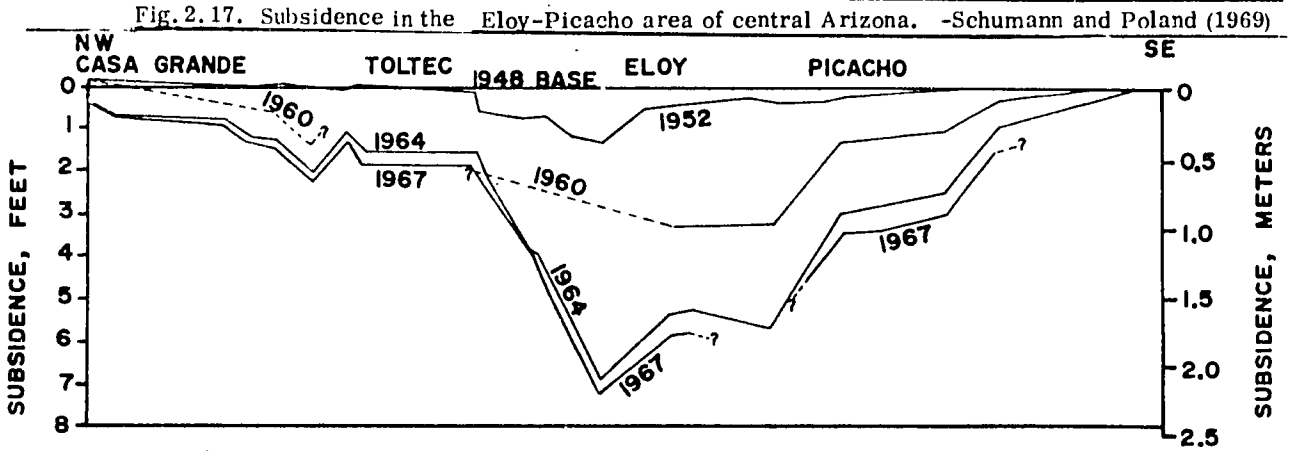
Investigators at the University of Arizona have observed in the Eloy-Picacho area of Arizona the creation overnight of a gully five feet deep, six feet wide, and 25 feet long where an existing drainage was breached by the surface opening of a fissure after (or during) a storm on July 23, 1976[15]. This gully can be seen in Fig. 2.12 and the original stream channel which was intercepted is seen in Fig. 2.13. These photographs, taken on November 20, 1976, depict the changes that have taken place since the gullying was initiated: at least two feet of backfilling of sediments in the gully at its intersection with the fissure; the growth of the gully from its originally observed 25-foot length to a measured 148-foot length, and its original six foot width to a greater than nine-foot width. When the water transmitted by these gullies is not absorbed by the material beneath the fissures, changes in drainage patterns can result (Kam, 1965). The amount of land lost to the use of man by fissuring, faulting, and subsequent gullying can only be speculated on.

iv. Economic Impact

Not so well understood is the economic impact of subsidence, although it is not a topic that has gone unrecognized: Most investigators of the physical aspects of the problem mention it very generally and just peripherally, often as justification for the work they are doing. But while there are few in-depth quantitative studies done on the actual cost of subsidence, fissuring, and faulting due to groundwater withdrawal, what little has been done indicates that the principal problems caused by subsidence are: 1) changes of elevation and gradient of natural drainages and water and sewer transport structures, 2) failure of water wells from compressive rupture of casings due to compaction, and 3) tidal encroachment and fresh water flooding in lowland coastal areas (Poland, 1973). To this list, the problems caused by fissuring and faulting can be added damages resulting from horizontal or vertical movement of the land surface to ditches, highways, railroads, and the like, and damages from loss of land due to erosion and gullying.

The Eloy-Picacho area, Arizona: There are three subsiding areas where the economic impact, to a certain extent, has been quantified: the Eloy-Picacho, Arizona, area, the Santa Clara Valley in California, and the Houston-Galveston, Texas, area. In the Eloy-Picacho area of central Arizona (see Fig. 2.17) McCauley and Gum (1972) and McCauley (1973) set the yearly economic damage due to subsidence at $207,050 during the late 1960s and early 1970s. This is primarily a rural, sparsely-populated region with groundwater-irrigated agriculture as its economic base. Groundwater pumpage was close to 1 maf/yr in the 1960s, up from 64,000 af/yr in 1937 when large scale pumpage began. Greater than 20 cubic kilometers have been removed from the aquifer (Schumann and Poland, 1969), a volume which produced a maximum decline in water level of 61 m and a maximum subsidence of around eight feet, plus numerous fissures (see Figs. 2.12-.16) and at least one fault (see Fig. 2.11).

Fig. 2.17. Subsidence in the Eloy-Picacho area of central Arizona. -Schumann and Poland (1969)



Because of the rural, agricultural nature of the area, damages resulting from subsidence, fissuring, and faulting are primarily agricultural. McCauley (1973) provides the following cost breakdown:

Agricultural damages/year:	$57,250	well repair and maintenance
	10,000	ditch repair and relevelling
	60,000	refilling of fissures
	60,000	field relevelling
	$187,250	total

[15] Oral communication, Michael Carpenter

Transportation damages/year:	$15,500	highway repair and maintenance
	4,300	railroad, bridge, and pipeline repair
	$19,800	Total
	$207,050	Total subsidence, fissuring, and fault-related damages/year

Although this may appear to be a high cost, it is not. If the yearly cost of agricultural damage is added to the cost of the groundwater extracted, the cost of water per acre foot at that time is raised from $13 to $13.19, a minor amount. McCauley (1973) did a benefit-cost analysis of three alternative management policies for this area: do nothing; control pumpage to stabilize subsidence; and import water to lessen groundwater withdrawal to stabilize subsidence. The benefit-cost ratio for controlling pumpage was 0.2; for importing water, 0.03. His conclusion: do nothing.

The Santa Clara Valley, California: Elsewhere the costs of subsidence are not so negligible nor so neglectable. In the Santa Clara Valley just southeast of the San Francisco Bay on the west coast of California, 250 square miles, over half the valley, has been affected by subsidence ranging from one to more than 12 feet (Poland, 1969B). The history of large-scale groundwater development began here in the 1920s with the development of the deep-well turbine pump and the availability of cheap electrical power. The amount of land under groundwater-irrigation jumped from 30 percent of the valley in 1912 to 67 percent in 1920 (Roll, 1967). With urbanization and high crop prices following World War II came greatly increased rates of groundwater withdrawal. Pumpage that had been 40,000 af/yr in 1915 grew to 180,000/yr in 1960 (Poland, 1969B).

In this urban center-agricultural-field mixture of the Santa Clara Valley, the costs of subsidence are expectedly much higher than in Arizona's Eloy-Picacho area, involving not only agricultural but also municipal damage. Flood flow problems have been aggravated where subsidence has flattened or reversed the Bay-ward stream channel gradients. Channels that originally were eight to ten feet deep have become filled with sediment and have had to be enlarged and deepened (Roll, 1967). By 1967 the public cost of constructing levees to protect against saline Bay-water innundation and to provide flood control was estimated to be $6 million (Poland, 1969B). Numerous storm and sanitary sewers have suffered a serious loss of carrying capacity due to flattening gradients, and have had to be replaced or paralleled with new lines at a cost of many millions of dollars (Roll, 1967).

Agricultural costs have been primarily in the form of damage to well fields and have been extremely high. In a survey made by the San Jose Water Works, the percentage of wells damaged due to subsidence was found to be increasing yearly (Roll, 1967). In 1961, 15 of the 25 wells surveyed (66 percent) were damaged; in 1962, 21 of 26 (80 percent); and in 1963, 32 of 33 (97 percent). Half of the valley's 5,000 wells are in the subsiding area. With an assumed damage rate of 80 percent of the wells in the subsiding area (or 2,000 wells) and a cost of $2,000/well repair, Roll (1967) estimated the total cost of repairing wells at $4 million.

Houston-Galveston area in Texas: The Eloy-Picacho area demonstrated the type and magnitude of problems and costs of subsidence in an arid rural agricultural area; the Santa Clara valley illustrated these aspects in an arid, urban-agriculture environment. Next, the economic impact of subsidence in an intensely urbanized-industrialized coastal area, the Houston-Galveston area in Texas, will be discussed. Although not an arid zone, the magnitude of its subsidence problems can be expected in any arid coastal industrial area where groundwater withdrawals are large.

Since 1942, 3,000 square miles in the Houston-Galveston area have been affected by subsidence of up to eight feet due to groundwater withdrawal (Figs. 2.18 and 2.19). The subsiding area, which includes the cities of Houston, Baytown, Galveston, Kemah, Pasadena, Texas City, and other municipalities, fronts the Galveston Bay and Houston Ship Channel, a fact which accounts for most of the damages.

In an excellent study, Warren et al (1974) found most subsidence-related damages due to tidal and freshwater flooding. Tidal-related damages are of two types: temporary innundation of normally dry areas due to storm tides, and permanent flooding of formerly dry land and improvements thereon. The freshwater flooding problems resulted from the changes in stream gradients which aggravate drainage problems during heavy rains and runoff.

Using the results from a survey made in a 300-square mile study area, Warren estimated that the subsidence-related costs since 1943 due to tidal and freshwater flooding were as follows: historical costs, $60.7 million; property losses, $48.9 million; and public costs, greater than $4 million, for a total of $113.6 million. Of this total, $53.2 million was incurred in 1973 principally due to a six-foot storm tide, which has a probability of occurrence in any one year of 20 percent. The projected

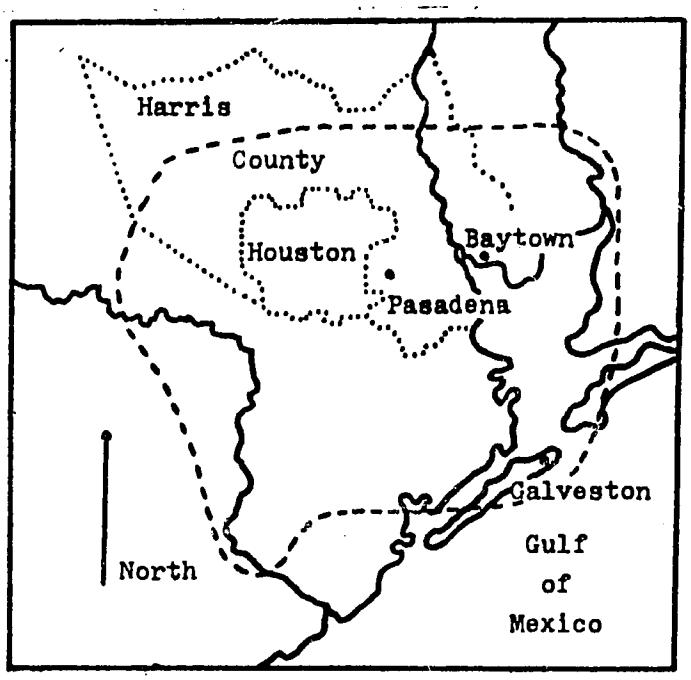


Fig. 2.18. The approximately 3,000 square miles (within dashed line) affected by land surface subsidence in Texas

-Warren et al (1974)

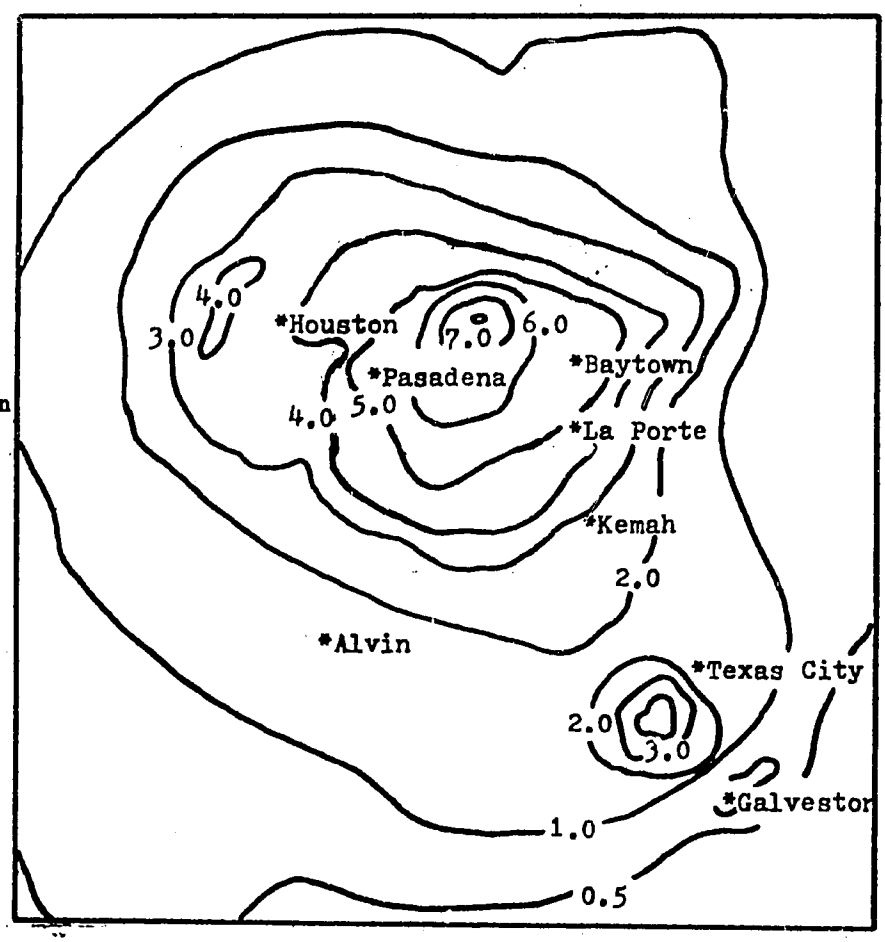


Fig. 2.19. Subsidence of the surface (contour lines in feet) in the area of Houston and Baytown, 1943-1973

estimates of future subsidence-related damages and property losses in 1973 dollars associated with this event are $54.4 million for two more feet of subsidence, and $63.5 million for five more feet.

During the period of this analysis the direct cost of groundwater was 5¢/1,000 gal. With an average yearly groundwater withdrawal of 118,895 million gallons, the total direct cost of groundwater is $5.9 million. Using the time period 1969-1973, Warren calculated that the average yearly cost of subsidence was $14.6 million. Thus the cost of subsidence in this coastal industrial area of Houston-Galveston is indeed high, two and one-half times greater than the direct cost of groundwater.

v. Legal aspects

In view of the magnitude of the economic impact of subsidence due to groundwater withdrawal a logical question to ask is: "What are the legal ramifications?" There is even less written on this topic than there is on the economic impact of subsidence. Steelhammer and Garland (1970) state that the case law has treated the general problem of subsidence as a support problem (the right to subjacent or lateral support) and also as a groundwater problem involving groundwater rights. Compton (1961) asks the interesting questions: "Who is entitled to support? Who is liable? How should damages be apportioned?" Does an individual have the right to the subjacent support of his land provided by groundwater? When that subjacent support is removed by excessive groundwater pumpage by others elsewhere in the groundwater basin, causing subsidence and property damages, can the individual expect any type of recovery, and if so, from whom?

Steelhammer and Garland (1970) provide some of the answers. When subsidence is treated as a support problem, there has been recovery by an adjoining landowner when lateral support has been removed and damages have resulted. But in the cases where subjacent support in the form of groundwater has been removed there has been no recovery.

When subsidence is treated as a groundwater problem, recovery is contingent upon groundwater law of an area. For instance, in countries or states (such as Texas) which have adopted the English doctrine of groundwater rights where the individual has the right to use percolating waters under his land for any purpose without regard to the effect of that use on adjoining land owners, there is no basis for recovery of damages due to groundwater withdrawal-caused subsidence. But where the reasonable use or correlative rights groundwater doctrine rules, the circumstances are weighted to determine if recovery is allowed.

Recently the American Law Institute reversed its position on the right to recovery in its Restatement (Second) of Torts in 1969 (Steelhammer and Garland, 1970). In the Restatement of Torts of 1939, the Institute's position was that "to the extent a person is not liable for withdrawing subterranean water from the land of another, he is not liable for a subsidence of the other's land which is caused by withdrawal." This has been replaced by: "One who is privileged to withdraw subterranean water, oil, minerals or other substances from under the land of another is not for that reason privileged to cause a subsidence of the other's land by such withdrawal."

4. Summary

The large-scale development of desert aquifers has yet to raise the ire of environmentalists and conservationists in a way that a proposal for the construction of a dam or for strip mining can. Yet the preceding discussion has shown that the development of groundwater can have environmental consequences extending far beyond the well site. These environmental impacts, involving deterioration of groundwater quality; subsidence, fissuring, and faulting of the land surface; changes in erosional regimes; the destruction of vegetation; and the decline of spring and streamflows, are of considerable economic, esthetic, psychological, and international importance to the residents of the Arid world. But so is the groundwater that has been withdrawn. One can only assume its benefits far outweigh the environmental costs of its extraction — to the individual pumper at least. But to society as a whole? That is a question that cannot be answered at this point. The important point to be gleaned is that the innocuous-looking modern well, particularly when found in large numbers, is a very effective agent of both surface and subsurface environmental change in Arid lands.

III: SOCIOECONOMIC IMPACTS OF GROUNDWATER DEVELOPMENT

1. Introduction

The previous chapter concentrated on the impact of groundwater development in the aquifer system and at its interface with the social system, the land surface. Here we will explore the system that resides above the aquifer system, the socioeconomic system, and how it is affected by such development. The following discussion is divided into three parts: health impacts, cultural impacts, and economic impacts. This division is not meant to imply that the three are distinct unrelated topics, for they are very intimately entwined and there will not be a change in one without a change in the other. But they are discussed separately for ease and simplicity in presentation. The emphasis is on these impacts in lesser developed areas, for it is here that these impacts can be seen most clearly, and it is here that most of the literature appears. The exception is the section on the impact of declining groundwater levels, and it is significant, perhaps, that this literature comes from the United States.

Unlike a study of the physical impacts of groundwater development, which in most cases are directly the result of groundwater development and could not have happened otherwise, this chapter is really a treatise on the impacts due to the introduction of an assured adequate water supply into an environment of previous water scarcity and risk. As such, it could also be a study of surface water development, but because the setting is the arid zone where surface water is scarce, the development of a dependable source of water in most cases usually means the development of groundwater.

One cautionary note before beginning: There is very little good literature available on these topics. Composite case studies that would be representative of these impacts in general cannot be developed. The specific case studies presented here were done so because the data was available to do so and not because they were representative (although they very well could be). Thus, care should be taken in extrapolating the type and/or magnitude of the impact into other geographical or cultural areas.

2. Health Impacts

Groundwater is usually of high biological purity, and when it is developed as an addition to or alternative for lower sanitary quality surface water it can offer distinct health advantages.[16] In the western world "the need to produce water free from pathogenic organisms was the motivation for drilling wells and the development of groundwater supplies" (Kazmann, 1972*). This is an equally important consideration in developing countries today, where some of the problems of underdevelopment appear to stem from low individual productivity due to poor health. Many of these diseases responsible for poor health are water-related and are particularly abundant and widespread in rural areas of the developing countries. Saunders and Warford (1976*) list some of these diseases in Tab. 3.1. White, Bradley, and White (1972*) group these diseases into four general categories: waterborne diseases, water-washed diseases, water-based diseases, and diseases with water-related vectors. This convenient categorization allows one to see how the development of a protected groundwater source can affect the occurrence of these diseases.

Waterborne diseases, such as cholera and typhoid, are those where water acts only as a passive vehicle for the infecting agent. This happens when certain disease agents gain access to drinking water and survive until the water is ingested. They then become established in the intestine making the consumer ill. To a certain extent these diseases can be prevented by providing a source of water that is inaccessible to the infecting agent.

---

[16] Groundwater, nevertheless, can become polluted due to man's activities. Todd and McNulty (1976) offer the most recent literature review on this topic.

Table 3.1. Water-related diseases. Reprinted from R. J. Saunders and J. J. Warford, Village Water Supply, c1976, by permission of the Johns Hopkins University Press, Baltimore and London.

Group	*Diseases*	*Route leaving man* [a]	*Route entering man* [a]
Waterborne diseases	Cholera	F	O
	Typhoid	F, U	O
	Leptospirosis	U, F	P, O
	Giardiasis	F	O
	Amoebiasis [b]	F	O
	Infectious hepatitis [b]	F	O
Water-washed diseases	Scabies	C	C
	Skin sepsis	C	C
	Yaws	C	C
	Leprosy	N(?)	?
	Lice and typhus	B	B
	Trachoma	C	C
	Conjunctivitis	C	C
	Bacillary dysentery	F	O
	Salmonellosis	F	O
	Enterovirus diarrheas	F	O
	Paratyphoid fever	F	O
	Ascariasis	F	O
	Trichuriasis	F	O
	Whipworm (*Enterobius*)	F	O
	Hookworm (*Ankylostoma*)	F	O, P
Water-based diseases	Urinary schistosomiasis	U	P
	Rectal schistosomiasis	F	P
	Dracunculosis (guinea worm)	C	O
Water-related vectors	Yellow fever	B	B mosquito
	Dengue plus dengue hemorrhagic fever	B	B mosquito
	West-Nile and Rift Valley fever	B	B mosquito
	Arbovirus encephalitides	B	B mosquito
	Bancroftion filariasis	B	B mosquito
	Malaria [c]	B	B mosquito
	Onchocerciasis [c]	B	B *Simulium* fly
	Sleeping sickness [c]	B	B tsetse

a. F = feces
O = oral
U = urine
P = percutaneous
C = cutaneous
B = bite
N = nose
S = sputum

b. though sometimes waterborne, more often water-washed

c. unusual for domestic water to affect these much

Water-washed diseases — leprosy, trachoma, and hookworm, for example — are those which occur where lack of water and poor personal hygiene create conditions favorable for their spread. In these diseases quantity of water rather than quality is a key element in their transmission. Thus, augmenting the available water supply, coupled with the establishment of good personal hygiene habits, is important in reducing their occurrence.

Water-based diseases, such as urinary and rectal schistosomiasis, are those where a necessary part of the life cycle of the infecting agent takes place in an aquatic animal. Infection occurs through repeated exposure to the contaminated water which builds up the load of parasites in the individual, causing ill health.

Diseases with water-related insect vectors, yellow fever and malaria, for example, are those spread by insects that breed in water or bite near it. In both this type of disease and the previous disease type, infection occurs because of behavior patterns that cause the individual to come into contact with the contaminated water or environment surrounding it.

If a groundwater source is developed and adequately protected, there are three ways it potentially could affect the type and occurrence of these water-related diseases. First, by making an additional quantity of water available and thus allowing for the possibility of good personal hygiene habits to be established, it would help eliminate the water-washed diseases that flourish due to lack of water and poor personal hygiene. Second, by providing an alternative source of water of higher biological

quality that is inaccessible to infecting agents, waterborne diseases could be mitigated. Third, by providing a source of water which allows the individual to alter the behavior patterns that previously exposed him to the infected water source and environment, the occurrence of water-based diseases and diseases with water-related insect vectors can be diminished.

When groundwater is developed as an alternative source, these potential benefits are contingent upon three conditions: that the supply is reliable, that the people use the new supply continuously without returning to the contaminated sources, and that other sources of exposure to the same contaminants do not exist simultaneously (Howe, 1976).

This then is how the development and protection of a groundwater source of supply could potentially affect health. Concurrent with this improvement in health, as the conventional wisdom goes, comes more productive people, which translates into desirable economic repercussions from the individual to the community to the state level.

But this is only conventional wisdom, conjecture that has yet to be confirmed or denied by detailed studies. The author could find very little research done on the impact of groundwater on health. In the absence of such studies, one wonders what provides the basis for the glowing reports that accompany a discussion of groundwater and health, such as "a new supply of pure groundwater has frequently led immediately to improved health conditions ..." (United National Water Resources Development Centre, 1960).

Even on the more general topic of the relationship between improved water supplies-health-economy, there is little good data. As Carruthers (1970*) observes: "There is much conviction but few facts on the benefit aspects of water supplies." Saunders and Warford (1976*) also note this and speculate as to why this is so:

> ... Studies of the association between health and water supply and sanitation allowing an accurate prediction of health (and economic) improvements under a variety of circumstances have not been carried out. The primary reasons for this failure are a) that social, economic, and physical conditions very greatly among target populations, precluding accurate generalizations, b) that the sampling problems and problems of uncontrollable exogenous factors greatly increase the probability of significant error in the results, and c) that the water supply-health relationship is highly colinear with a variety of economic, environmental, social, and cultural factors, the effects of which are difficult, if not impossible, to isolate.

Despite this lack of studies, Saunders and Warford (1976*) are able to offer some tentative comments, based on a review of the existing literature, on the relationship between improved rural water supplies, health, and economic growth. Some of these comments are equally applicable to the more specific topic of groundwater development, health, and economic growth, and are summarized here. In the absence of better data, these comments provide some insight into what the potential relationship between groundwater development-health-economic growth may be:

... More and better water and better sanitary facilities are associated with better health. The degree of improvement in health to be expected in any population depends on the level of health in the first place, the economic state, cultural habits, education level, the general physical environment including adequate means of waste disposal, and income level. In rural areas of developing countries where unskilled labor is abundant and greatly underemployed, a rural water supply and sanitation program, designed solely to improve the health of the labor force may increase the extent to which there is an oversupply of labor but have very little impact on economic output and earnings. Water and sanitation-related health improvements are much greater among children than adults. There is some evidence, with regard to waterborne diseases such as typhoid and cholera, that improved sanitation is, in the long run, more effective and less expensive than vaccination. Investing in complementary programs (health education, crop improvement, etc.) will increase the probability that the water supply and sanitation program will have an economic development impact on the area. If in a semiarid region or in areas with a dry season, a village water supply system is designed to include the provision that livestock can be watered and small gardens irrigated, the probability that the system will have a significant economic impact is substantially increased. Although a potable water supply for residents of a village may be a necessary condition for significant economic development, it is clearly not sufficient — even as a catalyst — to achieve this objective. -(after Saunders and Warford, 1976*)

To summarize, we may say that groundwater is generally of high sanitary purity and thus potentially offers distinct health advantages when it is developed and protected as an alternate supply to more highly polluted surface water. But there are little or no studies done on how groundwater development affects health and economic growth because of the complexity of the relationship between the variables. White, Bradley, and White (1972*) provide a grouping of water-related diseases which can be used to infer as to how groundwater development could affect health. Saunders and Warford (1976*) provide some conclusions that can be employed to try to ascertain the relationship between groundwater development, health, and economic development in developing countries.

3. Cultural Impacts: Groundwater Development and Nomadic Pastoralism

****

> There was more than water in these wells. -Fontana (1964*)
>
> You say that the pump will save our women much effort and time. If that happens, what are they going to do with themselves all day long? -Tannous (1944*)
>
> We have not made very much progress ... in tracing the cause-effect relationships by which technological innovation leads to changes in society. -Mesthene (1970*)

****

Water occupies a unique role in culture, as Padfield and Smith (Padfield and Smith (1968*) observe:

> Man's cultural recognition of water is probably as old as man himself. Both in its abundance and its scarcity, water has helped shape the evolution of his institutions, challenged the ingenuity of his technology, and inspired the imagination of his priests and poets. It is no less so in recent history than in ancient times, and water continues its inescapable influence upon human destiny ...

And Bennett (1974) points out the physiological basis for this importance:

> The cultural position of water has an ecological and physiological underpinning one does not find, for example, for air or soil. Air is too pervasive, and soil is used too indirectly. Water, on the other hand, exerts a constant pressure in the form of thirst, one of the basic biological drives underlying human responses.

In the Arid world, this role is magnified. The long history of occupation of the Arid zone belies the successful behavioral and cultural adaptation to water scarcity that enabled individuals and cultures to survive where modern man, sans modern technology, cannot. Language,[17] dress (see Norvelle, 1974*), law (Hills, ed., 1966*), values, patterns of movement and behavior, all have reflected the basic theme of water scarcity. This is particularly so for the occupants of those desolate expanses of land between the exotic rivers (such as the Nile) and the oases: the nomadic pastoralists.

With water playing such a role in culture, and with the uncertainty of water supplies dominating the lives of the desert dweller to such a degree, it is easy to envisage the magnitude of the impact that providing a stable adequate source of water would have on the traditional ways of desert life. When uncertain water supplies become certain the effect can be profound and may substantively alter the relationship of the desert dweller with his environment, initiating both cultural and environmental changes.

It is important to understand cultural attitudes and behavior that concern water and the impacts that may follow when groundwater development is undertaken as a tool of cultural-economic change in developing countries, for cultural responses and subsequent environmental changes are often undesirable. There is a growing body of literature that concerns itself with the cultural aspects of water development (for example, Smith and Padfield, 1969; Smith and Hogg, 1971; and Schramm, 1976), but to the author's knowledge no studies have been done to document the cultural impact of groundwater development. Bennett (1974) surveys the literature on the more general topic of water resources development

---

[17] For instance, the Arabic language has eight terms to denote different degrees of thirst (Hills, ed., 1966*).

and cultural ecology. The bulk of this deals with surface water projects, the impacts of which are not particularly applicable to groundwater development projects. Also, again on the topic of surface water development, James (1974*) discusses some of the social processes instigated by this development.

But environmental repercussions, the result of changes in cultural patterns due to groundwater development, have not escaped the ecological eye of the environmentally-conscious scientific community. Throughout much of the Arid parts of Africa, the Middle East, and southwest Asia, the development of groundwater supplies with modern technology has disrupted traditional patterns of migration of the nomadic pastoralist. With water supplies no longer limited temporally or volumetrically, animal herd sizes were increased as was the time spent at the well site. Overgrazing and desertification ensued, as is discussed earlier in this paper under the topic Livestock Use.

On the Papago Indian Reservation in southern Arizona, it appears that this same sequence of events — groundwater development, cultural change, enlargement of animal herds, and subsequent environmental degradation — occurred during an earlier time period. Fortunately, there is enough anthropological data available on what the cultural aspects of this groundwater development were to develop a case study that illustrates to a certain extent the nature of the cultural impact of groundwater development in traditional nomadic pastoralist societies.

3. i) Groundwater Development and the Papago Indians

Papaguería, three separate but administratively-unified Papago Indian reservations in southern Arizona, covers about 2,700,000 acres of dry desolate land in the heart of Arizona's Sonoran Desert (Fig. 3.1). It is a "strange wonderland, isolated and different," as Meinzer observed (Bryan, 1925*) dominated by broad gently-sloping alluvial basins alternating with NW-SE trending mountain

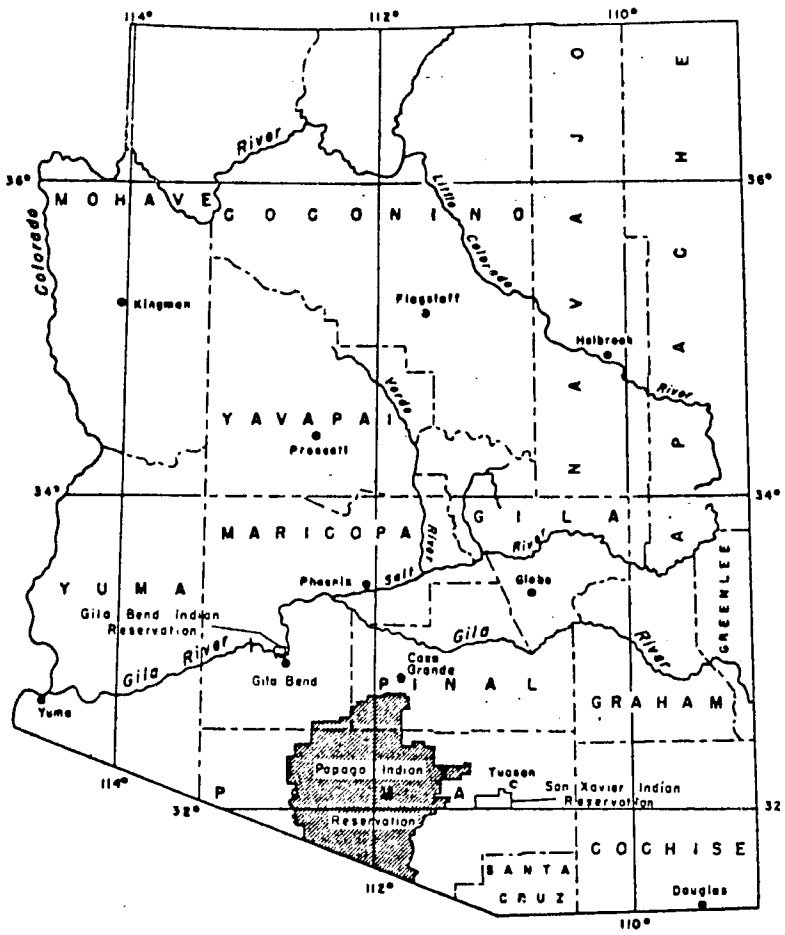


Fig. 3.1

Map of Arizona showing location of the Papago Indian Reservation

-Arizona State Land Department, Water Resources Report 9.

ranges that become lower in elevation and smaller in size from east to west. Precipitation is low, variable, and summer intense, decreasing from east to west. Drainage systems are poorly integrated and ephemeral. Except for the slopes on the higher mountain ranges in the east, where oak, pinyon, and juniper are found, vegetation in Papaguería is mainly of the lower Sonoran life zone, xerophytic, sparse. It is a place where "nearly every striking feature of this special world ... goes back ultimately to the grand fact of dryness — the dryness of the ground, of the air, of the whole sum-total" (Krutch, 1969*). The Papago Indian culture prior to about 1900 also reflected the dryness of this environment. Today, seven-plus decades later, the landforms, the vegetation, the animals, and stream systems still echo the theme of aridity; only the Papago have changed. This is the story of that change: their adaptation to aridity, their cultural response to groundwater development in the late 1800s and early 1900s, and the consequent environmental changes.

Papago Culture Pre-1900: Aboriginal Papago country originally spanned an area probably five times larger than the present reservation system on either side of the International boundary between Arizona and Sonora, Mexico (Fontana, 1976*). Early visitors to the area were able to identify three distinct forms of Papago culture which coincided with different degrees of water availability: the Sand Papago, the two-village people, and the one-village people. Hackenberg (1964*) and Fontana (1974*) discuss these three subcultures.

The Sand Papago occupied the driest portion of Papaguería, the western zone, where rainfall averaged 0 to 5"/yr, and where water supplies were scarcest. They exhibited the simplest form of Papago culture and had the lowest population density. They were the most truly nomadic, depending almost entirely on hunting and gathering for subsistence. None survived into the twentieth century.

The two-village people were intermediate in complexity and population density, living in the central zone where rainfall averaged from 5 to 10"/yr. It is with these people that this study is concerned, and their culture will be discussed further in the following sections.

The one-village people lived in the eastern part of Papago country where the rainfall was the highest ranging from 10 to 15"/yr. At that time there was a perennial supply of surface water in the flowing Santa Cruz River and in springs, in addition to a shallow groundwater supply. These people had the most complex culture, the highest population density, and lived in permanent settlements with an irrigated agriculture subsistence base. In 1874 the San Xavier Indian Reservation was established just south of Tucson, Arizona, for these people.

There are two items of interest to note here. First, the Papago Indians had successfully adapted to their arid environment prior to 1900, an environment that Meinzer claimed had "perhaps taken a larger toll of human life [Anglo Saxon] than any other arid section of the United States," and which was "so waterless and formidable a region that it has been rarely visited by white men" (Bryan, 1925). In this environment the Papago had been living since at least 1540, when the Spanish first came into contact with them, without any grand water resource development schemes, their success based on the fact that they relied on a knowledge of their environment, rather than a control over their environment.

Secondly, one cannot fail to appreciate how the contours of cultural distribution coincide with the contours of water availability (Hackenberg, 1964*); how the population density, the complexity of culture, and the availability of water increases from west to east. To determine why this is no longer the case, we return to the two-village people.

The two-village people occupied the area where the great body of the tribe is now found. They were semi-nomadic, migrating up to 30 miles between the Field village, where they spent the summer, and the Well village, where they spent the winter, following the water supply. The Field village, located in the lowlands usually at the mouth of a canyon, was considered their real home and it was here they grew corn, beans, and squash with rainfall and flashfloods from summer storms, while small herds of cattle and horses grazed on the lush summer grasses. Between rainstorms, water was gathered from charcos, natural or man-made depressions near or in drainage systems that trapped runoff; and shallow wells dug in alluvial stream channels. When the summer storms departed, and these sources of water dried up, the Field village was abandoned for the Well village higher in the mountains, located near a more permanent source of water: a spring, a shallow bedrock well, or a tinaja, a natural rock basin that concentrated rainfall runoff. Here the people and their animals spent the winter until water was again available in the lowlands. When years were particularly dry, the Papago went south into Mexico, or north to their cousins, the Pimas, for wage work. Hackenberg (1964*), Fontana (1964*, 1974*), and Kelly (1974*) provide good discussions of the two-village Papago culture prior to the development of the groundwater resource.

It is from Underhill (1936*) that we add another dimension to this historical note. From a 90-year old Papago woman's words, the relationship between the Papago and their environment, in particular, their water supply, becomes much more vivid and real:

> ... During the summer "we women did not have to fetch water. We could sit in the house and make baskets. Or else we could go off over the land to pick the fine fresh green things ... When the summer was over and the pond dried up Where the Water Whirls Around, we took our babies and went moving over the hills, following the water."
>
> After mealtime "when we were finished we did not wash dishes. How could we with no water? We scooped food out with our knuckles."
>
> Between the summer rains and the winter migration "there was no water at Mesquite Root; no water at all except what fell from the clouds, and I am telling about the month of Pleasant Cold when the rains were long over. Then our pond had dried up. If we wanted to stay in our houses, the girls had to run for water far, far up the hills [18] and across the flat land to a place called Where the Water Whirls Around. That was a low flat place, a good place for corn, and the water ran down to it from all the hills. A big water hole was there full of red mud. Oh yes, our water was always red. It made the corn gruel red. I liked that earth taste in my food. Yes, I liked it."
>
> "Many hours [the girls] had to run, and when they came back every family had two little jars of water to last for the day. But we did not mind. We knew how to use water. We have a word that means thirst-enduring and that is what we were taught to be. Why, our men, when they went off hunting, never drank at all. They thought it was womanish to carry water with them."

In addition to documenting how the traditional migration pattern followed the water supply, this 90-year old Papago woman reveals several aspects of Papago culture that are missing in the more conventional histories: individual methods of water conservation, attitudes and value systems that enabled the culture to adapt to aridity, and the role of women with respect to water.

This then was the state of affairs up to the late 1800s: a culture whose patterns of movement behavior, sustenance, attitudes and values reflected a successful adjustment to the arid landscape surrounding it.

Post-1900 Papago Culture: In 1853 the Gadsden Purchase added the lands south of the Gila River to the United States which resulted in the Papago Indians coming under the jurisdiction of the government of the U. S., and in the Papago country becoming public domain. Gold, silver, and copper were soon discovered in the area, and miners and ranchers moved in, taking over wells, springs, and grazing lands formerly used by the Papago. Not knowing they had legally to claim the land on which they had been living for at least the past three centuries, the Papago people were helpless.

By 1895 cattlemen had sunk wells 600 to 1,000 feet deep and were pumping water from the broad valleys of Papaguería. With the establishment of these new wells, "the history of Papago settlement, land use and occupancy began a new chapter" (Hackenberg, 1964*). But the development of new sources of water for the Papago did not stop here.

In 1917 the Papago Indian reservation was established. In the intervening years between the late 1800s and 1917 the Papago had taken over the wells at the mining sights when the ore ran out and the wells at the ranches when they were abandoned or bought by the Indian Service for the Indians. During the decade following the establishment of the Reservation, the Federal government spent $353,500 mainly on drilling wells and installing pumps. Between 1915 and 1932 the Indian Service bought from non-Indians or drilled 26 wells. Between 1933 and 1942 another 20 were drilled and 40 improved (Fontana, 1964*). During the 1930s, all told 56 wells, 41 masonry storage tanks, 18 dams, and 76 earth-walled tanks (charcos) were built (Kelly, 1974*). From 1953 to 1958, $1,041,181 was expended on stockwater development (Ibid.). In 1971, a $3.6 million range and water development program was funded through the Bureau of Indian Affairs (BIA) (Yoakum, 1973*). By this time there were some 200 wells supplying the Papago with water.

---

[18] Pumpelly (1870*) reported that water sources were as much as six-nine miles from their homes.

There is no question that the development of groundwater on the reservation had a tremendous impact on the Papago culture. Fontana (1964*) sums it up elegantly:

> ... There was more than water in these wells. It is probable that no other technological innovation in Papaguería had such a strong and lasting impact on the desert people as the drilling of deep wells by non-Indians. Their presence made it possible to stay in a single village the year around, and two-village people became one-village folk. Scattered settlements became concentrated in single large villages in valleys where these new wells were drilled, and Papagos who had learned to live with thirst and muddy water became dependent on clear-flowing stuff gushing from iron pipes.
>
> The drilling equipment, the windmills, other kinds of pumps — these were the White man's tools. And now these implements became tied to Indian water, that most basic of all life's necessities. In this way the Papago had to rely on foreign tools and on technological knowledge of Anglo-Americans to maintain an adequate supply of this desert-precious liquid. So for the two-village people there was cultural change in the well; there was satellite status for human beings who heretofore had been their own sun. It is not surprising that from time to time the old people objected to new wells.

More specifically, what were the changes in Papago culture that can be attributed to the groundwater development which began in the late 1800s? Admittedly, there were other forces acting synergistically at this time that undoubtedly affected the Papago, particularly the increasing contact with the White culture. But in which of the changes that are recorded in Papago history can it be said that groundwater development played an important role?

Groundwater development appears to have played a major role in changing the Papago's patterns of settlement and land use, their economic subsistence pattern, and their values, attitudes to and relationship with their environment, each of which will be discussed in the following paragraphs.

With the development of groundwater, the traditional patterns of Papago movement, settlement, and land use began to change. Groundwater development acted as both a scattering and a centralizing influence on the Papago (Xavier, 1974*). By drilling wells in areas that previously were without water and thus were unused, new areas of land were opened up to grazing and settlement, thus scattering population from its traditional centers. By providing a permanent source of water the year around, population centralized around these wells in permanent settlements, and the traditional migration patterns between the Field and Well villages were broken. Today, most of the 70 or more villages on the Reservation are located around a well drilled by the Federal government (Officer and King, 1957*). Consequent with the establishment of these permanent places of residence was the abandonment of old settlements. Hackenberg (1964*) states that between 1900 and 1950, 50 locations were abandoned in the central part of Papaguería, primarily well villages which deep wells in the valley had made obsolete.

In addition to the permanent village, another type of settlement was made possible for the Papago — the ranch (Mark, 1960*). There is no question that contact with White culture had revealed this type of settlement to the Papago and thus played a role in his acquisition of this new type of settlement. But without the deep wells and powerful pumps this settlement would have been impossible. Table 3.2 shows the history of these settlements, and their abrupt increase with the drilling of deep wells.

Table 3.2. Number of Papago Ranch and Grazing Locations Since Prior to 1850

	Total	Newly Founded
Before 1850	0	0
1850-1875	1	1
1876-1900	6	5
1901-1925	19	14
1926-1960	23	12

-Bauer (1971)

The increase in the number of ranches implies another change in Papago life, this one of a more economic nature: the increasing importance of cattle grazing as a method of subsistence. Prior to the groundwater development, cattle were important economically to them, as Fontana (1974*)

documents. But their numbers were kept relatively small (see Table 3.3), under the carrying capacity of the land, by lack of stockwater development (Anonymous, 1948*).

Table 3.3. Estimated Numbers of Livestock

Year	Cattle	Horses & Mules	Source
1876	2,500	45,300*	Fontana, 1974
1877	3,000	4,275	"
1886	3,000	11,000	"
1914	30-50,000	8-10,000	Bauer, 1971
1919	30,000	30,000	"
1939	27,000	18,000	"
1950	13,000	7,000	"
1960	18,000	3,000	"

* - typographical error

Opinions vary as to the degree the Federal government well drilling programs played in the large increases in herd size, and Bauer (1971) summarizes these differences. Nonetheless, there is a strong temporal correlation between the development of deep wells and the growth of cattle herds, at lease initially.

Although water supplies continued to grow into the 1960s, animal numbers did not, the result of a concerted effort by the Federal government to reduce the numbers of animals grazing in Papago country, drought, and disease. Papago country was undergoing the process of desertification. The huge numbers of cattle and horses that grazed here between the early 1900s and the 1950s "existed in the face of a 1944 BIA estimation of carrying capacity of the range of 11,000 cattle and 1,000 horses" (Fontana, 1976*). Between the late 1800s and the present, three to none inches of topsoil were destroyed on over 1,250,000 acres of land (Bauer, 1971), new (and less desirable, from man's standpoint) vegetation associations arose, and deep steep-walled arroyos began eating into the broad gently sloping alluvial basins. Although the causes of this process are no doubt complex [19], many investigators feel that the increased numbers of cattle played a major part (Fontana, 1976*; Bauer, 1971). Groundwater development, which allowed for greater numbers of grazing animals, must share part of the blame for desertification in Papaguería.

The last aspect of change to be discussed, the change in the Papago's values, attitudes to and relationship with their environment, is one not so easily documented. Are men who cannot go for long periods of time without water still considered "womanish"? Is the Papago word for thirst-enduring still used, and is that what they are taught to be? Do they still know how to use water, still "scoop food out with our knuckles" instead of washing dishes with water? Do the women still run for water? If not, how has her status changed? Can a family still live on two little jars of water per day? Is one able to say, as was said in the past, that "no Indians have more closely adapted their habits of life to the character of the region in which they live than the Papagos" (Bryan, 1925*)? If not, what has been lost? And what was it worth?

Today, Papaguería sits like a Third World country within the southern part of the booming state of Arizona. Unemployment is high, per capita income and health standards are low. Ironically, it appears that water has become a problem in a way it never was prior to the modern groundwater period. Pumping water from depths, trucking in water, piping in water, and suing for water [20] have replaced the traditional responses to water scarcity of adaptive behavior and geographic mobility. A successful adaptation to aridity has been replaced by a less-than-successful adaptation to the U. S. government agencies that provide the money and technology for water development (see Bauer, 1971).

While Papaguería has been the scene of many ecological changes in this past century [21], the development of groundwater by modern technology has certainly had one of the greater impacts on the traditional way of Papago life. To quote Fontana (1964*) once again: "There was more than water in these wells ... there was cultural change."

---

[19] See Hastings and Turner (1972*) for a discussion on post-late 1800s change in the Sonoran Desert, and Cook and Reeves (1976*) for a discussion of the gullying in Papaguería.

[20] "Suit could force southern Arizona to buy its water from Papagos, Interior aide says." -Arizona Daily Star, Tucson, October 20, 1976.

[21] Mark (1960*) provides a comprehensive treatment of this topic.

Summary: There is a great void in the literature on the cultural aspects of water resources development in general, and groundwater development in particular. Adaptive behavior to water scarcity on the individual and cultural levels has made possible the historical utilization of the Arid zone. Groundwater development, by providing a stable,assured and adequate source of water where none existed previously has great potential as a tool of cultural change, particularly when undertaken within a nomadic cultural context, because it eliminates the need for adaptive behavior. In the past, this has often led to undesirable cultural responses and subsequent environmental degradation — a fact which only serves to emphasize the need for understanding the cultural aspects of water development.

4. Economic Impacts: Groundwater Development and Irrigated Agriculture

> ... The whole question of occupancy of this arid region [is reduced] to a powerful pump and a properly laid out ditch.
> -Hinton, as quoted in Green (1973)

When contemplating the economic impact of groundwater development, two questions arise: What is the initial impact of development in a developing region? And what is the impact of a diminishing groundwater resource in a developed region? These questions arise naturally, the first because groundwater development (and water resources development in general) is seen as a key to economic development (and all that that implies) in the developing Arid nations; and, in the Arid developed nations, where aquifers have had a longer history of intense development, declining groundwater resources in many cases threaten the economic status quo of a region.

Both of these questions are asked in the context of irrigated agriculture. In the first case, this is because the developing Arid countries are agricultural economies; most groundwater developed is for irrigated agriculture. In the second case, in the Arid regions of the developed nations, irrigated agriculture is the largest volume but the lowest value water user; thus, it is first to go when groundwater supplies run short. And, of course, for both questions hovering in the background is the larger issue of regional economic development.

Basically, there are three levels from which to assess the economic impact of groundwater resource development: 1) the individual and regional, 2) the direct and indirect, and 3) backward and forward linkages. The first two are essentially the same; in other words, the direct economic impact falls on the individual farmer and the indirect impact is felt regionally. The backward and forward linkage effects of groundwater development are a subclass of the indirect effects. Backward linkages are "those effects on economic sectors which provide agricultural inputs (including the labor employed by these sectors)" and forward linkages are "those effects on economic sectors which purchase agricultural output to process into more finished products (including the labor employed by these sectors)" (Kelso, Martin, and Mack, 1973). Essentially, what this means is that groundwater development has an impact that is felt far beyond the field to which the water is initially applied and far beyond the farmer who reaps the economic benefits of the increased yields.

Keeping this in mind, the rest of this chapter addresses separately the two questions asked initially. One further point to be made is that although the central organizing theme of this chapter is "economic impacts," implicit in this term is cultural change, as should become obvious.

4. a) The Economic Impact of the Initial Development of Groundwater in Developing Regions

> ... In general, in [the developing countries], water shortage is the principal limiting factor to economic development. -United Nations (1964)

> ... Hardly another tool of economic progress appeals so deeply to the imagination, to the hopes and to the political consciousness of the emerging nations as water development. -Fritz (in German Foundation for Developing Countries, 1963*)

The role of groundwater in the economic development of undeveloped Arid regions is axiomatic, unfortunately. Recent history of the southwestern United States is replete with examples of desolate desert basins that were made into productive agricultural centers with the provision of groundwater via modern groundwater development technology. Elsewhere, in the developing countries, groundwater holds the promise of the future, such as in the Sahara, where the discovery of large groundwater resources during the late 1950s and early 1960s led to a previously unthinkable optimism about its use (Ambroggi, 1966*; Pallas, 1972*).

A statistical analysis done by Kneese and Zamora (1975*) to test the hypothesis "that climate as such, when other influences are accounted for, tends to affect per capita income negatively" adds extra credence to the belief that groundwater development is a vital element in economic growth of Arid nations. The conclusion, that "the effect of aridity on per capita income is generally negative, the more arid land a country has the more likely it is to have a low per capita income," implies that a remedy for aridity can do much toward alleviating this lowly state. And, of course, the provision of a stable adequate water supply through groundwater development is a prime remedy.

Yet few studies have been done on the economic effects of groundwater development. Peterson (1968) and Hargreaves (1972) offer general discussions on the topic. Peterson develops two general case studies, Israel and Pakistan, in pointing out the economic, social, and managerial benefits of groundwater development. Hargreaves sees groundwater development as a means of promoting irrigation experience and initial infrastructure growth. Green (1973), using historical data, shows how groundwater development on the High Plains of west Texas changed the use of the area from dryfarming and grazing into one of the most productive irrigated agricultural areas in the United States, and how this development affected the population and settlement patterns, the language, the growth of agricultural-related industries, and the general regional economic development. Howe (1976) cites the necessary conditions for water resource development to be successful as a tool for economic development: 1) that water is, in some sense, the real bottleneck to growth, 2) that capital is available for the water system under development and for related, complementary uses, 3) that institutions capable of managing the technology exist, 4) that the technology fits the social structure and values or that the latter will change to accommodate the technology.

Other studies on the economic impact of groundwater development for irrigated agriculture are less empirical and more predictive, using modelling and linear programming techniques to forecast future economic trends as they are related to groundwater resource development and availability for irrigation. Studies done on the High Plains of Colorado where the development of groundwater for irrigation agriculture has occurred only recently (Bowden, 1965; Rohdy et al (1970) are of this nature. A considerable body of literature of this type is also available for the High Plains of west Texas and central Arizona areas, and will be discussed later as it deals more with the impact of a declining groundwater resource than with the initial impact of development, the topic of concern here.

Good empirical studies are the primary requisite to analyzing the economic impact of groundwater, and they are sorely lacking. Fortunately there is one area in the Arid world where enough work has been done to present a case study that provides a beginning to understanding the economic role of groundwater in arid areas: Pakistan.

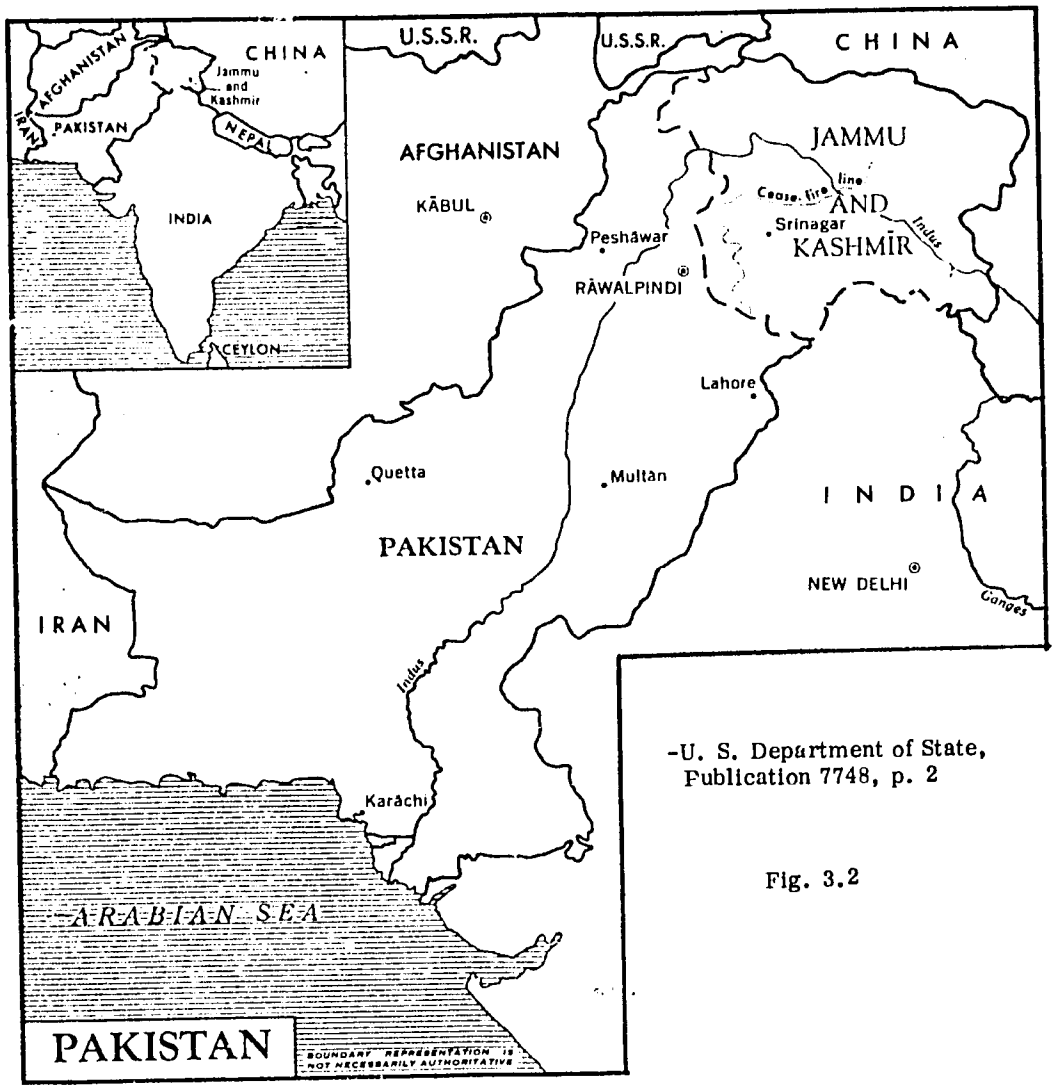
4. a) i. Groundwater as a Catalyst in Economic Development: Pakistan

Situated between Afghanistan to the west and India to the east, Pakistan is essentially an arid country (Fig. 3.2). Precipitation varies from less than eight inches in the lower area below the confluence of the Indus River and its tributaries to over 50 inches in the high northern hills, most of it falling during the summer monsoon.

The Indus River, which drains the high mountains to the north, courses through the central eastern section of Pakistan, discharging some 150 maf/yr. The Indus Basin has a long history of irrigation, going back some 5,000 years (Bokhari, 1975). The modern period of irrigation began under the British in the late 1800s. By 1972, 38,000 miles of canals supplied water to some 25 million acres of land, 60 percent of Pakistan's cultivated acreage (Nulty, 1972). It is the largest continuous irrigated area in the world.

In spite of this, and to a good degree because of this, by the late 1950s crop yields in Pakistan were among the lowest in the world. Human caloric intake was less than 2,000 calories/person/day. Population was growing at a rate of 2.5 to 3 percent/year while food production was rising at about 2 percent (Revelle, 1964). In a nation of farmers, food imports began in the early 1950s and rose steadily thereafter. Waterlogging and salinity problems had caused the abandonment of more than one million acres of land and hundreds of once prosperous villages. Between 50,000 and 100,000 acres of farm land were going out of production annually (Mohammad and Beringer, 1963). The prognosis for the future was indeed grim.

Various attempts, none very successful, had been made over the years to deal with the problems of waterlogging and salinity which began in the 1850s, and are summarized by Mohammad and Beringer (1963) and Bokhari (1975). The turn around began in the late 1950s and early 1960s through a combination of two events, one in the public sector, one in the private sector. In the first, the Pakistan government, under the auspices of the WAPDA (Water and Power Development Authority), launched one



-U. S. Department of State, Publication 7748, p. 2

Fig. 3.2

of its most sustained efforts to control waterlogging and salinity, the establishment of SCARP 1 (Salinity Control and Reclamation Project Number One) in which 2,000 public tubewells were installed in the Rechna Doab in 1959 and 1960 to reclaim waterlogged and saline soil that had recently been taken out of cultivation (Nulty, 1972).

In the private sector, tubewell drilling operations by private contractors on individual initiative in several districts began in earnest in 1958-1959 and 1959-1960. Mohammed (1965A) found this activity to coincide with the first provision of electricity to these districts, which made private tubewell operations both cheap and profitable. In 1960-1961 private drilling operations followed the provision of electricity to two other districts (Nulty, 1972). Soon private tubewell installation began to grow at an astronomical rate (Fig. 3.3). No longer was it confined to districts with electricity, for the economic benefits of installation made even the use of the more expensive energy, diesel fuel, profitable. By 1975 some 120,000 private tubewells were in operation (Bokhari, 1975). During this time public tubewell development also continued, though at a much slower rate; by 1972 some 8,000 had been constructed (Mundorff et al, 1976).

Consequent with this growth in tubewell numbers was the increased availability of irrigation water and the increase in groundwater's contribution to total supply as illustrated in Table 3.3. In 1960 the total supply of irrigation water was approximately 57 maf, of which groundwater supplied less than four percent. By 1969-1970 the total supply had risen to about 80 maf, of which groundwater's share was over 24 percent. Between 1960 and 1970, the total supply increased by about 23 maf. Eighty-four percent of this increase was accounted for by increased groundwater supplies.

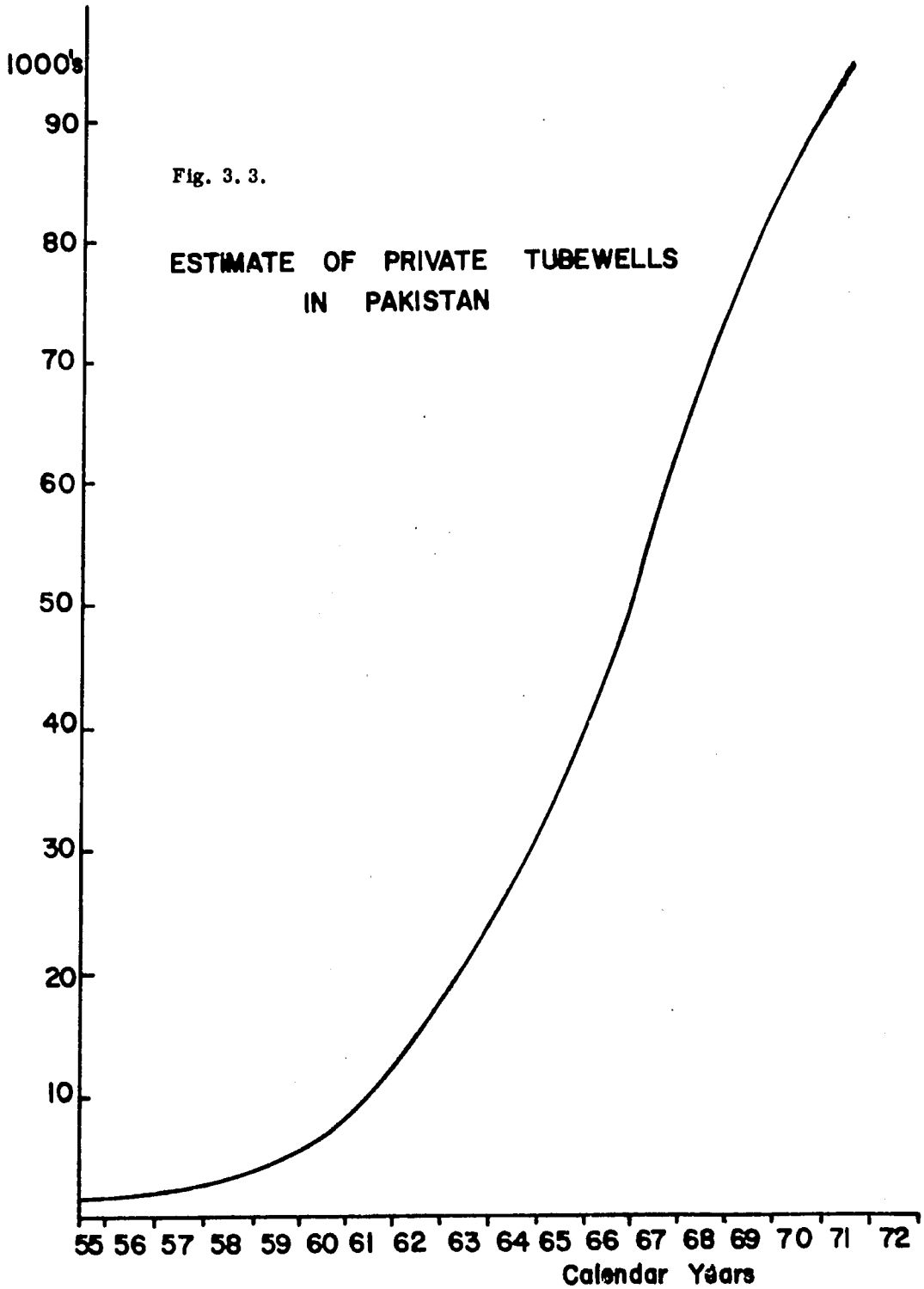


Fig. 3. 3.

ESTIMATE OF PRIVATE TUBEWELLS IN PAKISTAN

-after Eckert (1974*)

Table 3.4. Availability of Irrigation Water, by Source, Pakistan, 1960-1969/70 (maf)
-Nulty (1972)

Source	1960	1965/66	1967/68	1968/69	1969/70
Surface canals	55.0	57.3	58.0	63.8	60.8
Groundwater supplies					
Persian wheels	.50	8.7	n.a.	12.5	14.0
Private tubewells	.80		12.35		
Public tubewells	.90	2.6	3.39	4.6	5.3
Total	57.2	68.6	73.74	80.9	80.1

Tab. 3.5. Cropping Patterns and Cropping Intensities of Tubewell and Nontubewell Farmers, 1967
-Kaneda and Ghaffar (1970)

Crop	Cotton Area		Rice Area		Both Areas	
	Tubewell farmers	Non-tubewell farmers	Tubewell farmers	Non-tubewell farmers	Tubewell farmers	Non-tubewell farmers
	(..... per cent .....)					
Kharif Crops						
Cotton	31.6	19.8	1.8	4.9	19.7	13.9
Rice	4.4	0.6	41.0	17.5	19.1	7.3
Maize	1.3	1.5	0.5	1.0	1.0	1.3
Fruits	4.4	1.3	2.0	0.6	3.4	1.0
Kharif Fodders	14.1	11.9	16.0	13.5	14.9	12.5
Sugarcane	6.0	3.1	7.6	4.8	6.6	3.8
Other kharif crops	0.5	0	0	0	0.3	0
Subtotal Kharif	62.3	38.2	68.9	42.3	65.1	39.8
Rabi Crops						
Wheat	39.1	27.1	42.9	45.5	40.6	34.4
Oil Seeds	1.0	1.0	3.5	[illegible].6	2.0	1.2
Rabi Pulses	1.0	1.3	0.1	0.5	0.6	1.0
Potatoes	0.6	0.1	5.9	2.0	2.8	0.9
Fodders	10.9	8.7	13.5	10.7	11.9	9.5
Other Rabi Crops	1.3	0	2.9	0	2.0	0
Subtotal rabi	53.9	38.3	68.8	60.4	59.9	47.0
Sugarcane	6.0	3.1	7.6	4.8	6.6	3.8
Fruits	4.4	1.3	2.0	0.6	3.4	1.0
Subtotal	10.4	4.4	9.6	5.4	10.0	4.8
Grand Total (Cropping Intensity)	126.6	80.9	147.3	108.1	135.0	90.0

The impact of this large-scale groundwater development was two-fold: physical and economic. The physical aspects of this groundwater development and how it relates to the problems of waterlogging and salinity have been discussed earlier (see section on drainage in Chapter II). The following discussion is concerned with the economic and cultural impacts of this groundwater development, and its individual, regional, and national implications.

Elsewhere, where no source of water supply has existed, groundwater development's major impact is through providing a source. Here, in Pakistan where the Indus River carries 150 maf/yr and the largest continuous irrigation system in the world exists, the development of groundwater had its major impact in not only providing more water, but perhaps more importantly in relieving the farmer from the variability, uncertainty, and seasonality of water supplies. When a farmer develops groundwater, he eliminates the risk associated with surface water canal supplies, a risk that has both climatic and institutional roots. When the monsoon is late, early, small, or not at all, all this is reflected in the flow of the Indus. Institutional roots of risk lie in the fact that the surface water supplies are government controlled and water is distributed on a time basis. When part of the distribution system breaks down during a farmer's allotment time, he simply misses his share. Groundwater development (through the private sector) took the availability of water supply out of the hands of Mother Nature and the Pakistani government. And, quite simply, the results were spectacular.

The following series of tables tells the story numerically. (These tables are from two sources presenting data for different geographical areas and time periods and so are not consistent.) As they speak for themselves, only a few general summary comments will be made here.

Mohammed (1965A), Kaneda and Ghaffar (1970), and Nulty (1972) all discuss the impact of private tubewell development on the agricultural sector in some detail. Mohammed's pioneering study, based on data collected in 1963, determined that water pumped from tubewells enabled the farmer to increase the depth of irrigation for existing crops, increase the intensity of cropping by eliminating fallowing and by double cropping, grow more valuable crops, increase the use of fertilizer, increase the efficiency of bullock use, and increase the output per manual worker.

Kaneda and Ghaffar's study, an extension of Mohammed's study based on a 1967 survey, grouped these "output effects of tubewells" into four categories: effects of tubewells on cropping patterns and cropping intensities, effects of tubewells on crop yields, effects of tubewells on inputs, and effects of tubewells on the productivity of inputs. Table 3.5 presents cropping patterns and intensities of tubewell and non-tubewell farmers for two selected areas. Important things to note are the general increase in the area of crops of tubewell farmers; the increases in acreage in certain types of crops, which Nulty (1972) feels indicates increased emphasis on cash crops; and the increase in cropping intensity of tubewell farmers. Table 3.6 presents the average yield of crops for tubewell and non-tubewell farmers.

Table 3.6. Yields per Acre, with and without Tubewells. -Nulty (1972)

	Rice Area		Cotton Area	
Crop	Without Tubewells	With Tubewells	Without Tubewells	With Tubewells
Rice (cleaned)	14.7	15.1	13.3	18.9[b]
Seed cotton	7.9	5.6	8.8	10.6
Maize	12.3	15.4	12.4	15.3
Sugar cane[c]	30.0	36.0	27.4	35.9
Fruits/vegetables	60.0	70.0	70.0	85.0
Wheat	12.4	13.1	15.0	16.9
Oilseeds	5.0	6.0	6.5	7.8
Gram	7.0	8.0	8.0	9.6

The increase in the inputs (fertilizers, land, labor) due to tubewell development are shown in Tables 3.6 and 3.7. Differences in fertilizer application by tubewell and non-tubewell farmers during 1963-1964 are shown in Table 3.7. The dose of fertilizer for the crops to which it was actually applied was thus about 30 percent higher in the case of tubewell farmers. Table 3.8 shows the increase in land inputs. Kaneda and Ghaffar (1970) attribute the increase in farming unit size to the following factors: cultivation of unused areas, rental of additional land from neighboring non-tubewell farmers or absentee landlords, and the purchasing of additional units of land. Labor inputs are also presented in Table 3.8. Here we see that not only do the tubewell farmers have a longer labor input per day, but also a higher labor input per acre. Increased productivity of inputs is documented by Kaneda and Ghaffar (1970). Through the use of production functions and statistical analyses, they show that the increase in output was more than proportional to the increase in inputs.

Table 3.7. Size of Holding and Fertilizer Use of Tubewell and Nontubewell Farmers, 1963/64, Pakistan. -Nulty (1972)

Entry	Multan and Sahiwal Districts		Gujranwala and Sialkot Districts	
	With tubewell	Without tubewell	With tubewell	Without tubewell
Average area operated per holding (acres)	54.9	28.1	42.0	28.3
Average area cropped per holding (acres)	72.1	27.9	63.5	35.6
Cropping intensity	132%	99%	151%	126%
Lbs. of nitrogen applied per acre	39.6	37.5	42.7	36.6

Table 3.8. Land and Labor Inputs, Tubewell and Nontubewell Farms. -Kaneda and Ghaffar (1970)

	Non-tubewell Farms	Tubewell Farms
Average farm size	30.25 acres	33.60 acres
Average working hours per day:		
Family labor	8.30 hours	10.44 hours
Hired labor	9.20 hours	11.23 hours
Average	8.75 hours	10.84 hours
Labor per acre at average working hours:		
Family labor	0.082 men	0.084 men
Hired labor	0.045 men	0.061 men
Total labor	0.127 men	0.145 men

The income effects of private tubewell development are summarized in Table 3.9. In all cases the net farm income for tubewell farmers is substantially higher than for nontubewell farmers, and ranges from 36 percent to 104 percent, depending on farm size, area, and type of tubewell. While one should not put too much emphasis on the actual numbers in the table, the table is useful in indicating the orders of magnitude of the net increases in farm income due to investment in tubewells.

Nulty (1972) points out that tubewell technology is important for reasons far beyond profit accruing to individual private investors. From here the discussion leaves the topic of the impact of groundwater development through tubewells on the individual level and proceeds to a more regional-national level that has implications for the economic development of this lesser-developed country.

First of all, it is important to note that the studies that provided the data for the preceding series of tables were conducted prior to the dawn of the Green Revolution in Pakistan. In fact, the 1967 study that provided the basis for Kaneda and Ghaffar's (1970) paper just preceded the advent of the Green Revolution. Since 1968 the short-stemmed varieties of wheat and rice, and the greatly increased use of fertilizer have dramatically increased the agricultural output of Pakistan beyond that which the increased supplies of water through tubewell development were able to do. Between 1960 and 1965 gross agricultural production had risen by 30 percent. By 1970 it is thought to have risen another 50 percent (Nulty, 1972). The recent (post-1960) rise in agricultural production in Pakistan is being heralded as "one of the greatest agricultural advances in history" (Nulty, 1972). This phenomenal rate of agricultural growth is largely attributed to additional supplies of irrigation water through tubewell development

Table 3.9. Net Farm Income with and without Tubewells, by Size of Farm, Pakistan (Punjab)

-Nulty (1972)

Farm size (acres)	Number of acres cropped		Cropping Intensity		Net Farm Income			Increase in Net Farm Income with tubewell	
	without tubewell	with tubewell	without tubewell	with tubewell	without tubewell	with tubewell diesel	with tubewell electric	diesel	electric
Rice area									
100+	114	146	114%	146%	11,987	19,647	21,647	64%	81%
100	108	145	106%	145%	10,447	18,216	20,375	74%	95%
50	54	73	108%	145%	10,447	15,778	17,367	51%	66%
25	27	37	108%	145%	5,665	8,228	9,517	45%	68%
12.5	13.5	18.4	108%	147%	2,512	3,410	3,550	36%	41%
Cotton area									
100+	99	131	99%	131%	11,554	15,879	21,139	63%	83%
100	80.8	124.4	81%	124%	7,583	12,178	14,090	61%	86%
50	40.4	62.2	81%	124%	7,583	12,272	13,604	62%	79%
25	20.2	31.1	81%	124%	3,792	6,689	7,741	76%	104%
12.5	10.1	15.8	81%	126%	1,974	3,600	3,654	82%	85%

(Kaneda and Ghaffar, 1970; Nulty, 1972). As Kaneda and Ghaffar note: "There is no question that additional supplies of irrigation water [through tubewell development], which preceded the recent breakthrough in food grain production, played the role of a catalyst in introducing (and rapidly diffusing) the yield-increasing innovations [of the Green Revolution]." Gaitskell (in Nulty, 1972) adds that private tubewell development "enabled farmers to take up with confidence the other ingredients of the Green Revolution, the new fertilizer-tolerant seeds, fertilizer itself, and pest control."

Private tubewell development technology had important ramifications not only in the agricultural sector but outside it as well. Both Nulty (1972) and Child and Kaneda (1975) discuss the linkage effects between the agricultural sector and small-scale tubewell technology industry that has developed in new areas away from the established urban industrial centers. Entire towns and sections of towns have grown and developed around the domestic manufacturing of diesel engines for private tubewells, other tubewell parts, and drilling installation and repair operations (Nulty, 1972). These are usually run as family businesses (Child and Kaneda, 1975). Beside being a good specific example of industrial-agricultural interaction, Child and Kaneda feel that the growth of this industry is important because it occurred spontaneously with no subsidies, no tax concessions, no technical assistance, and no recognition by official agencies. And, more importantly, it has been a vehicle for marshalling indigenous minor savings and investible funds for the development of entrepenurial and managerial talent, for training of skilled and semi-skilled labor and their employment, and for the application of new technology. These authors also point out that of the total employment (7,550) in private small-scale industries producing consumer goods as well as producer goods in the spring of 1969 in the Punjab region, tubewell firms accounted for 6,000.

While discussing employment, another point should be made here that has to do with the increase in productivity of manual labor input on tubewell farms (Table 3.7). Nulty (1972) feels this is especially important because it was a case in which increases in output/worker were not associated with a decrease in the number of workers/cropped acre — a very important relationship in Pakistan where a high rate of population growth has been accompanied by an insufficient rate of labor absorption into non-agricultural sectors. Thus the development of groundwater through private tubewell installation has helped the employment problem in Pakistan both within the agricultural sector by increasing the demand for labor, and the industrial sector through employment in the newly-created tubewell-related light industries. With respect to the first point, however, Nulty notes an ominous trend toward tractor mechanization due to political and economic incentives. Tractor mechanization reduces the labor force 50 percent per farm, on the average. So if tractor mechanization continues its present trend, the initial labor-generating forces in the agricultural sector that accompanied tubewell development will be lost and most likely reversed.

Summary: Groundwater development can be a potent tool of economic development in Arid developing nations. In Pakistan, groundwater development in the private sector eliminated the risk associated with irrigation with erratic surface water supplies. This enabled the farmer to take up the ingredients of the Green Revolution: high yielding variety seeds, pesticides, fertlizers. This in turn led to increased farm revenues, increased agricultural output, increased labor productivity, the creation of an indigenous technology industry, the generation of employment, the development of entreprenurial and managerial skills, the growth of new towns and new parts of older towns, etc. Nulty (1972) cautions that this history may be unique, though Aggarwal (1973*) records much of the same sequence in the Indian Punjab. The Pakistani experience with groundwater development raises another interesting issue: the role of "appropriate technology" in determining the type and magnitude of an impact that groundwater development will have, to be discussed later.

4. b) The Economic Impact of a Diminishing Groundwater Resource

> When the water's gone, I'm leaving, too. -High Plains farmer, as quoted in Boyle, Graves, and Watkins, 1971*

> Water levels are dropping progressively year by year, and unless remedial measures are taken without delay, the present economy will suffer seriously and progressively until an additional water supply can be brought into the area. -Arizona Academy, as quoted in Kelso, Martin, and Mack, 1973

> Water supplies in Arizona will be a restraint on its economy — however, not necessarily a restraint on its growth but on its structure. (Ibid.)

The cry most often heard against groundwater development in Arid lands is that it gives birth to an economy it cannot sustain. Elsewhere, in more humid areas, aquifer recharge rates are much higher and groundwater is, to a certain extent, a renewable resource. In Arid lands, recharge rates are low and erratic, and groundwater is viewed as a stock, or finite resource. Thus development of the aquifer can eventually lead to depletion. This is happening in many of the desert basins in the United States, where groundwater has a history of development dating back to the early 1900s. In a number of these areas, such as central Arizona and the High Plains of west Texas, there are no surface water supplies locally available to be developed to supplement the declining groundwater resource base. Depletion of aquifers in cases such as this has given rise to much concern.

This depletion is most acutely felt by the irrigated agriculture sector for it is the largest volume and lowest value user, which means simply that it needs a great deal of low-priced water to survive. This is in contrast to other sectors of the economy, such as mining and manufacturing, where water produces a high marginal and average value per unit of water for small quantities of water use per unit of output (Fig. 3.4) (Kelso, Martin, and Mack, 1973). Figure 3.5 illustrates how different water users will respond to a change in the price of water. If the price of water rises from 'a' to 'b', the quantity of water used by irrigation is more than cut in half, from BC to B'C', while all other uses are cut only from B to B'. In other words, a small increase in water cost will affect agricultural use greatly and all other uses only slightly. This is why the focus of this discussion on the economic impact of a decreasing groundwater resource is on the irrigated agricultural sector.

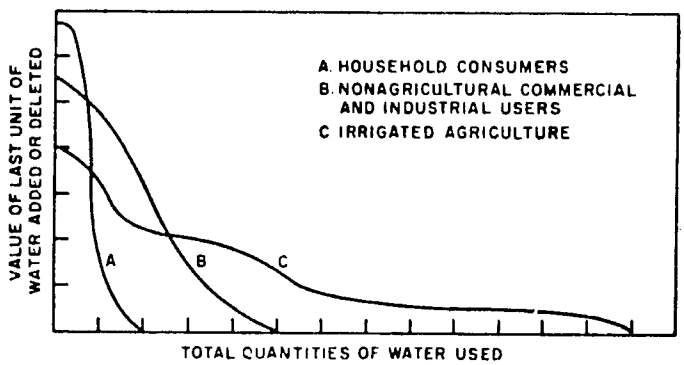
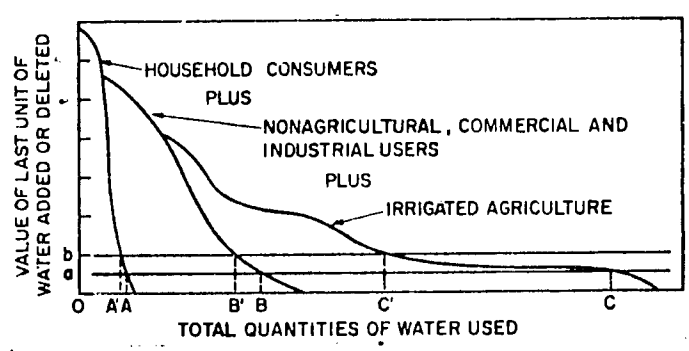


Fig. 3.4. Aggregate marginal demand curves for water for several types of users (hypothetical).

Reproduced by permission from Water Supplies and Economic Growth in an Arid Environment, by Kelso, Martin, and Mack, Tucson: University of Arizona Press, c1973.

Fig. 3.5. Composite aggregate marginal demand curve for water for several types of users (hypothetical).

Reproduced by permission from Water Supplies and Economic Growth in an Arid Environment, by Kelso, Martin, and Mack, Tucson: University of Arizona Press, c1973.



The economic effect of a declining water level on net farm income can be separated into two parts: 1) the increased pumping cost due to increased lift, and 2) the decline in crop yields due to a decline in water resource availability (Sanghi and Klepper, 1976). Of the two, the second effect, that of inadequate supply to maintain high crop yields is the most severe. This is because of the importance of the role of high yields on the net returns from irrigation. Profit is very sensitive to changes in crop yield. A 10 percent change in yield results in a much larger percentage change in profit (Ibid.). Interestingly enough, the problem of increased pumping cost due to increased lift has taken on importance only since the rapid rise in energy costs beginning in 1973. Prior to that, for the period 1891-1967, Martin and Archer (1971) have shown that in Arizona "after 1910, pumping costs per acre-foot per foot of lift in actual dollars declined rapidly until the 1940s and remained relatively constant until 1967," and that total costs per acre-foot of water, adjusted by the implicit price deflator, "fall rapidly between

1939 and 1950, and remain relatively constant thereafter in spite of generally increasing pumping lifts." They and Young (1970) attribute much of this to improved technologies in both the energy industry and in the pumping plants.

The literature available on the impact of a diminishing groundwater resource on irrigated agriculture is both empirical and theoretical and concentrates on two areas where this is a problem: Arizona and the High Plains of west Texas. Green's (1973) fascinating treatment of the history of groundwater development on the High Plains provides some empirical observations on the response of irrigated agriculture to a declining groundwater supply situation: 1) farmers experimented with other crops and increased livestock production, 2) the average irrigated farm grew larger in size, 3) groundwater districts began to play a more aggressive role in conservation, and 4) the farmers began to look elsewhere for water. Green reports other telling signs of a declining groundwater resource. The amount of irrigated acreage fell while the number of irrigation wells increased, indicating 1) an effort to obtain more water to augment supplies from older wells or to replace depleted wells, and 2) the decrease in the number of acres irrigated per well. Well yields declined. In 1963 one farmer reported his wells pumped 75 percent as much as they did three years earlier. The average value per acre declined in some places as much as five percent in two years.

With signs like this no fortune teller was needed to predict the future. Boyle, Graves, and Watkins (1971*) sum up what was felt to be the only possible conclusion to the era of groundwater development: "The collapse of irrigated agriculture (with a decline in groundwater) will create some noble ghost communities for the thriving towns and cities of the Texas High Plains — Lubbock, Plainview, Amarillo — all at bottom dependent for their health on the crop production made possible by crop irrigation."

In recognition of the need to predict future responses to a declining groundwater resource in order to provide data for the development of water policies now to prevent potential catastrophies such as just mentioned, many studies have been undertaken in both Arizona and Texas. Using modelling and linear programming techniques, the impact of a declining groundwater resource upon the individual farmer and the region has been predicted (for example, in Arizona see Burdak, 1970; Hock, 1973; and Stults, 1968; in Texas, see Grubb, 1966; Hughes and Magee, 1960; Lacewell, Jones, and Osborn, 1976; and Williford, Beattie, and Lacewell, 1976).

While the limiting assumptions of these studies (for example, in Osborne, Holloway, and Walker, 1972, tenure patterns, size of farms, consumption functions, prices, government agricultural programs, and technology remain constant) make a discussion of the quantitative aspects of these studies pointless, a qualitative composite profile can be drawn to illustrate the general drift of the findings.

For the farmer, the impact of a declining groundwater resource will be expressed through a combination of some of the following responses: a decline in water pumped, a decrease in irrigated acreage, an increase in farm size, an increase in dryfarm production, a decline in low marginal value crops, and a decline in agricultural output, cost of production, and total revenue. It is felt that this will be translated regionally into a decline of land values , a decrease in population, a decrease in taxes collected, a decline in community expenditures and services, and a decline in the economic activity of the backward and forward linkage industries. Lacewell, Jones, and Osborn (1976) after a summary of the literature on this topic in Texas concluded "that reduced annual withdrawals of groundwater for irrigating agricultural crops due to a progressively declining water supply will exert significant downward pressure on the economy of the region. The reduced agricultural output will be reflected throughout the region in terms of population, employment and gross output of non-agricultural sectors."

Grubb (1966) feels that community, state, and national economic interests of a large magnitude are at stake with the decline in irrigated agriculture on the High Plains of Texas. Indeed, the general trend of most of the literature has been to establish irrigated agriculture's economic importance and then to conclude that it must be maintained, through surface water importation schemes. As there is no water in west Texas to import, and as the east Texans will not part with their water, the boldest and most acceptable plan (to Texans, at least) has been that to import water from the Mississippi River over at least 1,000 miles across Louisiana and eastern and central Texas at an estimated cost of $20 billion. In Arizona, a water-importation scheme from the Colorado River (the Central Arizona Project) has already begun construction.

To this point, the literature coming out of Texas and Arizona has been in general agreement as to what will be the future impact of a declining groundwater resource on the irrigated agriculture sector. However, in the assessment of the impact of a diminishing water resource on regional economic growth and on the public policies that must be established to deal with this problem, there is a divergence. This divergent viewpoint is expressed by Young and Martin (1967), Martin and Young (1969), Young (1970), and summarized most eloquently and forcefully by Kelso, Martin, and Mack (1973).

Very simply stated, the difference between the two approaches is this: Most literature dealing with the problem takes a static approach to the role of water in economic growth, the Arizonans mentioned above take a dynamic approach. In Texas, the economic status quo is threatened by the decline of irrigated agricultural output due to a declining groundwater resource. A decline in irrigated agriculture's output implicitly means a general downward economic trend for the region. Therefore more water is necessary to maintain the role of irrigated agriculture in the economy. This is the thinking of those who take a static approach to the role of water in economic growth.

The Arizonans instead take an historical approach and emphasize the changing role of water in the economic growth of an arid economy.

Kelso, Martin, and Mack (1973) explain this as such. Young developing economies are primarily based on the exploitation of natural resources, namely minerals, forage, and land and water for irrigation agriculture. As economic development progresses, the incomes received from these sources become relatively less important to the nation's total economy, though the total amount may remain almost constant. The relative importance of these resource-based industries declines because other sources of income grow so much more rapidly. This changing importance of resource-based industries is a characteristic of economic growth wherever it is observed.

Now, different economic sectors have greatly different demands for water per unit of output or income and in the aggregate, as is illustrated in Figures 3.4 and 3.5. Because of these different demands, growth of the economy is not followed by a proportional growth in total water demand (except in the unlikely circumstance that all economic sectors grow in similar proportions). Data from Arizona illustrate this.

Figure 3.6 shows the growth in total personal income from all sources in Arizona between 1929 and 1970. A comparison with Fig. 3.7 verifies that the growth in water consumption was much less than proportionate. Figures 3.8 and 3.9 illustrate the changing importance of the resource-based industries in the total economy. Very apparent is the degree to which the structure of the economy has changed with attendant large increases in income and relatively small increases in water use.

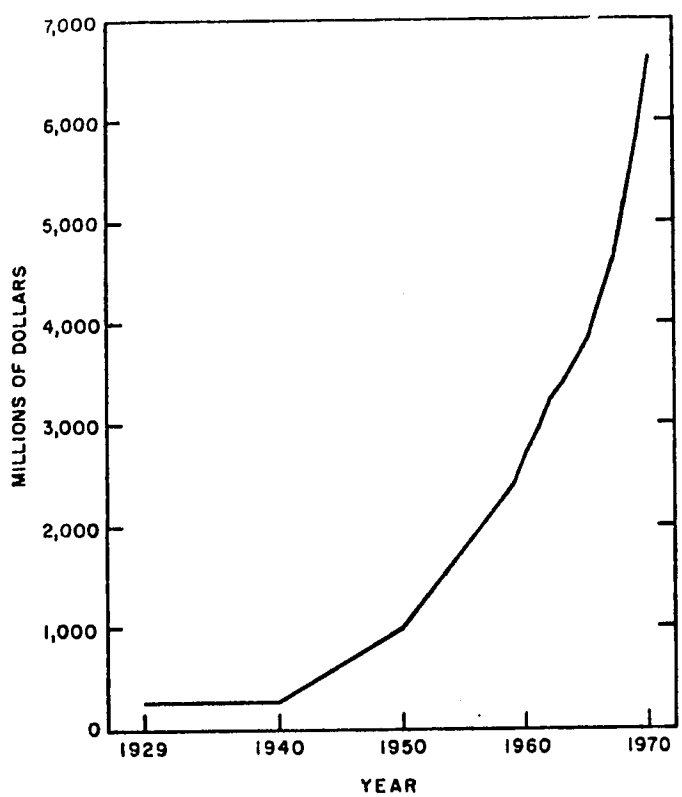
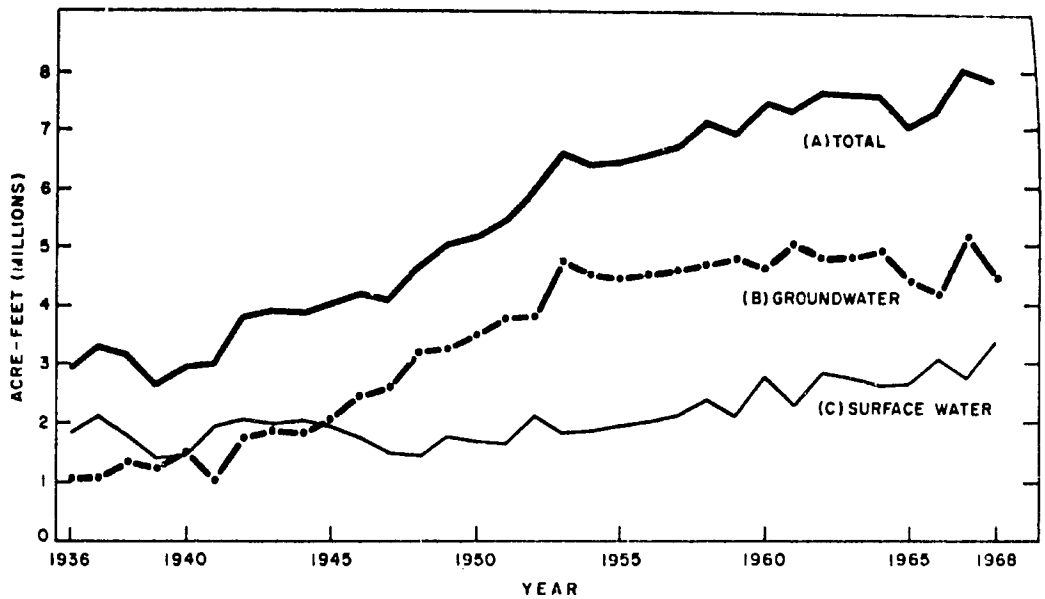


Fig. 3.6. Total personal income from all sources, Arizona, 1929-1970, in dollars of current purchasing power.

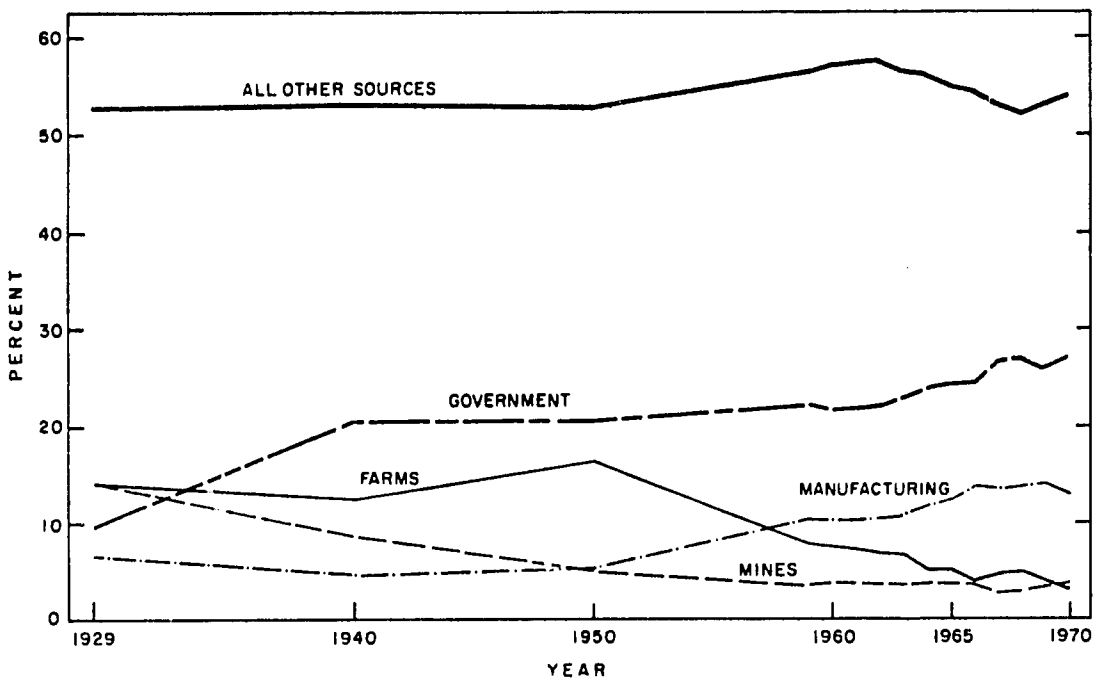
Reproduced by permission from Water Supplies and Economic Growth in an Arid Environment, by Kelso, Martin, and Mack, Tucson: University of Arizona Press, c1973.

Fig. 3. 7. Water Use in Arizona, 1936-1968.



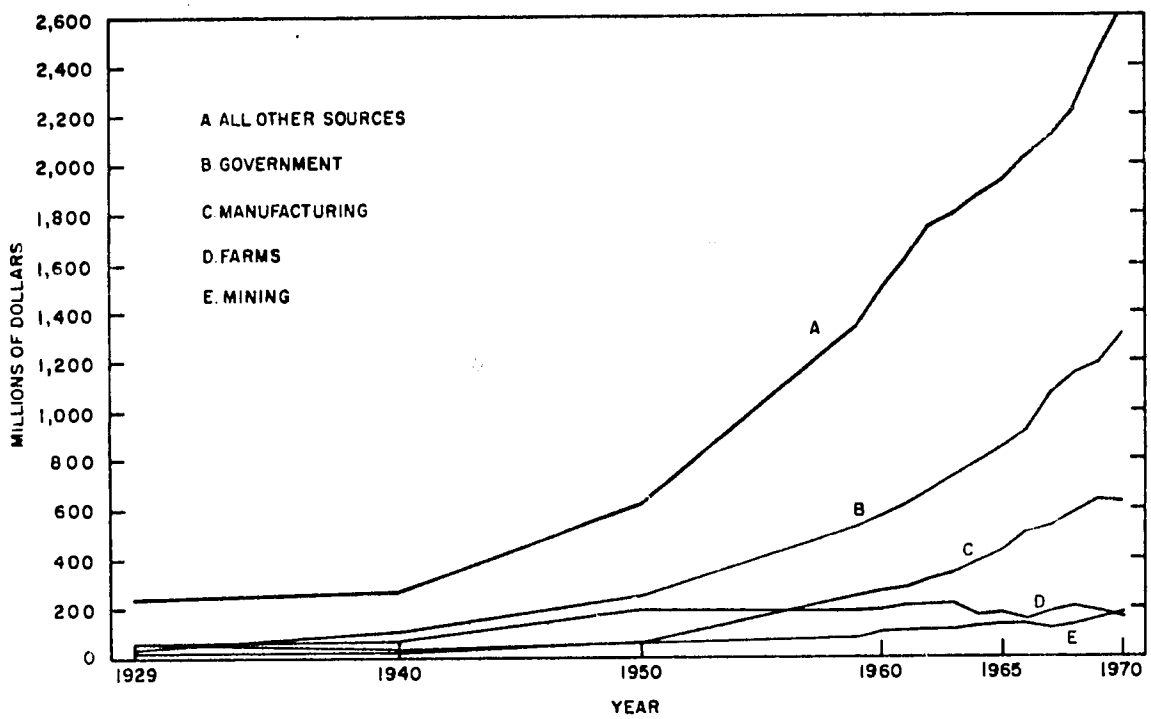
Reproduced by permission from Water Supplies and Economic Growth in an Arid Environment, by Kelso, Martin, and Mack, Tucson: University of Arizona Press, c1973.

Fig. 3.8. Percentage of Personal Income by Broad Source, Arizona, 1929-1970.



Reproduced by permission from Water Supplies and Economic Growth in an Arid Environment, by Kelso, Martin, and Mack, Tucson: University of Arizona Press,c1973.

Fig. 3.9. Personal income by broad source, Arizona, 1929-1970, in dollars of constant purchasing power (1957-1959 = 100).



Reproduced by permission from Water Supplies and Economic Growth in an Arid Environment, by Kelso, Martin, and Mack, Tucson: University of Arizona Press, c1973.

Table 3.9 summarizes these changes. Kelso, Martin, and Mack's (1973) observations on this table point out its significance:

> ... Between 1940 and the early 1950s when irrigated crop acreage increased significantly, total income from irrigated agriculture was equaled or surpassed only by government and "all other sources," and population increased by less than one-half million, total water diversions and pumpage increased by about 3.5 million acre-feet, and total income increased by 669 million dollars.
>
> But, between 1953 and 1968, when the increase in total state income took place almost wholly in the nonagricultural sectors and net incomes increased by 3,088 million dollars, together with a population increase of 845,000 people, water diversions and pumpage increased by only 1.27 million acre-feet.
>
> These data underscore a significant consideration in analyzing the relation between water supplies and economic growth in an arid economy, namely, the importance of the changing structure of an economy as a means for meeting the threat of water shortage as a restraint on growth.

These observations led Kelso, Martin, and Mack (1973) to ask the following questions:

> ... To what degree can or might the problem of water shortage as a restraint on growth be circumvented by changing the structure of the Arizona economy? And, stemming from this question, what are the prospects that the economy will, responding to ordinary market processes, "automatically" change its structure in the desired directions? And, do existing institutions facilitate or hinder such "automatic" changes in economic structure? Or, if purposive policy actions by the state can be used to change the supply of water available, what might be the purposive policy actions it could use to change the demand for water without adversely affecting, even, possibly, favorably affecting income creation and economic growth of the state?

Table 3.10. Changing structure of the Arizona Economy Related to Water Diversions and Pumpage

Factor	1940 Amounts	Changes from 1940 to early 1950s	Changes from early 1950s to 1968
Water (acre-feet annually)	2,954,000	+ 3,579,000	+ 1,266,000
Irrigated acres	665,000	+ 635,000	- 96,000
State income (million $/yr)*			
Agriculture	66	+ 129	+ 5
Mines	45	+ 14	+ 66
Manufacturing	25	+ 37	+ 518
Government	106	+ 139	+ 899
All other sources	272	+ 350	+ 1,600
Total	514	+ 669	+ 3,088
Population (number)	499,261	+ 395,000	+ 845,000

* Incomes are in dollars of constant purchasing power (1957-59 = 100)

Reproduced by permission from Water Supplies and Economic Growth in an Arid Environment, by Kelso, Martin, and Mack, Tucson: University of Arizona Press, c1973.

Their conclusions: "... Water supplies in Arizona will be a restraint on its economy — however, not necessarily a restraint on its growth but on its structure."

The public policy implications?

> ... the Arizona water problem is more a problem of the lack of man-made institutions (policies) for developing and transferring water than a problem of physically short supplies. At least, the problem can be resolved more cheaply for many years to come if it is approached through institutional (policy) reform relating to water transfer rather than through development and/or importation of additional water supplies. The water problem in Arizona is a "man-problem" rather than a "nature-problem."

Summary: Technological advances have, to a certain extent, partially offset the impact of a declining groundwater resource to the irrigated agricultural sector. Certain other adjustments to increasing water scarcity are inevitable: a declining groundwater resource threatens the economic status quo of irrigated agriculture in arid regions. The traditional approach to this problem has been the promotion of surface water importation schemes to maintain the health of the irrigated agricultural sector, a health that is considered necessary for the regional economic growth. This approach is being challenged by data that illustrate the changing economic role of the irrigated agricultural sector in economic development and that questions the economic necessity of its maintenance. Thus, while a declining groundwater resource base does threaten the existence of irrigated agriculture, it need not necessarily threaten future regional economic growth.

Underlying this discussion has been the unspoken issue of water supplies: irrigated agriculture, food production, population growth. There are those who argue that the decline in groundwater supplies which threatens the irrigated agricultural sector threatens world health:

> "... So the decline in underground water supplies poses a long-term threat to this country's agricultural output and to the farming sector's important contribution to U. S. export earnings. And for the fast-expanding, hunger-threatened population of much of the world, the impact could be grim indeed." [22]

[22] J. M. Winski: Running dry. Wall Street Journal, May 31, 1977.

On the other hand, there is the idea that irrigated agriculture promotes an undesirable population growth and that its decline will help stabilize population:

> " ... Perhaps all deserts ought not to bloom. If irrigation projects draw too many chairs up to the water table, causing shortages, perhaps irrigation in certain places is not a good idea. If the transformation of a desert into a fertile valley increases the potential of turning a drought into a disaster, perhaps we should begin planning for intelligent allocation of the water resource." [23]

Only the future will be able to tell us what the impact of a declining groundwater base will be.

---

[23] W. Safire: Do your part - drink screwdrivers, not water. Arizona Daily Star, June 7, 1977.

IV: AN OVERVIEW OF THE LITERATURE

A brief overview of the literature discussed in Chapters II and III is presented here for perspective and because of what it tells us about the nature of our science and the nature of the problem. First of all, there is no real body of literature that concerns itself directly and comprehensively with the topic "the impact of groundwater development in arid lands." Certain aspects have received much attention — the physical aspects. Subsidence, sea-water intrusion, salinzation all are topics that, to one degree or another, we have the scientific tools and techniques necessary to study. And study them we have. The bibliographic entries on these topics are only the tip of the iceberg.

In contrast are the socioeconomic impacts of groundwater development. Implicit in the lack of post-hoc socioeconomic evaluations are observations concerning the complex rather indeterminant nature of the topic, the lack of scientific techniques to really deal with the problem, the youth of our consciousness of the problem (and perhaps even the problem itself), and, perhaps very much indeed, the belief that groundwater development in arid lands can have only a beneficial effect, so why study it.

Related to this last point is the observation that the majority of this paper and the majority of the bibliographic entries are concerned with the negative impacts of development. There is a distinct tendency in our environmental sciences to study those problems that deal with undesirable effects in an effort to understand them and thus alleviate them. This paper reflects this literature tendency because it is a literature review. Thus, if one receives a rather negative overall impression about groundwater development in arid lands, he should be cautioned that this probably reflects more about the nature of the literature and our scientific concerns that about the nature of the topic. Indeed, the literature is very weak on both the socioeconomic and beneficial aspects of groundwater development.

One further comment on the limitations of the literature. The impacts of groundwater development extend far beyond the topics presented herein, into our institutions, other geographical areas, and into the future in ways that are presently mysterious, unobservable, and unimaginable, or perhaps just overlooked or too trivial to comment on. In some cases this paper has discussed impacts that have not yet received much attention in the literature, but in many cases it has not. The reader should be aware of this literature and this paper's limitations, lest he think that the impacts reviewed herein are the only impacts of groundwater development.

V: SOME FURTHER CONSIDERATIONS

> The manner in which groundwater resources are developed and utilized can greatly affect the development of a regional or local water supply system and the corresponding long term economy which the system can support, particularly in arid and semi-arid regions. -Hall and Dracup, 1967

Now that we know what some of the major impacts of groundwater development in Arid lands are, the obvious question then becomes: "How can we enhance the desired impacts and minimize the undesired impacts?" Directly related to this question is the observation that the impacts of groundwater development are not simply the result of the withdrawal of groundwater from beneath the surface. They are also a function of three other factors: the physical setting in which the development is taking place, technology, and the cultural-institutional factors that relate to its development. Understanding how these factors relate to and how they influence the scope and magnitude of the impacts is one step toward being able to control them.

1. The Physical Setting

The role the physical setting plays in the impact that groundwater development will have is obvious: Subsidence usually occurs in late Cenozoic unconsolidated to semi-consolidated alluvial and lacustrine deposits; sea-water intrusion afflicts coastal aquifers in hydraulic contact with the ocean; and large aquifers such as the Ogallala in the High Plains of West Texas make possible extensive irrigation agriculture — as examples.

2. Technology

Now we are addressing a different matter. Groundwater development technology is the interfact between the physical system (the aquifer) and the social system. It has replaced adaptive behavior as a means of coping with aridity. There are two ways in which it has and will affect the impact of groundwater development.

2. a) Technological change

The first way is through technological change. Until relatively recently, groundwater development involved fairly simple technologies and a good deal of time and energy. Their limitations precluded the possibility of any major environmental changes due to groundwater development. Consider the sip-well of the Bushmen of the Kalahari:

> ... The procedure is as follows, and is usually carried out by an old woman. A certain plant serves as indicator of damp sand at the spot chosen and the woman proceeds to scrape a hole in the sand to arm's length. She then takes a grass stem or hollow reed, surrounds one end of it with fine roots or grass, and places that end in the bottom of the hole. The sand is then carefully replaced round the reed and firmly tramped down. After an hour or two the woman begins to suck through the reed, producing, of course, a semi-vacuum in the wad of grass buried below. The sucking has to be maintained for anything up to an hour before the pressure of the atmosphere has pressed the films of water around each sand-grain to the bottom of the reed. The water then comes up into the woman's mouth, and she inserts a second and shorter reed in the other side of her mouth leading down to a small hole at one end of an ostrich egg. She alternately sucks with one side of her mouth and expresses the water from the other side down the

> reed to fill the ostrich egg shell. A number of these are filled, carefully sealed with clay, and buried in different parts of their hunting territory for use when the dry season comes upon them.
> -Debenham, as quoted in Amiran, 1966*

Or even the windmill, which had its own lifting device. It too had its limitations: shallow groundwater bodies and wind. Early observers thought this technology was destined to open up the Great Plains to human (Anglo-Saxon, at least) habitation:

> ... From Canada to Mexico the revolution on the Great Plains is now in full tide. It [the transfer of windmill technology to the Great Plains] is the most dramatic page in the history of American agriculture. It has saved an enormous district from lapsing into a condition of semi-barbarism.
> -Smythe, as quoted in Green, 1973

Smythe was wrong. He made the same mistake we currently are making in assessing our future resource availabilities: he locked technology into its historical present, he assumed that his technology — the windmill — was the ultimate end in groundwater development technology.

During the late 1800s and early 1900s (it is impossible to put a precise date on the time) groundwater development entered a new era "simply because the supporting technology — and an effective demand for the products of drilling — were in existence" (Kazmann, 1972*). Any technological change that facilitates the discovery of groundwater or increases the depth of drilling, decreases the cost of drilling or lifting water to the surface, or increases the flow available for withdrawal, offers some opportunity for extending the physical range of groundwater use and definitely will have some influence on the impact of the groundwater development. Ackerman and Löf (1959) in discussing the advances made in water development technology, offer a good example of the impact of technological advance: the vertical turbine pump.

Prior to its development, 50 feet was generally considered the greatest distance groundwater could be pumped, thus limiting groundwater development to areas of shallow groundwater bodies. In many areas this limit had been reached. Around 1957 the vertical turbine pump was finally perfected and commercialized, an achievement that changed the pumping depth considerably and created an impact that was immediate and widespread. "The introduction of high-capacity deep-well turbine pumps allowed a phenomenal expansion of irrigation ... In the sixteen years following introduction of this pump the number of wells multiplied twenty-five times in the Texas High Plains (Ackerman and Löf, 1959)."

These technological advances have had a considerable influence on the character and extent of the development of the Arid zone. It has made settlement by large numbers of people possible, it has initiated regional economic development, subsidence, sea-water intrusion, etc., in a way primitive technologies could not.

As Green (1973) notes, "the search for water" on the High Plains was largely a search for technological means to bringing water to the surface in large enough quantities and at a low cost. The search for technological means is not over. Technology will continue to advance as it has in the past — in response to market incentives, in the direction of conserving those resources that are scarce (Schultze, 1977*).

2. b) Appropriate technology

The other way by which technology influences the impact of groundwater development is in its "appropriateness." Appropriate technology is simply technology that is appropriate to a given socioeconomic system and to the goals of its (the technology's) implementation. Groundwater development in develping countries is often undertaken not only for the water it provides but also for the indirect processes it stimulates that relate to national economic development: the generation of increased incomes, employment, industries, skills, etc. In such a situation, the choice of technology for groundwater development can be a critical factor in how readily these goals are met.

Groundwater development technology can be broken down into five general categories: 1) drilling technique, 2) power source and type of engine, 3) type of pump, 4) screen material used, and 5) agency installing the wells. Within each category, different alternatives are available that have different labor (in terms of number of people and degree of training), cost, and infrastructure require-

ments for their construction, assemblage, operation and/or maintenance. Thus it is possible to put together any number of "packages" of technology that are labor- or capital-intensive, that rely on indigenous or imported raw materials, parts, and labor; and that are capable of being installed, assembled, constructed, and/or maintained by indigenous peoples or foreign contractors.

The following examples illustrate how appropriate groundwater development technology can affect the impact of groundwater development. In Pakistan, as was pointed out earlier, it was the groundwater development undertaken by the private sector that spawned the development of new industries, the rapid embracement of the Green Revolution, etc. The wells installed by the private sector were relatively cheap and simple. They utilized indigenous labor and raw materials. The demand for their parts, their construction, repair, and maintenance could be met from within the society. This is what gave birth to the new tubewell technology industries, as is discussed by Nulty (1972) and Child and Kaneda (1975).

In contrast, the groundwater development technology of the public sector was more expensive, more powerful and sophisticated. The public wells required foreign parts and skills to construct and maintain. They were financed, owned, and operated by the State. The whole package was far inferior to the groundwater development package of the private sector in terms of the goals for which it was undertaken, as Bokhari (1975) has shown. Comparative evaluation of public and private tubewell packages in India yields similar conclusions (Moorti, 1971; Mellor and Moorti, 1971*).

Table 5.1: Comparison of the Benefits of Two Tubewell Technology Alternatives for Installation in Bangladesh
-after Thomas (1975)

EVALUATIVE CRITERIA	LOW-COST WELLS	MEDIUM-COST WELLS
I. Economic Development Internal rate of return	48%	33%
employment and training	to install 20,000 wells, more than 26,000 man-years of employment for unskilled labor would be created; another 9,000 man-years would be created for drillers and assistant drillers; most of these opportunities would go to indigenous peoples.	to install 20,000 wells, 1,600 man-years of employment would be created; foreign contractors would make up most of the employment force; only a few hundred Bengalis would be needed.
location and distribution of benefits	drilling rigs weigh relatively little, can be easily taken apart and reassembled, can be transported from one site to another by almost any means; therefore benefits can be widely distributed across country and will be retained in the rural sectors.	drilling rigs are heavy, and mobility is limited by rivers and canals as well as the absence of roads and bridges; thus drilling must be concentrated in only a few districts; benefits would go to city-based or foreign contractors and the installation in itself would provide almost no benefit to the location in which it takes place.
linkage effects	would increase the number of private domestic contractors installing wells Rigs: the components could all be fabricated in Bangladesh; by the 5th year Rs. 1.5 million would have been spent domestically to obtain 3,000 rigs, and their fabrication and maintenance would have provided the basis for one or more small firms. Pipe & Screen: would create a demand for Rs. 20 million in bldn pipe. Pumps & Engines: can be manufactured here, meaning an investment of Rs. 105 million in domestic industry.	almost all materials would be imported, with no linkage effects
II. Organization and Implementation installation capacity	wells to be installed by the agricultural Development Corporation (local agency) which has limited administrative capacity	wells to be installed by foreign contractors who would have a greater capacity to install wells according to a predetermined schedule
organization of demand for water	would probably be greater because farmers participate in well construction process	would be less because equipment that the farmer does not understand would be used without his involvement
potential for non-governmental installation	only this technology has potential for non-governmental installation	no potential for non-governmental installation

Thomas' (1975) evaluation of tubewell alternatives in Bangladesh illustrates most clearly how the choice of technology can affect the achievement of economic development goals, as well as the type of impact groundwater development can have. He identifies three similar cost and technological well packages available to meet the government-declared goal of the installation of 20,000 wells: high-cost wells (over Rs. [rupees] 100,000), using capital-intensive imported technologies, imported equipment, foreign contractors to install wells, and electric generators to power them; medium-cost wells (Rs. 100,000 to 50,000), utilizing capital-intensive complex imported technologies and supplies by relying on diesel power, with installation by foreign or domestic contractors; and low-cost wells (under Rs. 50,000), utilizing labor-intensive methods, adapted technologies, and supplies generally manufactured or assembled within the country and installed by domestic contractors, agencies of the government, or agricultural cooperatives.

His analysis of two of these alternatives (the high-cost wells were dropped from consideration because of financial infeasibility) is shown on table 5.1. Thomas' conclusion: " ... the arguments for the low-cost wells over medium- and particularly high-cost were impressive. Bangladesh's development objectives, economic return, employment creation and training, distribution of benefits as well as the potential for the creation of domestic industry would have been better served by the low-cost wells ... On balance, this evidence, plus the fact that the low-cost wells were the only ones proven in actual operation in Bangladesh suggest that the low-cost wells utilizing the simple technology represented the tubewell technology most consistent with the objectives and needs of the country." [24]

It is interesting to note the criteria Thomas used to evaluate the alternatives. The technological packages were evaluated not only in terms of how they could promote economic development goals but also with respect to infrastructural and institutional capacities. Implicit in this is the recognition of the importance of the cultural-institutional setting in which groundwater development is undertaken — the next topic.

3. Cultural-Institutional Aspects

The cultural-institutional setting in which groundwater development takes place determines to a large degree the type and magnitude of the impact of the development. Within the larger context of the whole cultural-institutional setting, this paper is concerned in particular with two smaller aspects: Cultural behavior and attitudes toward water development, and institutions dealing in any way with water. Two different cultural-institutional settings are pertinent to this discussion: those of developing and of developed nations.

3. a) Developing countries

In developing countries there is often great discrepancy between expectations and results of water resource development projects. Where, in some developing countries groundwater development has had a very beneficial impact (see the case history on Pakistan), elsewhere practical results of completed projects have frequently been disappointing (see Holmberg, 1952*). Financial constraints have often been blamed for these failures. Schramm (1976) feels, on the contrary, that "in many cases the financial constraints are less important, and less binding, than the human related ones" and that while financial constraints can be overcome, "the constraints related to human factors must generally be defined as structural problems which will yield little in the short run and only very slowly and reluctantly in the long run."

Wiener (1973*) discusses this:

> ... The reasons for the differences in the ... approach to [water] projects between developed and underdevelped countries is obvious. Farmer populations in developed countries possess sufficient adaptive capacity to spontaneously take up appropriate production methods in response to an improved production environment (such as a new irrigation project) and to spontaneously set up the necessary rural institutional framework: in short, they are development-minded, and if they need some technological information, they will know how to look for it themselves. Such rural societies are, to a great extent, self-regulative; a new

[24] The medium-cost well package was in fact chosen. Organizational requirements of the implementing agencies (including international donor agencies) — risk avoidance, appearance of modernity, established procedures, familiar techniques , and control — in the final analysis outweighed development policy objectives.

> challenge will elicit an appropriate response. By definition, this is not the case in Third World countries; farmers are governed by traditional methods and will resist sudden change. No spontaneous adaptation to new production environments will occur. Project interventions will therefore have to comprise all those activities that relate to the transformation and upgrading of the psychological space of the farmer, with a view to motivating him to respond appropriately to new production environments.

Wiener suggests that water projects in developing countries must be broadened in scope (to include such things as information on agro-techniques , rural institutions, farmer's motivation) to bring about the necessary change in the farmer's response to water development in order to meet the goals of the development.

Smith and Hogg (1971), while also emphasizing the necessity of understanding the cultural constraints, take a slightly different approach to the problem: "A concern with relations among people in water resource development means that the values they hold regarding effective development must be considered in decision making." Rather than changing the culture to fit the goals of water resource development, they suggest changing the water resource development package to fit the culture. Through an example of benefit-cost analysis within different socio-economic cultural contexts, they illustrate how the methodology developed in the industrialized nations to evaluate projects may not be applicable to different cultures where values and inter-personal relationships are strikingly different. In other words, the goals of water development, and the way a project is implemented, evaluated, and managed ought to be site-specific to a given cultural context if success is to be attained.

Cultural behavior is not the only factor inhibiting the impact of water resource development in developing countries. A lack of a skilled labor and managerial force, and an inappropriate (or lack of) institutional infrastructure to deal with water add to the problems (see Howe, 1976; and Schramm, 1976).

Though water is often viewed as a major constraint to development in arid developing countries, the provision of water is not always the answer to problems of underdevelopment. The impact that water resource development can have is very much related to the cultural-institutional setting in which it is undertaken. In developing countries this setting often is such that little is to be gained by water development because of this, no matter how much desired.

3. b) Developed countries

The situation is somewhat different in the industrialized nations. Here the problem is not a lack of an appropriate response on the individual's part to groundwater resource development to further his own economic interests. It is, rather, the opposite: Individuals are maximizing their present economic benefits through the use of a groundwater resource in ways that are questionable (for example, growing low-value high water-consuming crops in arid areas) and at a rate promoting undesirable physical consequences such as subsidence and sea-water intrusion, and which threatens future availability of the resource.

The basic theme underlying most articles on groundwater management is that our institutions have not kept up with our ability to exploit the groundwater resource. This institutional failure is largely blamed for all the undesirable consequences of groundwater development. Most laws, through their presence or absence, tend to promote rapid depletion of aquifers and do little to prevent negative consequences. For example, groundwater law in Arizona puts "heavy pressure on the groundwater user to get as much water out of the ground as he can, economically and legally, in as short a time as possible. The obvious result is rapid extraction of groundwater for so long as marginal-value product from its use is equal to or above the operating cost of the pumps by which it is extracted. Thus, short-run security is gained by each at the expense of long-run insecurity on the part of all ... Furthermore, pressure on each groundwater user to bolster his individual short-run security at the cost of long-run insecurity for all, forces users heavily dependent upon rapidly deepening groundwater stocks to search eagerly for replacement water supplies. Groundwater law encourages rapid depletion of groundwater stocks, thus forcing long-run search for developable replacement surface supplies" (Kelso, Martin, and Mack, 1973). Furthermore, lack of flexibility in Arizona groundwater law causes a "rigid 'locking in' of groundwater to existing sites and to existing uses" which may ultimately result in a curtailment of economic growth of the state (Ibid.).

In addition to law, other institutional factors pertinent to this discussion include the structure and organization of public agencies dealing with water. One factor frequently cited as a reason for

failure of political institutions to deal with water problems is that water management decisions are rarely made as a single entity. In Arizona, for example, 14 different public agencies, each with a different constituency, a different sovereignty, a different perception, and a different function, have some sort of say in how water is developed and/or used (Null, 1970*). This political fragmentalization has led to a failure to deal adequately with water problems (and thereby enhancing them) for reasons Straayer (1970) identifies as due to: 1) the relationship between the pattern of governmental organization and problem boundaries, 2) variations in the number and nature of functions performed by the different agencies, 3) variations in the resources possessed by and demands placed upon those agencies, and 4) a resultant variation in the propensity of decision makers to treat a given set of environmental conditions as a public problem and then to incur the decision-costs necessary to deal with the problem.

In this brief but by no means comprehensive discussion, it is hoped its purpose has been served, namely to illustrate the role of the cultural-institutional setting in the impact of groundwater development. Readers interested further in this topic are referred to Fox (1976*), Gray and Trock (1971*), Kelso (1974*), and Trock (1971*), in addition to others already cited, for starters. Suffice to say, in both developing and developed countries institutions significantly affect the manner in which groundwater is developed and used and the impact of its development. And, because they are not fixed physically in nature, as is the ultimate amount of groundwater available in arid lands, they represent one potential way through which our water problems can be approached.

VI: SUMMARY and CONCLUSIONS

As I write this, a water crisis is perceived at every level of my political existence: my own home, city (Tucson), state (Arizona), region (the West), country (United States), and even on the global level. The headlines in general interest magazines: "Warning: Water Shortages Ahead" [25]; financial news media: "Running Dry"[26]; editorials by political commentators: "Do Your Part - Drink Screwdrivers, Not Water" [27]; local city newspapers: "Tucson's Water Supply Draining Fast" [28]; and even college campus newspapers: "Lack of Water Dries up Future of Arizona Indians" [29] — all bespeak the concern with our water supplies and indicate the degree to which it has permeated different levels of our culture.

The topic of this literature review and bibliography, The Impact of Groundwater Development in Arid Lands, is very intimately related to this topic of water shortage. The historical response to water shortages has usually been to develop more water supplies. It is inevitable that groundwater supplies will be increasingly developed as cities, states, nations scramble for water to serve a growing and increasingly affluent world society. With this prognosis, it is of interest to all concerned to have some idea of what the effects of groundwater development might be. "Forewarned is forearmed." Knowledge of future impacts, if used, can only enhance the planners' ability to mitigate the undesirable effects, and promote the desirable impacts.

From the preceding literature review, the following general observations can be made regarding the impact of groundwater development:

1) Groundwater development can cause considerable environmental changes to occur both on and beneath the land surface. The types of changes will depend upon the physical setting of the groundwater development.

2) Groundwater development is also an agent of socioeconomic change. Its relative importance as this kind of agent will depend upon the state and stage of the economy. The cultural changes are most dramatic when groundwater development is undertaken within a nomadic economy. The role of groundwater to economic growth changes as an economy matures from its initial agricultural state to an industrial economy, being most important in young economies.

3) The cultural-institutional setting within which groundwater development takes place influences to a large degree the magnitude of the physical and socioeconomic impacts. This is because our cultural-institutional framework determines how we respond to water development, how water is used, how much is used, what is economic, and what is permissible, to list only a few factors.

4) And, of course, both the physical and socioeconomic impacts of groundwater development depend ultimately upon the amount and rate of water withdrawal. This in turn is a function of our technological ability. The past century has been a period of great technological change. Those technological advances that relate to groundwater development, perhaps more than any other innovation in man's history, have changed the character and extent of the development and settlement of the Arid lands. Such change, through its appropriateness, can promote the achievement of the goals of economic development in developing countries. Through its pace, because it has outstripped the pace of our institutional capacility to respond, it has promoted some impacts which society may ultimately define as extremely undesirable.

But in a certain sense both technology and institutions are directed toward the same ends in water development, as Ackerman and Löf (1959) have noted:

---

[25] [Anonymous], Time, April 4, 1977, p. 48

[26] Winski, J. M., Wall Street Journal, May 31, 1977

[27] Safire, W., Arizona Daily Star, June 7, 1977, p. 13-A

[28] Turner, T., Arizona Daily Star, Oct. 19, 1975, p. 1-1

[29] Buel , B. J., Arizona Daily Wildcat, April 13, 1977, p. 9

> ... Both are concerned with the reconciliation of demand for water and the natural supplies, whatever the physical location of the specific demand or supply. Technology in this instance is concerned with the application of scientific knowledge and material techniques to the alteration or channeling of water demand,to the production, storage or transportation of water. Administrative organization is concerned with the application of social techniques to the same ends ... Accordingly, it seems obvious that technology and administrative organization of water development must have relations which profoundly affect the course that water and later economic development follow.

There is no question that technology will continue to advance, in a direction that will increase the amount of water available and also decrease the demand. But the amount of water available will be limited by economics, and ultimately by the amount that is physically available at any one time. Our institutions must be compatible with technology and the goals of water development if the goal of the promotion of the general welfare (for which our institutions exist) is to be realized now and in the future.

SUPPLEMENTARY REFERENCES

Wherever reference is made to SWRA throughout the Supplementary References and the following Bibliography, a complete abstract will be found in the appropriate issue of Selected Water Resources Abstracts (SWRA), a semimonthly publication of the Water Resources Scientific Information Center, Office of Water Research and Technology, U. S. Department of the Interior, Washington, D. C. 20240. Users interested in these abstracts can access them through any regional RECON terminal or any library file of SWRA.

SUPPLEMENTARY REFERENCES

[Indicated in text by asterisk (*) following citation date]

Aggarwal, P. C. (1973) The Green Revolution and rural labor. Shri Ram Centre for Industrial Relations and Human Relations, India. 148 p.

Afyal, M. (1973) Statistical estimation of useful life of tubewells. Pakistan Development Review 12(1):81-90.

Ambroggi, R. (1966) Water under the Sahara. Scientific American 214:21-29.

Amiran, D. H. K. (1966) Man in arid lands. I: Endemic cultures. In E. S. Hills, ed., Arid lands, a geographical appraisal, p. 219-238. Methuen & Co., Ltd., London.

Anonymous (1948) Papago development program 1948. Arizona State Museum, Tucson, unpublished manuscript. 61 p.

Arizona Town Hall, 4th. Castle Hot Springs (1964) Arizona's water supply. Arizona Academy, Phoenix. 165 p.

Arizona Water Commission (1975) Arizona State water plan. Phase I: Inventory of resource and uses. Phoenix. 224 p.

Artichoker, J., Jr. (1966) Survey of income and employment, Papago Reservation Calendar, year 1966. Arizona State Museum, Tucson. 37 p.

Backus, C. E. / Brown, M. L. (1976) Water requirements for solar energy. American Water Works Association, Journal 68(7):366-369.

Baker, R. (1973) The need for long term strategies in areas of pastoral nomadism. In D. Dalby and R. J. Harrison Church, eds., Drought in Africa. Report of the Symposium held July 19-20, 1973, p. 79-84. University of London, School of Oriental and African Studies, Centre for African Studies.

Barry, R. (1969) The world hydrologic cycle. In R. Chorley, ed., Water, earth, and man, p. 11-29. Methuen & Co., Ltd., London.

Batisse, M. (1969) Problems facing arid-land nations. In W. G. McGinnies and B. J. Goldman, eds., Arid Lands in Perspective, p. 1-12. University of Arizona Press, Tucson. 421 p.

Batty, J. C. / Hamad, S. N. / Keller, J. (1974) Energy inputs to irrigation. Utah State University, Logan, Department of Agricultural and Irrigation Engineering. 25 p.

Beaumont, P. (1971) Qanat systems in Iran. International Association of Scientific Hydrology, Bulletin 16(1):39-50. SWRA 72-04849.

Biswas, A. K. (1972) History of hydrology. North-Holland Publishing Co., Amsterdam-London. 336 p.

Boyle, R. H./Graves, J. / Watkins, T. H. (1971) The water hustlers. Sierra Club, San Francisco. 253 p.

Brown, L. R. (1976) Social well-being and water resources planning. Water Resources Bulletin 12(6):1181-1190.

Bryan, K. (1925) The Papago country, Arizona. U. S. Geological Survey, Water-Supply Paper 499. 436 p.

Bull, W. (1976) The critical gradient threshold. In P. Paylore and R. A. Haney, Jr., eds., Desertification: Process, problems, perspectives, p. 51-52A. University of Arizona, Tucson. 125 p.

Caldwell, J. C. (1975) The Sahelian drought and its demographic implications. American Council on Education, Washington, D. C., Overseas Liaison Committee, Paper 8. 87 p.

Carruthers, I. D. (1970) Assessing the contribution of rural water investment to development. East African Journal of Rural Development 3(2):96-110.

Casey, H. E. (1972) Salinity problems in arid lands irrigation: A literature review and selected bibliography. University of Arizona, Tucson, Office of Arid Lands Studies, Arid Lands Resource Information Paper 1. 300 p.

Clay, C. (1970) A review of the Texas water plan: Issues and attitudes. In C. W. Johnson and S. H. Lewis, eds., Contemporary developments in water law, p. 160-172. University of Texas, Austin, Center for Research in Water Resources, Water Resources Symposium 4.

Conover, C. S. (1954) Ground-water conditions in the Rincon and Mesilla Valleys and adjacent areas in New Mexico. U. S. Geological Survey, Water-Supply Paper 1230. 200 p.

Cooke, R. U. / Reeves, R. W. (1976) Arroyos and environmental change in the American Southwest. Clarendon Press, Oxford. 213 p.

Cressey, G. (1958) Qanats, karez, and foggaras. Geographical Review 48(1):27-44.

Davis, S. N. (1969) Porosity and permeability of natural materials. In R. De Wiest, ed., Flow through porous media, p. 53-89. Academic Press, New York.

--- --- / De Wiest, R. (1966) Hydrogeology. John Wiley & Sons, Inc., New York. 463 p.

Dobyns, H. F. (1949) Report on investigations on the Papago Reservation. Cornell University, Ithaca, Department of Sociology-Anthropology. Processed. 74 p. [Copy in Arizona State Museum, Tucson]

Eckert, J. B. (1974) Private tubewell numbers in Pakistan: A synthesis. Pakistan Development Review 13(1):94-105.

Farvar, M. / Milton, J., eds. (1972) The careless technology: Ecology and international development. Natural History Press, Garden City, New York.

Fontana, B. L. (1964) The Papago Indians. Arizona State Museum, Tucson. Unpublished manuscript, 245 p.

--- --- (1974) Man in arid lands: The Piman Indians of the Sonoran Desert. In G. W. Brown, Jr., ed., Desert biology, vol. 2, p. 489-529. Academic Press, New York.

--- --- (1974) The Papago tribe of Arizona. In D. A. Horr, ed., Papago Indians, vol. 3, p. 227-273. Garland Publishing Co., New York, London.

--- --- (1976) Desertification of Papaguería: Cattle and the Papago. In P. Paylore and R. A. Haney, Jr., eds., Desertification: Process, problems, perspectives, p. 59-69. University of Arizona, Tucson. 125 p.

Food and Agriculture Organization of the United Nations, Rome / UNESCO, Paris (1973) Irrigation, Drainage, and Salinity: An international source book. Hutchinson/FAO/UNESCO, Paris. 510 p.

Food and Agriculture Organization of the United Nations, Rome (1973) Man's influence on the hydrological cycle: A draft report of the UNESCO/FAO working group on the International Hydrological Decade. FAO, Rome, Irrigation and Drainage Paper 17. 71 p. SWRA W75-10863.

Fox, I. K. (1976) Institutions for water management in a changing world. Natural Resources Journal 16(3):745-758.

Frederick, K. D. (1977) Water uses and misuses: A world view. Resources for the Future, Washington, D. C., Resources 55: 1,3-5.

German Foundation for Developing Countries (1965) Water development in less developed areas. In International Conference held in Berlin from 17 to 21 May 1963, Transactions. Duncker and Humblot, Berlin. 203 p.

Gray, R. M. / Trock, W. L. (1971) A study of the effects of institutions on the distribution and use of water for irrigation in the lower Rio Grande basin. Texas A&M University, Water Resources Institute, Technical Report 36. 92 p.

Gyuk, I. (1973) Notes on a history of water use. In V. T. Chow, et al, eds., Water for the human environment, p. 233-242. World Congress on Water Resources, 1st, Proceedings.

Hackenberg, R. A. (1964) Aboriginal land use and occupancy of the Papago Indians. Arizona State Museum, Tucson. Unpublished manuscript. 282 p.

--- --- (1974) Aboriginal land use and occupancy. In D. A. Horr, ed., Papago Indians, vol. 1, p. 23-308. Garland Publishing Co., New York, London.

Hastings, J. R. / Turner, R. M. (1972) The changing mile. University of Arizona Press, Tucson. 317 p.

Hills, E. S., ed. (1966) Arid lands, a geographical appraisal. Methuen & Co., Ltd., London / UNESCO, Paris. 461 p.

Hirshleifer, J. / De Haven, J. C. / Milliman, J. W. (1970) Water supply, economics, technology, and policy. University of Chicago Press, Chicago and London. 386 p.

Holburt, M. B. (1975) International problems of the Colorado River. Natural Resources Journal 15(1):11-26.

Hollander, J. T. / White, N. D. (1963) Recharge of ground water to the alluvial aquifers in the Basin and Range lowlands. In Arizona State Land Department, Phoenix, Water Resources Report 15:39-46.

Holmberg, A. R. (1952) The wells that failed: Attempt to establish a stable water supply in Viru Valley, Peru. In E. H. Spicer, ed., Human problems in technological change, p. 113-123. Russell Sage Foundation, New York.

International Association of Scientific Hydrology (1961) Groundwater in arid zones. Symposium of Athens, September 10-18, 1961. IASH Publication 57, vol. 2. 740 p.

International Boundary and Water Commission, United States and Mexico (1973) Minute 242.

James, L. D. (1974) The challenge to the social sciences. In L. D. James, ed., Man and water, the social sciences in management of water resources, p. 1-33. University Press of Kentucky, Lexington.

--- ---, ed. (1974) Man and water, the social sciences in management of water resources. University Press of Kentucky, Lexington. 258 p.

Kahana, Y. (1966) Some aspects of ground water management. In L. Schiff, ed., Biennial conference on ground water recharge, development and management, Proceedings p. H/10-19. U. S. Department of Agriculture, Fresno Field Station, University of California, Los Angeles.

Kalinin, G. / Bykov, V. (1969) The world's water resources. Impact of Science on Society 19(2):135-150.

Kazmann, R. (1972) Modern hydrology. Harper & Row, New York. 301 p.

Kelly, W. H. (1974) The Papago Indians of Arizona: A population and economic study. In D. A. Horr, ed., Papago Indians, vol. 3, p. 9-150. Garland Publishing Co., New York, London.

Kelso, M. M. (1974) Economic implication of public water policy in Arizona. University of Arizona, Tucson, OWRR Project 14-01-0001-1001, Completion Report. 133 p.

Kneese, A. V. / Zamora, J. (1975) The future of arid lands. In Y. Mundlak and S. F. Singer, eds., Arid zone development, potentialities and problems. Symposium cosponsored by the American Academy of Arts and Sciences and the Hebrew University of Jerusalem, MIT, Boston, October 23-25, 1975. Processed.

Krutch, J. W. (1969) The voice of the desert. William Sloan Associates, Apollo Editions, New York. 223 p.

Lauten, J. H. (1976) Energy for water. American Water Works Association, Journal 68(7):353-356.

Lebaron, A. / Mohtadi, M. (1968) Mining water in Iran. Utah Science 29(3):88-89, 92. SWRA W71-00958.

Lebon, J. H. G. (1965) Land use in Sudan. Metropolis Press, Ltd., London. 191 p.

Lewis, W. C. et al. (1973) Regional growth and water resource investment. Lexington Books, Lexington, Massachusetts. 172 p.

Lohman, S. W. (1972) Ground-water hydraulics. U. S. Geological Survey, Professional Paper 708. 70 p.

L'Vovich, M. (1971) The water balance of the continents of the world and the method of studying it. [Reported at] International Union of Geodesy and Geophysics, General Assembly, 15th, 1971, Moscow. 24 p.

Major, D. C. / Kirshen, P. / Lengyel, Z. (1974) A long-range plan defining alternative stragegies for the development of the Sahel-Sudan zones. 10: Water resources. Massachusetts Institute of Technology, Cambridge, Center for Policy Alternatives, Sahel-Sudan Project. Preliminary draft of final report to U.S. Agency for International Development. 139 p.

Mann, D. E. (1969) The political implications of migration to the arid lands of the United States. Natural Resources Journal 9(2):212-227.

Mann, H. S. / Malhotra, S. P. (1976) Biotic factors and desertification in arid zone of Rajasthan. In Problems in the development and conservation of desert and semidesert lands, Pre-Congress Symposium K26, Working Group on Desertification in and around arid lands, Ashkhabad, USSR, July 20-26, 1976, p. 161-162. International Geographical Congress, 23rd, Moscow, 1976, with the support of UNESCO, the International Geographical Union, and the University of New South Wales, Australia. 216 p.

Mark, A. K. (1960) Description of and variables relating to ecological change in the history of the Papago Indian Reservation. University of Arizona, Tucson (M.S. thesis). 110 p.

Maxey, G. B. (1968) Hydrogeology of desert basins. Groundwater 6(5):10-22. SWRA W69-01013.

McGinnies, W. G. / Goldman, B. J. / Paylore, P., eds. (1968) Deserts of the world: An appraisal of research into their physical and biological environments. University of Arizona Press, Tucson. 788 p.

Mellor, J. W. / Moorti, T. W. (1971) Dilemma of state tube wells. Economic and Political Weekly (Bombay) 6(13):37-47.

Mesthene, E. G. (1970) Technological change: Its impact on man and society. Harvard University Press, Cambridge, Massachusetts.

Murphy, R. (1951) The decline of North Africa since the Roman occupation: Climatic or human? Association of American Geographers, Annals 41(2):116-132.

Nace, R. (1960) Water management, agriculture, and groundwater supplies. U. S. Geological Survey, Circular 415.

--- --- (1964) Water: Essential factor of economic development. Impact of Science on Society 14(1):39-55.

Nir, Dov (1974) The Semi-Arid world. Longman, London. 187 p.

Norvelle, M. (1974) The Arab bedouin as an example of environmental adaptation. University of Arizona, Tucson, Department of Hydrology and Water Resources Administration. Unpublished manuscript. 18 p.

Null, J. A. (1970) The politics of water resource management through Arizona water-related regulatory agencies. University of Arizona, Tucson (Ph.D. dissertation). 316 p.

Officer, J. / King, B. (1957) A report on resource development programs and relocation of Arizona Indian reservations. Arizona State Museum, Tucson, Library Archives A-216. 108 p.

Olmstead, F. H. / Loeltz, O. J. / Irelan, B. (1973) Geohydrology of the Yuma area, Arizona and California. U. S. Geological Survey, Professional Paper 486-H.

Padfield, H. / Smith, C. L. (1968) Water and culture: New decision rules for old institutions. Rocky Mountain Social Science Journal 5(2):23-32.

Pallas, P. (1972) Water resources in the northern Sahara. Nature and Resources 8(3):9-17.

Paylore, P. (1976) Desertification: A World bibliography. Prepared for the 23rd International Geographical Congress, Moscow, 1976, Pre-Conference meeting of the IGU Working Group on Desertification, Desert Research Institute, Ashkhabad, Turkamn SSR. University of Arizona, Tucson, Office of Arid Lands Studies. 644 p.

Pumpelly, R. (1870) Across America and Asia. Notes of a five years journey around the world and residence in Arizona, Japan and China. Leypoldt and Holt, New York. 454 p.

Rapp, A. (1974) A review of desertization in Africa: Water, vegetation, and man. Secretariat for International Ecology, Stockholm, SIES Report 1. 77 p. SWRA W75-04142.

Rhinehart, J. F. (1977) Colorado River Basin salinity control project, Title I. Arizona Water Resources Project Information, Project Bulletin 16. 4 p.

Roberts, S. H. (1968) History of Australian land settlement. Johnson Reprint Corporation, New York. 460 p.

Robinson, T. W. / Waananen, A. O. (1970) Evapotranspiration by woody phreatophytes in the Humboldt River Valley, newr Winnemucca, Nevada. U. S. Geological Survey, Professional Paper 491-D. 41 p.

Ruttan, V. W. (1965) The economic demand for irrigated acreage. Johns Hopkins Press, Baltimore, Maryland. 139 p.

Saunders, R. J. / Warford, J. J. (1976) Village water supply. Johns Hopkins University Press, Baltimore and London. 279 p.

Sax, J. L. (1968) Water law, planning and policy. Bobbs-Merrill Co., Inc., New York. 520 p.

Scheiber, M. (1974) Assessing technology for development. UNITAR News 6(4):15-18.

Schoeller, H. (1959) Arid zone hydrology. Recent developments. UNESCO, Paris, Arid Zone Research 12. 125 p.

Schultze, C. L. (1977) The public use of private interest. Harper's Magazine 254(1524):43-62.

Schumacher, E. F. (1973) Small is beautiful. Harper Colophon Books, Harper & Row, New York. 290 p.

Smith, C. L. / Hogg, T. C. (1971) Benefits and beneficiaries: Contrasting economic and cultural distinctions. Water Resources Research 7(2):254-263.

Soth, L. (1975) Foolish waste to irrigate West — even for more food. Tucson Daily Citizen, June 12. p. 35

Sterling, C. (1974) The making of the sub-Saharan wasteland. Atlantic Monthly, May, p. 98-105.

Swidler, W. A. (1972) Some demographic factors regulating the formation of flocks and camps among the Brahui of Baluchistan. Journal of Asian and African Studies 7(1/2):69-75.

Tamers, M. A. (1967A) Radiocarbon ages of groundwater in an arid zone unconfined aquifer. In Isotope technology in the hydrologic cycle. p. 143-152. American Geophysical Union, Geophysical Monograph series 11.

--- --- (1967B) Surface-water infiltration and groundwater movement in arid zones of Venezuela. In Symposium on Isotopes in Hydrology, held by the International Atomic Energy Agency in co-operation with the International Union of Geodesy and Geophysics in Vienna, 14-18 November 1966, Proceedings, p. 339-353. International Atomic Energy Agency, Vienna.

Tannous, A. (1944) Extension work among the Arab Fellahin. Human Organization 3(3):1-12.

Thatcher, L. / Rubin, M. / Brown, G. F. (1961) Dating desert groundwater. Science 134:105-106.

Thomas, H. E. (1962) Water and the southwest, what is the future? U. S. Geological Survey, Circular 469. 15 p.

Towle, C. L., Jr. (1976) Feasibility of introducing solar powered irrigation on a representative Arizona farm. University of Arizona, Tucson (M.S. thesis). 90 p.

Trock, W. L. (1971) Institutional factors influencing water development in Texas. Texas A&M University, Water Resources Institute, Technical Report 35. 35 p.

Turner, T. (1974) There are ways to save groundwater. Arizona Daily Star, September 22, p. 1H.

Underhill, R. (1936) The autobiography of a Papago woman. American Anthropological Association, Memoirs 46. 64 p.

--- --- (1974) Acculturation at the Papago village of Santa Rosa. In D. A. Horr, ed., Papago Indians, vol. 1, p. 309-348. Garland Publishing Co., New York, London.

United Nations, Department of Economic and Social Affairs (1964) Water desalination in developing countries. ST/ECA/82. 325 p.

--- --- (1972) Abstraction and use of water: A comparison of legal regimes. 254 p.

--- --- (1973) Ground water in Africa.

Universal Oil Products, St. Paul, Minnesota, Johnson Division (1975) Ground water and wells. 440 p.

Wade, Nicholas (1974) Sahelian drought: No victory for western aid. Science 185:234-237.

Walton, K. (1969) The arid zones. Aldine Publishing Co., Chicago, Illinois. 175 p.

Warner, D. (1973A) Evaluation of the benefits of rural water supply projects in Tanzanian villages. In Water for the Human Environment, Proceedings of the first World Congress on Water Resources, vol. 3: Technical sessions, p. 209-219. International Water Resources Association, Champaign, Illinois.

--- --- (1973B) Evaluation of the developmental impact of rural water supply projects in East African villages. Stanford University (Ph.D. dissertation).

Weinberg, E. (1969) Intrastate, interstate, and international legal and administrative problems of large-scale water transfer. In W. G. McGinnies and B. J. Goldman, eds., Arid Lands in Perspective, p. 352-358. University of Arizona Press, Tucson. 421 p.

Whetstone, G. A. (1970-1971) Interbasin diversion of water: An annotated bibliography. Texas Tech University, Water Resources Center. 2v.

White, G. F. (1960) Science and the future of the arid lands. UNESCO, Netherlands. 95 p.

--- --- / Bradley, D. J. / White, A. U. (1972) Drawers of water. University of Chicago Press, Chicago and London. 306 p.

Widstrand, C. G. (1975) The rationale of nomad economy. Ambio 4(4):146-153.

Wiener, A. (1972) The role of water in development. McGraw-Hill, New York. 483 p.

--- --- (1973) Water resources development policies and transfer of knowledge from developed to developing countries. In E. Vlachos, ed., Transfer of water resources knowledge, p. 237-245. Water Resources Publications, Ft. Collins, Colorado.

Wollman, N. (1962) The value of water in alternative uses. University of New Mexico Press, Albuquerque, New Mexico. 426 p.

Woodbury, R. B. / Woodbury, N. F. S. (1962) A study of land use on the Papago Indian Reservation. University of Arizona, Tucson, Bureau of Ethnic Research. Unpublished manuscript in Arizona State Museum, Tucson. 60 p.

Xavier, G. H. (1974) The cattle industry of the southern Papago districts, with some information on the Reservation cattle industry as a whole. In D. A. Horr, ed., Papago Indians, vol. 1, p. 349-402. Garland Publishing Co., New York, London.

Yoakum, G. (1973) Papagos begin digging in as long drought continues. Arizona Daily Star, October 28.

BIBLIOGRAPHY

Wherever reference is made to SWRA throughout this Bibliography, a complete abstract will be found in the appropriate issue of Selected Water Resources Abstracts (SWRA), a semimonthly publication of the Water Resources Scientific Information Center, Office of Water Research and Technology, U. S. Department of the Interior, Washington, D. C. 20240. Users interested in pursuing such abstracts can access them through any regional RECON terminal or any library file of SWRA.

BIBLIOGRAPHY

0001

ACHI, K.

1972

SALINIZATION AND WATER PROBLEMS IN THE ALGERIAN NORTHEAST SAHARA. IN M.T. FARVAR AND J. P. MILTON, EDS., THE CARELESS TECHNOLOGY: ECOLOGY AND INTERNATIONAL DEVELOPMENT, P. 276-287.

NATURAL HISTORY PRESS, N.Y. 1030 P.

THE LOWER ALGERIAN SAHARA CONSTITUTES A ZONE WITH A RELATIVELY DENSE POPULATION WHERE THE ONLY RESOURCES ARE PROVIDED BY AGRICULTURE: 11, 000 HECTARES OF DATE PALMS. ABUSIVE EXPLOITATION OF THE SUBTERRANEAN ARTESIAN WATERS EVENTUALLY HAD A DISASTROUS EFFECT ON THE SUPERFICIAL WATER TABLE, PARTICULARLY SO BECAUSE THE REGION LACKS GOOD SUBTERRANEAN OUT FLOW OF WATER. SALINITY HAS RESULTED IN THE DEATH OF MANY PALMS AND A REDUCTION IN YIELD OF SUBSISTENCE CROPS GROWN BETWEEN THE ROWS OF PALMS. SOCIOLOGICAL ASPECTS ARE TREATED AS ARE ECOLOGICAL CONSIDERATIONS IMPORTANT IN INDICATING UNFAVORABLE CONDITIONS OF ARID LANDS FOR IRRIGATION DEVELOPMENT.

OALS/ALGERIA/SAHARA/DATES/PALMS/GROUNDWATER/WATER RESOURCES DEVELOPMENT/ WATER TABLE/SALINITY/IRRIGATION PRACTICES/SOCIAL ASPECTS/ECONOMIC DEVELOPMENT/ARTESIAN WELLS/DRAINAGE/IRRIGATION EFFECTS

0002

ACKERMAN, E./LOEF, G.

1959

TECHNOLOGY IN AMERICAN WATER DEVELOPMENT.

JOHNS HOPKINS PRESS, BALTIMORE, 710 P.

SEE: SWRA W70-03008

TECHNOLOGY/WATER RESOURCES DEVELOPMENT/ADMINISTRATION/POLITICAL ASPECTS/ WATER UTILIZATION/WATER DEMAND/WATER SUPPLY/WATER QUALITY/GROUNDWATER/ SEA WATER/IRRIGATION/TRANSPORTATION/RUNOFF/FLOOD CONTROL

0003

AERO SERVICE CORP., PHILADELPHIA, DIVISION OF LITTON INDUSTRIES

196-

REPORT ON THE NIGER WATER RESOURCES SURVEY. AN ECONOMIC AND HYDROGEOLOGICAL REVIEW OF THE GOVERNMENT OF NIGER REQUEST FOR 200 DUG WELLS AND 15 DRILLED WELLS.

SAME AS AUTHOR. CONTRACT AFR-452. 154 P.

AN EVALUATION OF THE PROPOSED WATER RESOURCES PROGRAM REQUESTED BY THE GOVERNMENT OF NIGER AND TO BE FINANCED BY THE U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT. THE CURRENT ECONOMIC SITUATION IN NIGER, ESPECIALLY AS IT APPLIES TO WATER RESOURCES DEVELOPMENT, IS SURVEYED. AVAILABLE WATER SOURCES AND THE WELL DEVELOPMENT PROGRAMS SUGGESTED BY THE GOVERNMENT OF NIGER ARE OUTLINED. COST-BENEFIT BALANCE OF THE PROGRAM IS ANALYZED AND THE TECHNOLGOCAL PROBLEMS OF THE CONSTRUCTION ARE DISCUSSED. DESPITE SUCH GENERAL OBJECTIONS TO THE WELL PROPOSAL AS THE RUDIMENTARY NATURE OF NATIVE TECHNOLOGY, HIGH CONSTRUCTION COSTS, AND ADMINISTRATIVE OVERLAP IN THE REGION BETWEEN THE AGENCY FOR INTERNATIONAL DEVELOPMENT AND OTHER SPONSORING ORGANIZATIONS, THE WELL DEVELOPMENT PROGRAM IS SEEN TO BE BOTH NECESSARY AND FEASIBLE. RECOMMENDATIONS FOR THE PROGRAM INCLUDE THE CONSTRUCTION OF SURFACE CATCHMENT BASINS IN THE NOMAD ZONE, AS WELL AS PERCUSSION DRILLING OF LARGE DIAMETER WELLS. TWO FUTURE PROJECTS ARE ALSO SUGGESTED TO STUDY THE POSSIBILITY OF DRILLING WELLS IN THE SEDENTARY AND NOMADIC REGIONS OF THE COUNTRY, THUS OPENING THESE AREAS TO AGRICULTURE. MAPS, PHOTOS, DRAWINGS. (OALS)

OALS/AID/KWIC N 21/WATER RESOURCES DEVELOPMENT/HYDROGEOLOGY/WATER SOURCES/ WELLS/SHALLOW WELLS/NIGER/ECONOMIC DEVELOPMENT/COST-BENEFIT ANALYSIS/COSTS/ NOMADS/CATCHMENTS/DRILLING/IRRIGATION PROGRAMS/LIVESTOCK/MAPS/GEOLOGIC MAPS/ LAND USE/DEVELOPING COUNTRIES/SAHELIAN ZONE

0004

AHMAD, N.

1965

WATERLOGGING AND SALINITY IN THE INDUS PLAIN: COMMENT.

PAKISTAN DEVELOPMENT REVIEW 5(3):371-380.

AUTHOR FEELS THAT THE TUBEWELL PROJECT ADVOCATED BY THE REVELLE REPORT TO EASE THE PROBLEMS OF WATERLOGGING AND SALINITY IS NOT VIABLE. TUBEWELLS HAVE A SHORT ECONOMIC LIFE BECAUSE RAPID INCRUSTATION OF STRAINERS. TUBEWELL PUMPAGE AT THE RATE SUGGESTED BY THE REVELLE REPORT WOULD LOWER THE WATER TABLE BELOW THE PUMPS IN ABOUT 9 YEARS MAKING THE 2000 WELLS IN SCARP 1 USELESS. BY LOWERING THE WATER TABLE THE BENEFITS OF SUB-IRRIGATION WILL BE LOST. THE PUMPING OF SALINE GROUNDWATER HAS DISPOSAL PROBLEMS. AUTHOR SUGGESTS AN ALTERNATIVE PLAN WHICH WOULD MINIMIZE THE AMOUNT OF GROUNDWATER PUMPED AND RESTRICT ITS WITHDRAWAL TO THE DRY PERIOD.

PAKISTAN/WATERLOGGING/SALINITY/DRAINAGE/WELLS/GROUNDWATER/GROUNDWATER RECHARGE/SURFACE WATERS/GROUNDWATER MINING/WATER TABLE/IRRIGATION/IRRIGATION PRACTICES/CROPS/SALINE WATER/PUMPING/CANALS/REVELLE REPORT/TUBEWELLS/ INCRUSTATION/TURBINE PUMPS/CENTRIFUGAL PUMPS/WATER QUALITY

0005

AMIRAN, D.H.K.

1970

EL DESIERTO DE SECHURA, PERU: PROBLEMS OF AGRICULTURAL USE OF DESERTS.

REVISTA GEOGRAFICA 72:7-12. SWRA W71-10490.

AGRICULTURAL DEVELOPMENT IN DESERT REGIONS IS SUBJECT TO MANY PROBLEMS, AND THIS IS WELL ILLUSTRATED IN THE AREA OF PIURA, LOCATED IN THE DESERT OF SECHURA, ONE OF THE WIDEST SECTIONS OF THE PERUVIAN COASTAL DESERT. ESTABLISHED ABOUT 40 YEARS AGO, THE AREA HAS 1300 FARMING UNITS OF 40 HECTARES EACH. COTTON IS THE MAIN CROP IRRIGATED BY BASIN FLOODING FROM THE PIURA RIVER. ADDITIONAL WATER SOURCES ARE WELLS SUFFERING FROM SEVERE OVERDRAFTS AND CONSEQUENT RISING SALINITY LEVELS, LEADING TO EXTENSIVE LAND DETERIORATION. THE RIVER ITSELF TURNS INTO AN ALKALINE DRAINAGE DITCH DURING LOW WATER SEASON DUE TO LACK OF A SEPARATE DRAINAGE SYSTEM FOR REMOVING USED IRRIGATION WATERS. A SIZABLE STORAGE RESERVOIR WITH A CAPACITY OF 258 MILLION CUBIC METERS HAS BEEN BUILT AT SAN LORENZO, BUT SUFFERS FROM ENORMOUS EVAPORATIVE LOSSES AND AN INSUFFICIENT REGIONAL HYDROLOGIC DATA BASE. AMAZINGLY, IN THIS REGION SUFFERING FROM A SPECTRUM OF RESOURCE PROBLEMS, THERE IS NO AGRICULTRUAL RESEARCH STATION. NOT FAR TO THE NORTH, THE LARGE EFFICIENT MALLARES FARM (6000 HECTARES) FURNISHES A STARTLING CONTRAST IN DESERT AGRICULTURE. INTELLIGENT LOCAL MANAGEMENT RESULTS IN A PROSPEROUS ENTERPRISE, INTEGRATING ADVANCED AGRICULTURE TECHNIQUES, BIOLOGICAL PEST CONTROL AND MINIMUM USE OF PESTICIDES AND ARTIFICIAL FERTILIZERS, AND FIRST AND FOREMOST, A STRICT IRRIGATION CUM DRAINAGE REGIME. (OALS)

OALS/ARID LANDS/IRRIGATION PRACTICES/SALINE WATER/LAND USE/LAND MANAGEMENT/ WATER CONSERVATION/GROUNDWATER/RESERVOIRS/WATER RESOURCES DEVELOPMENT/WATER SOURCES/ENVIRONMENTAL EFFECTS/EVAPORATION/REGIONAL ANALYSIS/PERU/PERUVIAN DESERT/GOSSYPIUM/ORYZA/CROP PRODUCTION/PESTS(INSECTS)/BIOLOGICAL CONTROLS/ PESTICIDES/SECHURA DESERT/WATER MANAGEMENT/RESOURCES/SALINITY

0006

ANONYMOUS

1970

THE PROTECTION OF GROUNDWATER RESOURCES.

WATER WELL JOURNAL 24(7):31-33.

SEE: SWRA W71-08542

GROUNDWATER/WATER RESOURCES DEVELOPMENT/REVIEWS/FEDERAL GOVERNMENT/ WATER POLLUTION SOURCES/WATER QUALITY CONTROL/POLLUTANT IDENTIFICATION/ INJECTION WELLS/WATER MANAGEMENT(APPLIED)/SURFACE-GROUNDWATER RELATIONSHIPS

0007

ARIZONA TOWN HALL, 10TH, CASTLE HOT SPRINGS, 1967

1967

DO AGRICULTURAL PROBLEMS THREATEN ARIZONA'S TOTAL ECONOMY?

ARIZONA ACADEMY, PHOENIX. 173 P.

REVIEWS ARIZONA'S CROP AND LIVESTOCK INDUSTRIES, BY CONSIDERING THEIR IMPORTANCE TO THE STATE, AND THE RELATIONSHIP OF AGRICULTURAL NEEDS TO WATER SUPPLY. PARTIAL SOLUTIONS TO PROBLEMS OF OVERDRAFTING GROUNDWATER SUPPLIES CAN BE ACCOMPLISHED BY A NUMBER OF CONSERVATION TECHNQIUES. THE AUTHORS ENVISION UNSOLVED WATER SUPPLY POLICY FOR AGRICULTURE AS POSSIBLY LEADING TO DIVERSION OF LIMITED WATER SUPPLIES AND THE CONVERSION OF ARABLE LAND TO URBAN SPRAWL.

WATER SUPPLY/ECONOMICS/GROUNDWATER/MANAGEMENT/WATER DEMAND/WATER COSTS/ OVERDRAFT/CONJUNCTIVE USE/WATER YIELD/WATER TABLE/WATER CONSERVATION/WATER ALLOCATION(POLICY)/CROP PRODUCTION/LIVESTOCK/URBANIZATION/DIVERSION/ AGRICULTURAL USE OF WATER

0008

BAGLEY, E.S.

1961

WATER RIGHTS LAW AND PUBLIC POLICIES RELATING TO GROUNDWATER MINING IN THE SOUTHWESTERN STATES.

JOURNAL OF LAW AND ECONOMICS 4:144-174.

IN MANY AREAS OF THE SOUTHWEST GROUNDWATER IS BEING WITHDRAWN FASTER THAN IT IS BEING RECHARGED. WATER RIGHTS DOCTRINES AND THE LEGAL STATUS OF GROUNDWATER MINING IS REVIEWED FOR EACH STATE. THE EFFECT OF GROUNDWATER DOCTRINES ON DEPLETION OF GROUNDWATER IS DISCUSSED. DESPITE POLICIES TO AVOID OVERDRAFT, IT IS OCCURRING BECAUSE OF LACK OF CONCLUSIVE DATA ON RECHARGE, THE BELIEF THAT LANDOWNERS HAVE THE RIGHT TO USE WATER UNDER THEIR LAND, AND THE LARGE AMOUNT OF GROUNDWATER IN STORAGE WHICH ALLOWS OVERDRAFT TO CONTINUE FOR A PROLONGED PERIOD WITHOUT SERIOUS ECONOMIC PROBLEMS. ECONOMICS, PATTERNS OF LAND OWNERSHIP, AND AQUIFER CHARACTERISTICS SEEM TO BE MORE IMPORTANT IN DETERMINING THE RATE AND GEOGRAPHY OF DEPLETION THAN GROUNDWATER DOCTRINES.

WATER LAW/GROUNDWATER/LEGAL ASPECTS/WATER RIGHTS/LEGISLATION/WITHDRAWAL/ WATER TABLE/SUBSURFACE WATERS/SOUTHWEST U.S./GROUNDWATER MANAGEMENT/IRRIGATION EFFECTS/WATER LEVEL FLUCTUATIONS/GROUNDWATER MINING/PUBLIC RIGHTS/ INSTITUTIONAL CONSTRAINTS/OVERLYING PROPRIETOR

0009

BAGLEY, J.M.

1965

EFFECTS OF COMPETITION ON EFFICIENCY OF WATER USE.

AMERICAN SOCIETY OF CIVIL ENGINEERS, IRRIGATION AND DRAINAGE DIVISION, JOURNAL 91 (IR1):69-77.

MANY FACTORS OPERATE TO INFLUENCE THE RELATION BETWEEN COMPETITION FOR WATER AND ITS EFFICIENCY OF USE. CAREFUL ATTENTION MUST BE GIVEN TO DEFINITION OF BOUNDARIES, TERMINOLOGY, ETC., IF MEANINGFUL RELATIONS ARE TO BE OBTAINED IN SPECIFIC INSTANCES. AN APPRECIATION FOR THE INTERCONNECTION OF ALL NATURAL WATERS TOGETHER WITH THEIR VARIABLE AND MOBILE CHARACTERISTICS IS NEEDED. A RECOGNITION OF THE EFFECT OF LEGAL AND INSTITUTIONAL MECHANISMS WHICH MODIFY THE RELATION BETWEEN COMPETITION AND WATER USE IS REQUIRED ALSO. SPECIFIC EXAMPLES ILLUSTRATE BOTH FAVORABLE AND ADVERSE EFFECTS OF COMPETITION ON EFFICIENCY OF WATER USE. (AUTHOR)

COMPETITION/IRRIGATION/WATER CONSUMPTION/WATER DISTRIBUTION

0010

BAIRD, F.L./SMITH, R.E.

1976

ATTITUDES AND PUBLIC PARTICIPATION ON THE HIGH PLAINS TOWARD GROUNDWATER PLANNING AND MANAGEMENT INSTITUTIONS.

TEXAS TECH UNIVERSITY, LUBBOCK. 69 P. AVAILABLE NTIS AS PB-253 519/3WN.

SEE: SWRA W76-08375.

GROUNDWATER/TEXAS/GROUNDWATER MINING/WATER LEVEL FLUCTUATIONS/GROUNDWATER MANAGEMENT/SOCIAL ASPECTS/POLITICAL ASPECTS/BEHAVIOR/IRRIGATION WELLS

0011

BARICA, J.

1972

SALINIZATION OF GROUNDWATER IN ARID ZONES.

WATER RESEARCH 6(8):925-933.

SEE: SWRA W73-07642.

GROUNDWATER/ARID LANDS/WATER POLLUTION/WATER QUALITY/IRRIGATION/SALINE WATER INTRUSION/SALINE WATER-FRESHWATER INTERFACES/ENVIRONMENTAL EFFECTS/GROUNDWATER RECHARGE/SALINITY/SALTS

0012

BARKLEY, P.W.

1967

RESEARCH IN GROUND-WATER ECONOMICS IN THE HIGH PLAINS AREA OF COLORADO.

GROUND WATER 5(3):23-26.

THE GROUNDWATER AQUIFER UNDERLYING THE NORTHEAST CORNER OF COLORADO IS ESTIMATED AT 80,000,000 ACRE FEET, 30,000,000 OF WHICH IS ECONOMICALLY RECOVERABLE. RECHARGE RATE IS VERY LOW AND THE RATE OF USE BY IRRIGATION IS INCREASING, AND DEPLETION IS A POSSIBILITY. FEW EMPIRICAL STUDIES ARE AVAILABLE TO SHOW ECONOMIC CONSEQUENCES OF ALTERNATIVE RATES OF USE, AND GROUNDWATER POLICY LAGS BEHIND NEEDS OF DEVELOPING AREAS. RESEARCH BY THE ECONOMICS DEPARTMENT AT COLORADO STATE UNIVERSITY WILL BE EXAMINING THE FOLLOWING THEMES: 1) THE ECONOMICS OF COMMON PROPERTY RESOURCES AND THE DIFFERENT MANAGEMENT PROBLEMS ASSOCIATED WITH THEM; 2) PROBLEMS FACED BY INDIVIDUAL FARMERS AS THEY MAKE THE SWITCH FROM DRY-LAND TO IRRIGATED FARMING; 3) PROBLEMS LIKELY TO BE FACED BY INHABITANTS OF COMMUNITIES IN DEVELOPING AREAS; 4) POLICY RECOMMENDATIONS APPROPRIATE TO AREAS OF RAPID GROUNDWATER DEVELOPMENT. (AFTER AUTHOR)

COLORADO/GROUNDWATER/ARID LANDS/ECONOMICS/OGALLALA AQUIFER/WATER MANAGEMENT(APPLIED)/POLICY

0013

BAUER, R.W.

1971

THE PAPAGO CATTLE ECONOMY. IMPLICATIONS FOR ECONOMIC AND COMMUNITY DEVELOPMENT IN ARID LANDS. IN W.G. MCGINNIES, B.J. GOLDMAN, AND P. PAYLORE, EDS., FOOD, FIBER AND THE ARID LANDS, P. 79-102.

UNIVERSITY OF ARIZONA PRESS, TUCSON. 437 P.

A HISTORY AND COMPARISON OF FEDERAL PROJECTS TO DEVELOP A MODERN CATTLE INDUSTRY FOR THE PAPAGO TRIBE OF ARIZONA POINTS OUT IMPORTANT SOCIAL FACTORS AFFECTING THE TRANSFER OF RESPONSIBILITY FOR PROGRAM PLANNING AND IMPLEMENTATION FROM PROFESSIONAL ADMINISTRATORS AND TECHNICIANS TO INDIAN COMMUNITIES. THE AUTHOR RECOMMENDS RECOGNITION OF AN EXISTING OR SPECIALLY FORMED GROUP WIDELY VIEWED AS BELONGING TO AND REPRESENTATIVE OF THE ENCLAVE

GROUP, INVESTMENTS INTO THE ENCLAVE-CONTROLLED ORGANIZATION; MAINTENANCE OF A GEOGRAPHICAL SEPARATION FROM THE ENCLAVE COMMUNITY OR POLICY-MAKING BODY; AND NEGOTIATION OF ECONOMIC-DEVELOPMENT PLANS WITH THE ENCLAVE COMMUNITY ORGANIZATION UNDER ITS CONTROL, AT ITS REQUEST, AND WITH ACCOUNTABILITY TO THAT BODY. (AFTER AUTHOR)

LIVESTOCK/CATTLE/PAPAGO INDIAN RESERVATION/ARIZONA/SONORAN DESERT/ECONOMIC DEVELOPMENT/GOVERNMENT/SOCIAL ORGANIZATION/INDIANS OF NORTH AMERICA

0014

BEAUMONT, P.

1976

WATER PROBLEMS IN SOUTHWEST ASIA. IN PROBLEMS IN THE DEVELOPMENT AND CONSERVATION OF DESERT AND SEMIDESERT LANDS, PRE-CONGRESS SYMPOSIUM K26, WORKING GROUP ON DESERTIFICATION IN AND AROUND ARID LANDS. ASHKHABAD, USSR, JULY 20-26, 1976, P. 105-110.

INTERNATIONAL GEOGRAPHICAL CONGRESS, 23RD, MOSCOW, 1976. WITH THE SUPPORT OF UNESCO, THE INTERNATIONAL GEOGRAPHICAL UNION, AND THE UNIVERSITY OF NEW SOUTH WALES, AUSTRALIA. 216 P.

IN THE MIDDLE EAST IT WOULD APPEAR THAT DEVELOPMENT OF WATER RESOURCE PROJECTS HAS HAD ONLY A SMALL MULTIPLIER EFFECT IN TERMS OF ECONOMIC DEVELOPMENT, PARTLY THE RESULT OF HIGH POPULATION GROWTH AND RAPID RATE OF URBANIZATION, FACTORS WHICH MEANS A LARGE PROPORTION OF NEW WATER RESOURCES HAVE HAD TO BE USED FOR SUPPLYING ESSENTIAL NEEDS OF A GROWING POPULATION RATHER THAN FOR INCREASING THE PRODUCTIVE CAPACITY OF INDUSTRY. SINCE POPULATION GROWTH IS UNLIKELY TO BE CHECKED, FURTHER WATER RESOURCE PROJECTS WILL HAVE TO BE DEVELOPED JUST TO MAINTAIN PRESENT LIVING STANDARDS. UNFORTUNATELY MOST OF THE EASILY DEVELOPABLE WATER RESOURCE SCHEMES HAVE ALREADY BEEN IMPLEMENTED, WITH THE RESULT THAT FURTHER PROJECTS WILL OFTEN BE HIGHLY EXPENSIVE, WHICH IN TURN WILL PUT INCREASING WATER COSTS ONTO AGRICULTURE AND INDUSTRY. (AFTER AUTHOR)

MIDDLE EAST/WATER RESOURCES DEVELOPMENT/WATER SUPPLY/WATER ALLOCATION(POLICY)/POPULATIONS/DESALINATION/URBAN AREAS

0015

BECKER, R.J.

1975

NON-CONSERVATION IN ARIZONA: ESTIMATES OF SOME COSTS.

ARIZONA ACADEMY OF SCIENCE, JOURNAL 10(2):90-97.

DAMAGE CAUSED BY MAN IN ARIZONA TO LAND, WATER AND AIR IS DISCUSSED AND COST ESTIMATES OF THE LOSSES ARE MADE. LAND IS DAMAGED BY EROSION WHEN THE PLANT COVER IS DESTROYED. LAND IMPROVEMENTS FOR FARMING ARE LOST BY CITY GROWTH AND BY DECLINING WATER TABLES. WATER IS LOST WHEN THE HYDROLOGIC CYCLE IS DISRUPTED AND LESS RAIN FALLS; WHEN GROUNDWATER IS PUMPED OUT AND NOT ALLOWED TO RECHARGE; WHEN FORMERLY DRY AREAS ARE FILLED WITH WATER; OR WHEN WET AREAS ARE DRAINED. AIR IS LOST WHEN ITS CARRYING CAPACITY FOR WASTES HAS BEEN EXCEEDED, AS IT HAS IN MANY PARTS OF ARIZONA. (OALS)

OALS/ARIZONA/CONSERVATION/LAND RESOURCES/WATER RESOURCES/WATER CONSERVATION/POLLUTION/AIR POLLUTION/WATER POLLUTION/ENVIRONMENTAL IMPACT/COSTS/NATURAL RESOURCES/FLOODS/PERTURBATION/SOCIAL ASPECTS/ECOLOGY/ECONOMICS/LAND USE

0016

BEKURE, S.

1971

AN ECONOMIC ANALYSIS OF THE INTERTEMPORAL ALLOCATION OF GROUNDWATER IN THE CENTRAL OGALLALA FORMATION.

OKLAHOMA STATE UNIVERSITY (PH.D. DISSERTATION). 227 P.

SEE: SWRA W71-06266.

ALLOCATION/MODELS/CROP PRODUCTION/WATER TABLE/GROUNDWATER/WITHDRAWAL/LINEAR PROGRAMMING/ECONOMIC IMPACT/WATER UTILIZATION/WATER SUPPLY/OGALLALA AQUIFER

0017

BENNETT, J.W.

1974

ANTHROPOLOGICAL CONTRIBUTIONS TO THE CULTURAL ECOLOGY AND MANAGEMENT OF WATER RESOURCES. IN L.D. JAMES, ED., MAN AND WATER, P. 34-81.

UNIVERSITY PRESS OF KENTUCKY, LEXINGTON.

A REVIEW OF THE ANTHROPOLOGICAL CONTRIBUTION TO WATER RESOURCES DEVELOPMENT, THE MAJOR WATER RESOURCE DEVELOPMENT PROBLEMS THAT MIGHT BE SOLVED WITH ASSISTANCE FROM ANTHROPOLOGISTS, AND THE PROFESSIONAL INCENTIVE AND REWARDS FOR INCREASED ACTIVITY OF ANTHROPOLOGY IN WATER-RELATED RESEARCH. SIX TOPICS ARE DEVELOPED: 1) WATER RESOURCE DEVELOPMENT IN PREHISTORIC CULTURES, 2) THE THEORETICAL CONCEPT OF A HYDRAULIC SOCIETY, 3) THE ECOLOGICAL AND CULTURAL CONSEQUENCES OF MODERN WATER DEVELOPMENT IN TROPICS, 4) ETHNOLOGICAL AND APPLIED ANTHROPOLOGICAL WORK ON WATER USE IN MODERN TRIBAL AND PEASANT SOCIETIES, 5) PROBLEMS OF WATER MANAGEMENT, AND 6) CULTURAL IMPLICATIONS OF WATER RESOURCE DEVELOPMENT AND CONSERVATION IN NORTH AMERICA. EXTENSIVE BIBLIOGRAPHY.

WATER RESOURCES DEVELOPMENT/ECOLOGY/WATER MANAGEMENT(APPLIED)/SOCIAL ASPECTS/ SOCIAL ORGANIZATION/HUMAN RESOURCES/BEHAVIOR/ARCHEOLOGY

0018

BITTINGER, M.W.

1964

THE PROBLEM OF INTEGRATING GROUND-WATER AND SURFACE WATER USE.

GROUND WATER 2(3):33-38.

THE PROBLEM OF INTEGRATING OR COORDINATING SURFACE WATER AND GROUNDWATER SUPPLIES IS BECOMING SERIOUS IN MANY AREAS WHERE THE TWO SUPPLIES ARE HYDRAULICALLY CONNECTED. BECAUSE SURFACE WATERS WERE GENERALLY DEVELOPED FIRST IN THE WEST, LATER DEVELOPMENT OF CONNECTED GROUNDWATER SUPPLIES HAS TENDED TO DEVALUE THE PRIOR APPROPRIATIONS ON THE STREAMS. LEGALLY, THOSE WITHDRAWING SUCH GROUNDWATER MAY BE IN JEOPARDY. HOWEVER, THE HIGHEST BENEFICIAL USE OF THE TOTAL WATER RESOURCE CAN ONLY BE OBTAINED THROUGH A COMBINED OR INTEGRATED USE OF BOTH SURFACE AND GROUNDWATER. A SIMPLE HYPOTHETICAL STREAM-AQUIFER SITUATION IS USED TO ILLUSTRATE THE INFLUENCE OF GROUNDWATER PUMPING UPON SURFACE FLOWS AND WATER AVAILABLE FOR DIVERSION. ONE EXAMPLE OF A POSSIBLE SITUATION IS PRESENTED. LEGAL AND ECONOMIC FACTORS MUST ALSO BE CONSIDERED IN DESIGNING THE BEST PHYSICAL SITUATION. (AUTHOR)

GROUNDWATER/STREAMFLOW/SURFACE-GROUNDWATER RELATIONSHIPS/LEGAL ASPECTS/ MODELS/WATER LAW/ECONOMIC IMPACT/GROUNDWATER MANAGEMENT

0019

BOKHARI, S.M.H.

1975

MANAGEMENT OF WATER RESOURCES UNDER DIFFERENT SOCIO-ECONOMIC CONDITIONS.

UNIVERSITY OF ARIZONA (PH.D. DISSERTATION). 290 P.

THE INDUSTRIAL REVOLUTION WAS A TURNING POINT IN THE HISTORY OF WATER MANAGEMENT. NEW TECHNIQUES HELPED TO DESIGN MULTIPURPOSE PROJECTS. IN THE DEVELOPED COUNTRIES WATER MANAGEMENT OF MULTIOBJECTIVE PROJECTS HAS THE TWO OBJECTIVES OF ECONOMIC GROWTH AND ENVIRONMENTAL QUALITY. THE SYSTEM IS FLEXIBLE ENOUGH TO ACCOMMODATE ANY SUBSEQUENT TECHNOLOGICAL INNOVATION OR CHANGE IN USE REQUIREMENTS. IN CONTRAST, WATER MANAGEMENT IN DEVELOPING COUNTRIES IS LESS FLEXIBLE AND LESS ABLE TO MEET WATER DEMANDS. THE PERFORMANCES OF THE WELLTON-MOHAWK IRRIGATION DISTRICT IN THE U.S. AND THE SALINITY CONTROL AND RECLAMATION PROJECT NO. 1 ARE COMPARED TO EVALUATE WATER MANAGEMENT UNDER DIFFERENT SOCIO-ECONOMIC CONDITIONS. SUGGESTIONS ARE MADE TO REMOVE MANAGEMENT CONSTRAINTS IN THE DEVELOPING COUNTRIES IN GENERAL, AND PAKISTAN IN PARTICULAR.

WATER MANAGEMENT(APPLIED)/ECONOMIC DEVELOPMENT/DEVELOPING COUNTRIES/ IRRIGATION CANALS/WATER TRANSFER/ARIZONA/PAKISTAN/WATER RESOURCES DEVELOPMENT/ SURFACE WATERS/GROUNDWATER/DRAINAGE/WATERLOGGING/SALINITY/DESALINATION/ECONOMIC ASPECTS/WELLTON-MOHAWK IRRIGATION DISTRICT/SALINITY CONTROL AND RECLAMATION PROJECT 1

0020

BOOKMAN, M.

1968

LEGAL AND ECONOMIC ASPECTS OF SALT-WATER ENCROACHMENT INTO COASTAL AQUIFERS. IN LIMITED PROFESSIONAL SYMPOSIUM ON SALT-WATER ENCROACHMENT INTO AQUIFERS, PROCEEDINGS, P. 169-192.

LOUISIANA WATER RESOURCES RESEARCH INSTITUTE, BATON ROUGE.

AN INTEGRAL PART OF SALT-WATER INTRUSION PREVENTION IS CONTROL AND REDUCTION OF GROUNDWATER PRODUCTION, WHICH, IN LOS ANGELES COUNTY, CALIFORNIA, REQUIRED COURT ACTION. LEGISLATIVE ACTION WAS ALSO NECESSARY TO EMPOWER LOCAL WATER DISTRICTS TO CONSTRUCT, OPERATE, AND FINANCE SALT-WATER PREVENTION FACILITIES. SUCH ACTION, HOWEVER, TOOK 17 YEARS. AT PRESENT, 70 PERCENT OF THE WATER IS IMPORTED. IMPLEMENTATION OF CONTROLS WAS A 3-STEP PROCESS: 1) SHARING OF IMPORTED RIVER WATER WITH UPSTREAM OWNERS; 2) INJUNCTIONS AGAINST COASTAL AND CENTRAL BASIN PUMPERS; AND 3) ESTABLISHMENT OF A SALT-WATER BARRIER. BARRIER FINANCING CAME THROUGH AD VALOREM TAXES AND DISTRICT GENERAL FUNDS. OTHER LEGISLATION PROVIDED FOR IMMEDIATE AND LONG-TERM FINANCING OF THESE PROJECTS AND ESTABLISHED AGENCIES TO ENFORCE COURT DECISIONS. SALT-WATER PREVENTION IN THE WEST COAST BASIN IS ADMINISTERED BY 6 STATE AND LOCAL AGENCIES AND ONE CITIZENS' ASSOCIATION. THIS ARRANGEMENT HAS PROVED SUCCESSFUL AND ECONOMICAL. (AUTHOR)

AQUIFERS/SALINE WATER INTRUSION/OVERDRAFT/GROUNDWATER BARRIERS/ECONOMICS/FLOOD CONTROL/COST-BENEFIT ANALYSIS/ADJUDICATION/GROUNDWATER MANAGEMENT/ ASSESSMENTS/ADMINISTRATIVE AGENCIES/OVERLYING PROPRIETOR

0021

BOROVSKIY, V.M.

1968

THE SALTING FACTORS OF IRRIGATED SOILS IN THE TURAN PLAIN.

INTERNATIONAL CONGRESS OF SOIL SCIENCE, 9TH, ADELAIDE, AUSTRALIA, 1968, TRANSACTIONS 1:473-481.

SEE: SWRA W70-02439.

GROUNDWATER/SALINITY/IRRIGATION EFFECTS/EVAPORATION/DRAINAGE/IRRIGATED LAND/ SALINE WATER/SALT BALANCE/SOIL CHEMICAL PROPERTIES/SOILS/CAPILLARY ACTION/ IRRIGATION PRACTICES/SALTS/SALINE SOILS/SOIL PHYSICAL PROPERTIES/ARID LANDS/ DESERTS/HYDROLOGIC PROPERTIES/USSR

0022

BOWDEN, C.

1975

IMPACT OF ENERGY DEVELOPMENT ON WATER RESOURCES IN ARID LANDS.

UNIVERSITY OF ARIZONA, TUCSON, OFFICE OF ARID LANDS STUDIES, ARID LANDS RESOURCE INFORMATION PAPER 6. 278 P.

WATER IS BASIC TO ENERGY CONVERSION SYSTEMS, NATURAL AND MANMADE. THIS PAPER EXPLORES THE CONSEQUENCES OF ENERGY EXTRACTION AND CONVERSION IN ARID LANDS WHERE WATER IS SCARCE. THE HISTORICAL PAST IS UTILIZED AS A RECORD FOR CASTING MODERN DEVELOPMENT PLANS INTO PERSPECTIVE; THE WORLDWIDE GROWTH IN ENERGY CONSUMPTION RATES IS CONSIDERED AS THE MOTIVE FORCE BEHIND MANY CURRENT ENERGY PROJECTS IN ARID LANDS. ENERGY SOURCES (COAL, OIL, GAS, OIL SHALE, SOLAR ENERGY, ALTERNATIVE ENERGY SOURCES, FISSION, FUSION, AND GEOTHERMAL) ARE REVIEWED IN TERMS OF THEIR CONSEQUENCES ON THE AIR, LAND, WATER, AND INHABITANTS OF SUCH REGIONS. TWO RIVERS, THE COLORADO AND THE MISSOURI, PROVIDE SMALL-SCALE MODELS OF THE REWARDS AND HAZARDS OF HEAVILY EXPLOITING WATER-SHORT AREAS. IN BOTH INSTANCES, IT IS FOUND THAT ENERGY DEVELOPMENT PLANS, AS NOW PROPOSED, WILL SERIOUSLY DEPLETE THE WATER SUPPLY, ALTER THE QUALITY OF THE WATER, LAND, AND AIR, AND INCREASE THE HUMAN POPULATION. (AUTHOR)

BIBLIOGRAPHIES/ARID LANDS/WATER DEMAND/WATER SHORTAGE/ENERGY/STRIP MINES/STRIP MINE WASTES/OIL SHALES/COALS/GREAT PLAINS/COLORADO RIVER BASIN/MISSOURI RIVER/ ROCKY MOUNTAIN REGION/SOUTHWEST U.S./ENVIRONMENTAL EFFECTS/SOCIAL ASPECTS/ WATER ALLOCATION(POLICY)/WATER QUALITY/ENERGY CONVERSION/GEOTHERMAL STUDIES/ NUCLEAR ENERGY/NUCLEAR WASTES

0023

BOWDEN, L.W.

1965

DIFFUSION OF THE DECISION TO IRRIGATE: SIMULATION OF THE SPREAD OF A NEW RESOURCE MANAGEMENT PRACTICE IN THE COLORADO NORTHERN HIGH PLAINS.

UNIVERSITY OF CHICAGO, DEPARTMENT OF GEOGRAPHY, RESEARCH PAPER 97. 146 P.

GROUND WATER IRRIGATION AS AN ECONOMIC WAY OF LIFE ON THE NORTHERN HIGH PLAINS OF COLORADO BEGAN IN THE 1960S AFTER SHORT BUT SEVERE DROUGHTS BROUGHT ECONOMIC DISASTER TO THE DRYLAND FARMER AN[illegible] ATTLE RANCHER. REASONS BEHIND THE DECISION TO IRRIGATE AND THE DEVELOPMENT AND SPREAD OF THE NEW RESOURCE PRACTICE ARE DISCUSSED. THE MONTE CARLO SIMULATION OF DIFFUSION METHOD IS USED TO PROJECT FUTURE DIFFUSION OF WELLS. THE DIFFUSION OF A NEW RESOURCE PRACTICE IS DEPENDENT UPON WHETHER IT IS PHYSICALLY POSSIBLE, ECONOMICALLY GAINFUL, SOCIALLY ACCEPTABLE AND [illegible]LY PERMISSIBLE. PUMP IRRIGATION IS MOST SUCCESSFUL UNDER THE SHREW[illegible] FINANCED, ENLIGHTENED RESOURCE MANAGER. THE TREND IN AGRICULTURE OF THE [illegible]N HIGH PLAINS OF COLORADO, FACILITATE[illegible] BY THE SPREAD OF PUMP IRRIGATION, [illegible]OWARD CORPORATED, UNSUBSIDIZED, COMPETITIVE AGRICULTURE.

IRRIGATION/WELLS/AGRICULTURE/COLORADO/GROUNDWATER/ECONOMIC IMPACT/ARID LANDS/ SOCIAL ASPECTS/LEGAL ASPECTS/MODELS/ECONOMIC DEVELOPMENT

0024

BRUINGTON, A.E.

1968

THE AMELIORATION OR PREVENTION OF SALT-WATER INTRUSION IN AQUIFERS: EXPERIENCE IN LOS ANGELES COUNTY, CALIFORNIA. IN LIMITED PROFESSIONAL SYMPOSIUM ON SALT-WATER ENCROACHMENT INTO AQUIFERS, PROCEEDINGS, P. 153-168.

LOUISIANA WATER RESOURCES RESEARCH INSTITUTE, BATON ROUGE.

TWO THIRDS OF ALL WATER USED BY LOS ANGELES COUNTY IS IMPORTED. SURFACE STORAGE IS NOT ADEQUATE FOR EMERGENCIES AND PEAK DEMAND. UNDERGROUND STORAGE FROM WINTER STORMS IS USED FOR THESE PURPOSES AND DAY-TO-DAY SUPPLEMENTAL WATER. THE PRESSURE-RIDGE METHOD WAS SELECTED FOR RECHARGE OF THE AQUIFERS AND TO DETER SALINE INTRUSION. A LINE OF INJECTION WELLS CREATES A PRESSURE FIELD MUCH LIKE A CONTINUOUS CURTAIN WALL. WATER LOGGING HAS BEEN CONTROLLED IN LOW AREAS BY SEAWARD EXTRACTION ALONG WITH THE PRESSURE-RIDE INJECTION. INJECTED WATER MUST BE OF HIGH QUALITY TO PREVENT CLOGGING OF WELLS, INCREASE WELL LIFE, AND REDUCE WELL-CLEANING COSTS. OBSERVATION WELLS ARE NEEDED AT CRITICAL POINTS ALONG THE BARRIER LINE TO MONITOR THE GROUND-WATER ELEVATION. THE LOCATION OF THE BARRIER LINE HAS ALLOWED A CERTAIN AMOUNT OF SALT WATER TO BE CUT OFF, OR TRAPPED, BEHIND THE BARRIER. THE ACRE-FOOT COST OF INJECTED WATER FOR 1966, 13.00 DOLLARS, DID NOT INCLUDE THE COST OF SUPPLY WATER, AMORTIZED CAPITAL OUTLAY PER WELL, PIPELINES, AND OTHER APPURTENANCES. (AUTHOR)

SALINE WATER INTRUSION/AQUIFERS/GROUNDWATER BARRIERS/INJECTION WELLS/ PIEZOMETRIC LEVEL/UNIT COST/WATER REUSE/GROUNDWATER RECHARGE/NATURAL RECHARGE/ PIT RECHARGE/WATER QUALITY/WELL SCREENS/WELL CASINGS/CONSTRUCTION COSTS/ OPERATING COSTS

0025

BRUNE, G.

1975

MAJOR AND HISTORICAL SPRINGS OF TEXAS.

TEXAS WATER DEVELOPMENT BOARD, AUSTIN, REPORT 189. 95 P.

SEE: SWRA W75-07152.

SPRINGS/TEXAS/HISTORY/HYDROGEOLOGY/SPRING WATERS/WATER SOURCES/WATER SUPPLY/ ARTESIAN AQUIFERS/ARTESIAN WELLS/GROUNDWATER/GROUNDWATER MOVEMENT/GEOLOGY/ DISCHARGE(WATER)

0026

BRYAN, K.

1928

CHANGE IN PLANT ASSOCIATIONS BY CHANGE IN GROUND WATER LEVEL.

ECOLOGY 9(4):474-478.

AUTHOR REVIEWS HISTORICAL LITERATURE ON THE HYDROLOGIC AND VEGETATIVE CONDITIONS OF SOME OF THE VALLEYS OF THE ARID SOUTHWEST--THE SANTA CRUZ AND THE SAN PEDRO VALLEYS IN ARIZONA; AND THE SONOITA RIVER VALLEY IN SONORA, MEXICO--TO DOCUMENT THE CHANGE IN VEGETATION THAT HAS ACCOMPANIED THE LOWERING OF THE GROUNDWATER. PRIOR TO THE 1880S, MANY VALLEYS IN THIS AREA HAD SHALLOW, ILL DEFINED STREAM CHANNELS, SWAMPS AND CIENEGAS WITH LUSH STANDS OF SACATON GRASS, COTTONWOOD, TULE, WILLOWS AND MESQUITE. AFTER THE 1880S A PERIOD OF ARROYO CUTTING BEGAN WHICH DRAINED THE SWAMPY AREAS AND REPLACED THE BROAD SHALOW STREAM CHANNELS WITH NARROW, STEEP WALLED GULLIES. THE WATER TABLE WAS LOWERED AND ONLY THE PHREATOPHYTES COULD SURVIVE THIS CHANGE. AUTHOR FEELS THE CAUSE OF THE ARROYO CUTTING PROCESS MAY BE A CHANGE TO A DRIER CLIMATE WITH OVERGRAZING OF CATTLE AS AN ACCESSORY.

GROUNDWATER/PHREATOPHYTES/WATER TABLE/RIPARIAN VEGETATION/PLANT COVER/ VEGETATION/PLANT COMMUNITIES/STREAMFLOW/SOUTHWEST U.S./ARIZONA/SONORA/SANTA CRUZ RIVER BASIN/SAN PEDRO VALLEY/VEGETATION CHANGE/OVERGRAZING/CLIMATIC CHANGE/HISTORY

0027

BULL, W.B.

1975

LAND SUBSIDENCE DUE TO GROUNDWATER WITHDRAWAL IN THE LOS BANOS - KETTLEMAN CITY AREA, CALIFORNIA. 2: SUBSIDENCE AND COMPACTION OF DEPOSITS.

U.S. GEOLOGICAL SURVEY, PROFESSIONAL PAPER 437-F. 90 P.

PUMPING OF GROUNDWATER HAS INCREASED THE STRESSES TENDING TO COMPACT UNCONSOLIDATED DEPOSITS BY AS MUCH AS 50 PERCENT, THEREBY CREATING THE WORLD'S LARGEST AREA OF INTENSE LAND SUBSIDENCE IN THE WEST-CENTRAL SAN JOAQUIN VALLEY, CALIFORNIA. AS OF 1966, 2000 SQUARE MILES HAD SUBSIDED MORE THAN 1 FOOT. MAXIMUM SUBSIDENCE AS OF 1968 WAS ESTIMATED TO BE 28 FEET. SPECIAL COMPACTION RECORDERS IN WELLS PENETRATING MOST OF THE AQUIFER SYSTEM TAPPED BY WELLS INITIALLY MEASURED AS MUCH AS 99 PERCENT OF THE SUBSIDENCE. SINCE 1963 MOST RECORDERS HAVE BEEN MEASURING PROGRESSIVELY LESS OF THE SUBSIDENCE WHICH INDICATES THAT COMPACTION DUE TO PORE-PRESSURE DECLINE IS OCCURRING AT GREATER DEPTHS. MAXIMUM COMPACTION OCCURS AT PUMPING WELLS, BECAUSE THEY ARE POINTS OF MAXIMUM APPLIED STRESS. (AFTER AUTHOR)

SUBSIDENCE/GROUNDWATER/ARTESIAN WELLS/CALIFORNIA/AQUIFERS/ARID LANDS/ WITHDRAWAL

0028

BULL, W.B./MILLER, R.E.

1975

LAND SUBSIDENCE DUE TO GROUNDWATER WITHDRAWAL IN THE LOS BANOS - KETTLEMAN CITY AREA, CALIFORNIA. 1: CHANGES IN THE HYDROLOGIC ENVIRONMENT CONDUCIVE TO SUBSIDENCE.

U.S. GEOLOGICAL SURVEY, PROFESSIONAL PAPER 437-E. 71 P.

IRRIGATED AGRICULTURAL DEVELOPMENT THROUGH THE PUMPING OF GROUNDWATER BEGINNING IN THE 1920'S HAS DISRUPTED THE NATURAL GROUNDWATER RESERVOIR FLOW SYSTEMS IN THE WEST-CENTRAL AREA OF THE SAN JOAQUIN VALLEY, CALIFORNIA. FLOWING WELLS WERE COMMON AND THE LOWER ZONE POTENTIOMETRIC SURFACE, WHICH WAS IN PLACES 20 FEET ABOVE LAND SURFACE, HAD A SLOPE OF 2-5 FEET/MILE TO THE EAST IN THE EARLY 1900'S. BY 1960, DUE TO GROUNDWATER PUMPING, THE LOWER ZONE POTENTIOMETRIC SURFACE WAS SLOPING 30 FEET/MILE TO THE WEST AND OVERALL HEAD DECLINES OF 300 TO 400 FEET WERE COMMON. CHANGES IN THE UPPER ZONE AQUIFER HAVE NOT BEEN AS PRONOUNCED AS IT HAS NOT BEEN AS INTENSIVELY PUMPED. LOCALLY THE WATER TABLE HAS DECLINED MORE THAN 300 FEET AND IN OTHER AREAS IT HAS RISEN 25 TO 100 FEET AND MUCH OF THE AREA MAY BE THREATENED WITH INSUFFICIENT DRAINAGE FOR CROPS. THE DIFFERENT AQUIFER SYSTEMS ARE DESCRIBED.

SUBSIDENCE/WELLS/CALIFORNIA/GROUNDWATER/PUMPING/IRRIGATION WELLS/AQUIFERS/ ARTESIAN WELLS/WITHDRAWAL/ARID LANDS

0029

BULL, W.B./POLAND, T.F.

1975

LAND SUBSIDENCE DUE TO GROUNDWATER WITHDRAWAL IN THE LOS BANOS - KETTLEMAN CITY AREA, CALIFORNIA. 3: INTERRELATIONS OF WATER-LEVEL CHANGE, CHANGE IN AQUIFER-SYSTEM THICKNESS, AND SUBSIDENCE.

U.S. GEOLOGICAL SURVEY, PROFESSIONAL PAPER 437-G. 62 P.

BY INCREASING THE STRESSES TENDING TO COMPACT THE DEPOSITS BY AS MUCH AS 50 PERCENT, MAN HAS CREATED THE WORLD'S LARGEST AREA OF INTENSE LAND SUBSIDENCE IN THE WEST-CENTRAL SAN JOAQUIN VALLEY, CALIFORNIA. CHANGES IN THE AQUIFER-SYSTEM MAY BE BOTH ELASTIC (ARE REVERSIBLE AND OCCUR WITH MINOR TIME DELAY) AND INELASTIC (ARE IRREVERSIBLE AND OCCUR WITH LARGE TIME DELAY). COMPACTION CEASES WHEN AQUIFER PORE PRESSURES RISE TO EQUILIBRIUM WITH THE MAXIMUM PORE PRESSURE IN A CONTIGUOUS AQUITARD, THUS PREVENTING FURTHER EXPULSION OF WATER. IMPORTATION OF SURFACE WATER HAS RESULTED IN ALLEVIATION OF SUBSIDENCE IN SOME AREAS. (AFTER AUTHOR)

SUBSIDENCE/GROUNDWATER/AQUIFERS/ARTESIAN WELLS/CALIFORNIA/WATER TRANSFER/ ARID LANDS/WITHDRAWAL

0030

BURDAK, T.G.

1970

PROJECTIONS OF FARMER RESPONSE TO A FALLING GROUNDWATER TABLE: MARRIAGE OF ECONOMIC AND HYDROLOGIC MODELS.

UNIVERSITY OF ARIZONA (M.S. THESIS). 140 P.

GROUNDWATER PROBLEMS OF CENTRAL ARIZONA ARE ILLUSTRATIVE OF MOST OF THE IMPORTANT GROUNDWATER MANAGEMENT PROBLEMS ENCOUNTERED IN OTHER ARID REGIONS. RAPID DECLINES OF GROUNDWATER LEVELS PROVOKES PUBLIC CONCERN OVER WHAT IS THE BEST GROUNDWATER MANAGEMENT POLICY. TO PROVIDE OBJECTIVE CRITERIA FOR SELECTING BETWEEN ALTERNATIVE PUBLIC POLICIES, IT IS NECESSARY TO PROJECT THE CONSEQUENCES OF EACH. THIS REQUIRES THAT THE INTERACTIONS THROUGH TIME BETWEEN THE WATER USING SECTORS OF THE ECONOMY AND THE PHYSICAL STATE OF THE AQUIFER BE ESTIMATED. A PROCEDURE INCORPORATING DYNAMIC PROPERTIES INTO BOTH FORMAL ECONOMIC AND HYDROLOGIC MODELS IS DEVISED AND TENTATIVE POLICY IMPLICATIONS ARE DRAWN. (AFTER AUTHOR).

GROUNDWATER/ARIZONA/IRRIGATION/AGRICULTURE/MODELS/ECONOMIC IMPACT/ARID LANDS/ PUMPING/CROP PRODUCTION

0031

BURDON, D.J.

1971

EXPLOITATION OF GROUNDWATER FOR AGRICULTURAL PRODUCTION IN ARID ZONES. IN W.G. MCGINNIES, B.J. GOLDMAN, AND P.PAYLORE, EDS., FOOD, FIBER AND THE ARID LANDS, P. 289-300.

UNIVERSITY OF ARIZONA PRESS, TUCSON. 437 P.

SEE: SWRA W72-03666.

ARID LANDS/GROUNDWATER/IRRIGATION PRACTICES/EXPLOITATION/SALINITY/SALINE SOILS/SALINE WATERS/EVAPOTRANSPIRATION/DRAINAGE PRACTICES/AQUIFERS/SEMIARID CLIMATE/WATER RESOURCES DEVELOPMENT/STOCK WATER/WATER QUALITY

0032

CALIFORNIA, DEPARTMENT OF WATER RESOURCES

1960

SEA-WATER INTRUSION IN CALIFORNIA.

SAME AS AUTHOR, DIVISION OF RESOURCES PLANNING, BULLETIN 63.

CONTAINS THREE APPENDICES: APPENDIX C WITH LABORATORY AND MODEL STUDIES, AN ABSTRACT OF THE LITERATURE, AND A REVIEW OF FORMULAS AND DERIVATIONS; APPENDIX D, AN INVESTIGATION OF SOME PROBLEMS IN PREVENTING SEA-WATER INTRUSION BY CREATING A FRESH-WATER BARRIER; AND APPENDIX E, PRELIMINARY CHEMICAL-QUALITY STUDY IN THE MANHATTAN BEACH AREA, CALIFORNIA.

SALINE WATER INTRUSION/CALIFORNIA/GROUNDWATER/MODELS/BIBLIOGRAPHIES/SALINE WATER-FRESHWATER INTERFACES/WELLS/WATER QUALITY/WATER CHEMISTRY/SALINITY

0033

CALIFORNIA, DEPARTMENT OF WATER RESOURCES

1972

SEA-WATER INTRUSION: MORRO BAY AREA, SAN LUIS OBISPO COUNTY.

SAME AS AUTHOR, BULLETIN 63-6. 104 P.

BECAUSE THE QUALITY OF GROUNDWATER HAS BEEN DEGRADED BY THE INTRUSION OF SEA WATER, SEVERAL WELLS HAVE BEEN ABANDONED ALONG THE COASTAL MARGIN OF MORRO, CHORRO, AND LOS OSOS GROUNDWATER BASINS. INCREASES IN CHLORIDE-ION CONTENT IN GROUNDWATER HAVE OCCURRED IN RESPONSE TO THE LOWERING OF WATER LEVELS TO BELOW SEA LEVEL DURING PERIODS OF INTENSIVE PUMPING ALTHOUGH OTHER SOURCES OF DEGRADATION EXIST LOCALLY. (AFTER AUTHOR)

GROUNDWATER/SALINE WATER INTRUSION/WATER LEVEL FLUCTUATIONS/PUMPING/ CALIFORNIA/COASTS

0034

CASTANY, G./MARGAT, J.

1967

FROM CATCHMENT TECHNIQUES TO THE STRATEGY OF OPTIMUM UTILIZATION OF WATER RESOURCES: EXPANSION OF THE ROLE OF HYDROGEOLOGY. IN INTERNATIONAL CONFERENCE ON WATER FOR PEACE, 1967, WASHINGTON, D.C., WATER FOR PEACE 2:926-929.

U.S. GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C.

MAN'S ACCELERATING RATE OF WATER CONSUMPTION, THE AVAILABILITY OF A TECHNOLOGY TO EXPLOIT WATER ON A LARGE SCALE, AND POLICIES THAT FAVOR EXPLOITATION COMBINE TO CREATE PROBLEMS RELATING TO GROUNDWATER EXPLOITATION OF A NEW DIMENSION. OPTIMAL UTILIZATION OF GROUNDWATER IS DEPENDENT UPON AN UNDERSTANDING OF THE AQUIFER'S PARAMETERS. FOUR DIFFERENT AQUIFER TYPES ARE DESCRIBED: 1) AQUIFERS WITH SMALL RESERVES BUT HIGH RENEWAL RATES, 2) AQUIFERS WITH SMALL RESERVES AND LOW, IRREGULAR RECHARGE, 3) AQUIFERS WITH SUBSTANTIAL RESERVES AND HIGH RENEWAL RATES, AND 4) CONFINED AQUIFERS WITH LOW RENEWAL RATES. DELINEATION OF AQUIFER TYPE IS AN IMPORTANT CONTRIBUTION BY THE HYDROGEOLOGIST IN THE RESEARCH OF THE OPTIMIZATION OF UTILIZATION.

GROUNDWATER/AQUIFERS/GROUNDWATER RECHARGE/HYDROGEOLOGY/WATER CONSUMPTION/ WITHDRAWAL/GROUNDWATER MANAGEMENT/INSTITUTIONAL EFFECTS

0035

CASTLEBERRY, J.N., JR.

1975

A PROPOSAL FOR ADOPTION OF A LEGAL DOCTRINE OF GROUND STREAM WATER INTERRELATIONSHIP IN TEXAS.

ST. MARY'S LAW JOURNAL 7(3):503-514.

GROUNDWATER LAW IN TEXAS IS INCONSISTENT WITH MODERN SCIENTIFIC KNOWLEDGE OF GEOLOGY AND HYDROLOGY. THE POLICY CONSIDERATIONS WHICH SHOULD UNDERLIE A MODERN RULE OF LAW ARE REALIZED THRU THE RECOGNITION AND APPLICATION OF SCIENTIFICALLY DEMONSTRABLE INTERRELATIONSHIP BETWEEN THE WATERS OF A FLOWING STREAM AND THOSE GROUNDWATERS WHICH FEED OR CONTRIBUTE TO THE FLOW OF THAT STREAM. BASIC GROUNDWATER DOCTRINES ARE BRIEFLY REVIEWED. CASES FROM CALIFORNIA, COLORADO, NEW MEXICO AND UTAH, WHICH RECOGNIZE THE RELATIONSHIP BETWEEN SURFACE AND GROUNDWATERS, ARE DISCUSSED TO ILLUSTRATE SCIENTIFICALLY RATIONAL GROUNDWATER LAWS. MODERN, SCIENTIFIC KNOWLEDGE MUST BE USED IN THE COURTS IF CURRENT AND FUTURE DEMANDS FOR WATER ARE TO BE MOST EFFECTIVELY AND EFFICIENTLY ATTAINED.

GROUNDWATER/SURFACE-GROUNDWATER RELATIONSHIPS/TEXAS/GROUNDWATER LAW/ STREAMFLOW/WITHDRAWAL/WELLS/WATER MANAGEMENT(APPLIED)

0036

CHALMERS, J.R.

1974

SOUTHWESTERN GROUNDWATER LAW: A TEXTUAL AND BIBLIOGRAPHIC INTERPRETATION.

UINVERSITY OF ARIZONA, TUCSON, OFFICE OF ARID LANDS STUDIES, ARID LANDS RESOURCES INFORMATION PAPER 4. 229 P. AVAILABLE NTIS AS PB-228 130. SWRA W74-04460.

THIS PAPER ATTEMPTS TO BRING TOGETHER UP-TO-DATE INFORMATION ON THE INTERPRETATION OF GROUNDWATER LAW DOCTRINES AND APPLIED WATER MANAGEMENT POLICIES IN THE SOUTHWESTERN STATES OF ARIZONA, CALIFORNIA, COLORADO, NEVADA, NEW MEXICO, TEXAS, AND UTAH, WHERE NONE IS ABLE TO MEET PRESENT WATER DEMAND FROM SURFACE SUPPLIES. THE RESULTING MINING OF GROUNDWATER, LARGELY TO MEET IRRIGATION NEEDS, IS CREATING A CRITICAL SITUATION THAT EACH OF THE STATES COVERED SEEKS TO MEET IN A VARIETY OF WAYS. THE DOCTRINES OF CORRELATIVE RIGHTS, THE ENGLISH COMMON LAW, PRIOR APPROPRIATION AND ITS CONTEMPORARY MODIFICATIONS, ARE ALL DISCUSSED, STATE BY STATE. WHILE ARIZONA HAS BEEN SELECTED TO SERVE AS A CASE STUDY TO PUT THE PROBLEM OF A DIMINISHING GROUNDWATER SUPPLY IN PERSPECTIVE, THERE IS ALSO A CHRONOLOGICAL SURVEY OF THE DEVELOPMENT OF GROUNDWATER RIGHTS LAW FOR EACH OF THE STATES. A FINAL CHAPTER DEALS WITH THE AUTHOR S CONCEPT OF A STATUTORY REVISION OF ARIZONA S CODE, WITH A MODIFIED PRIOR APPROPRIATION DOCTRINE RECOMMENDED. APPENDED IS A 180-ITEM COMPUTERIZED ANNOTATED BIBLIOGRAPHY.

OALS/GROUNDWATER/LEGAL ASPECTS/SOUTHWEST U.S./ARIZONA/CALIFORNIA/COLORADO / NEVADA/NEW MEXICO/TEXAS/UTAH/BIBLIOGRAPHIES/CONJUNCTIVE USE/GROUNDWATER MINING/WATER LAW/IRRIGATION WATER /PUMPING/PRIOR APPROPRIATION/REASONABLE USE/SURFACE-GROUNDWATER RELATIONSHIPS/WATER RIGHTS/WATER MANAGEMENT /WATER RESOURCES DEVELOPMENT/COMPETING USES

0037

CHILD, F.C./KANEDA, H.

1975

LINKS TO THE GREEN REVOLUTION: A STUDY OF SMALL-SCALE AGRICULTURALLY RELATED INDUSTRY IN THE PAKISTAN PUNJAB.

ECONOMIC DEVELOPMENT AND CULTURAL CHANGE 23(2):249-275.

THE RAPID GROWTH OF AGRICULTURAL OUTPUT IN PAKISTAN DURING THE 1960S INSTIGATED THE DEVELOPMENT AND GROWTH OF A SMALL-SCALE ENGINEERING INDUSTRY WHICH SUPPLIES KEY DURABLE-GOODS INPUTS, MAINLY DIESEL ENGINES, PUMPS AND STRAINERS FOR TUBEWELLS. GROWTH OF THIS INDUSTRY IS IMPORTANT TO NOTE BECAUSE: 1) IT IS A GOOD SPECIFIC EXAMPLE OF INDUSTRIAL/AGRICULTURAL INTERACTION, 2) IT IS TRULY SMALL-SCALE AND HAS BEEN A VEHICLE FOR DEVELOPING MANAGERIAL AND ENTREPRENERIAL TALENT, TRAINING OF SKILLED AND SEMI-SKILLED LABOR, AND FOR APPLICATION OF NEW TECHNOLOGY AND 3) IT OCCURRED SPONTANEOUSLY WITH NO SUBSIDIES, NO TAX CONCESSIONS, NO TECHNICAL ASSISTANCE OR RECOGNITION BY OFFICIAL AGENCIES. THE DEVELOPMENT, STRUCTURE AND BEHAVIORAL CHARACTERISTICS OF THIS INDUSTRY ARE DISCUSSED. SUGGESTIONS FOR PUBLIC POLICIES RELATING TO INDUSTRY AND ECONOMIC DEVELOPMENT ARE MADE.

ECONOMIC DEVELOPMENT/GREEN REVOLUTION/INDUSTRY/PAKISTAN/TECHNOLOGY

0038

CLYMA, W./YOUNG, R.A.

1968

ENVIRONMENTAL EFFECTS OF IRRIGATION IN THE CENTRAL VALLEY OF ARIZONA.

AMERICAN SOCIETY OF CIVIL ENGINEERS, NATIONAL MEETING ON ENVIRONMENTAL ENGINEERING, CHATTANOOGA, TENNESSEE, MAY 13-17, PREPRINT. 28 P. SWRA W70-07053.

IRRIGATION HAS MODIFIED THE ENVIRONMENT OF THE CENTRAL VALLEY OF ARIZONA FOR THE PAST 2500 YEARS, BEGINNING WITH THE IRRIGATION SYSTEMS OF THE HOHOKAM INDIANS. MODIFICATION OF THE PHYSICAL ENVIRONMENT HAS INCLUDED CHANGES IN CLIMATE, GROUNDWATER, SURFACE WATER AND VEGETATION. THE SOCIAL ENVIRONMENT HAS BEEN CHANGED FROM A RURAL ECONOMY TO AN URBAN INDUSTRIAL ECONOMIC SYSTEM. PRESENT AND FUTURE

PROBLEMS RELATED TO IRRIGATION IN THE AREA ARE DISCUSSED. SOME OF THE PROBLEMS ARE WATER DEMAND, LAND SUBSIDENCE, SALINITY, GROUND-WATER MANAGEMENT, AND ALLOCATION OF COLORADO RIVER WATER. SOLUTIONS TO SOME OF THESE PROBLEMS ARE SUGGESTED. (OALS)

ARIZONA/ENVIRONMENTAL EFFECTS/IRRIGATION EFFECTS/WATER SUPPLY/WATER RESOURCES DEVELOPMENT/IRRIGATION/IRRIGATION WATER/CLIMATE/VEGETATION/ GROUNDWATER/GROUNDWATER MINING/SALINITY/SURFACE WATERS/WATER UTILIZATION/ WATER RESOURCES/WATER TRANSFER/WATER QUALITY/SOCIAL ASPECTS/SALT RIVER VALLEY/OALS

0039

COMPTON, R.L.

1961

THE RIGHT TO THE SUBJACENT SUPPORT OF OIL AND GAS.

CALIFORNIA LAW REVIEW 49:354-367.

PROPERTY OWNERS IN THE INDUSTRALIZED AREA OVERLYING THE WILMINGTON OIL FIELD IN LOS ANGELES COUNTY, CALIFORNIA, HAVE SUFFERED AN ESTIMATED 50 MILLION DOLLARS OF PROPERTY DAMAGE DUE TO SUBSIDENCE CAUSED BY THE WITHDRAWAL OF OIL AND GAS. NO CALIFORNIA STATUTE PROVIDES A PRIVATE REMEDY FOR SUBSIDENCE DAMAGE IN THIS AREA. LEGAL CASES DEALING WITH ANALOGUS COMMON-LAW SITUATIONS (THE EXTRACTION OF GROUNDWATER AND MINERALS) ARE REVIEWED WITH A VIEW TOWARD EVALUATING THE OIL PRODUCER'S LIABILITY FOR SUBSIDENCE DAMAGE. A PLAINTIFF IN ACTION FOR DAMAGES CAUSED BY OIL AND GAS SUBSIDENCE WOULD BE FACED WITH TWO OBSTACLES TO RECOVERY: 1) THE PRINCIPLE THAT THERE IS NO LIABILITY FOR SUBSIDENCE CAUSED BY THE WITHDRAWAL OF PERCOLATING GROUNDWATER; 2) THE NUMEROUS COAL SUBSIDENCE CASES HOLDING THAT THERE IS NO LIABILITY FOR DAMAGE TO SURFACE STRUCTURES IN THE ABSENCE OF NEGLIGENCE. THESE OBSTACLES CAN BE OVERCOME THROUGH LEGISLATIVE ACTION WHICH RECOGNIZES THAT WHILE THE WELFARE OF THE COMMUNITY REQUIRES THAT THE OIL COMPANIES BE PERMITTED TO CONTINUE OPERATING, PRIVATE PROPERTY THAT IS DAMAGED IN THE PUBLIC INTEREST MUST BE SPEEDILY COMPENSATED FOR.

CALIFORNIA/OIL/SUBSIDENCE/GROUNDWATER/WITHDRAWAL/LEGAL ASPECTS/ECONOMIC IMPACT

0040

CONOVER, C.S.

1961

GROUND WATER IN THE ARID AND SEMIARID ZONE: ITS SOURCE, DEVELOPMENT AND MANAGEMENT. IN GROUNDWATER IN ARID ZONES, SYMPOSIUM OF ATHENS, 1961.

INTERNATIONAL ASSOCIATION OF SCIENTIFIC HYDROLOGY, PUBLICATION 57(2):513-529.

GROUNDWATER IN ARID AND SEMIARID AREAS IS GOVERNED BY THE SAME GEOLOGIC AND HYDROLOGIC CONTROLS AS IN HUMID AREAS. HOWEVER THE MEAGER AND VARIABLE PRECIPITATION AND THE HIGH EVAPOTRANSPIRATION RATE IN THOSE AREAS EXERT A PROFOUND INFLUENCE UPON THE ACCUMULATION AND REPLENISHMENT OF GROUNDWATER. OPTIMUM DEVELOPMENT, MANAGEMENT, AND CONTROL OF GROUNDWATER IN THE ARID AND SEMIARID ZONES REQUIRES SPECIAL PHILOSOPHICAL AND ECONOMIC CONSIDERATION AS WELL AS UNDERSTANDING AND APPLICATION OF HYDROGEOLOGIC PRINCIPLES. SUCCESSFUL LONG-TERM UTILIZATION MUST RECOGNIZE AND BE TAILORED TO 2 SITUATIONS: 1) AREAS WITH A LARGE VOLUME OF WATER IN STORAGE AND NEGLIGIBLE RECHARGE; AND 2) AREAS IN STREAM VALLEYS WHERE GROUND AND SURFACE WATERS ARE INTIMATELY RELATED.

GROUNDWATER/ARID LANDS/SEMIARID CLIMATE/SURFACE-GROUNDWATER RELATIONSHIPS/GROUNDWATER MINING/WELLS/HYDROGEOLOGY/NATURAL RECHARGE/ STORAGE/WATER MANAGEMENT(APPLIED)/ECONOMICS

0041

DARLING, F.F./FARVAR, M.A.

1972

ECOLOGICAL CONSEQUENCES OF SEDENTARIZATION OF NOMADS. IN M.T. FARVAR AND J.P. MILTON, EDS., THE CARELESS TECHNOLOGY: ECOLOGY AND INTERNATIONAL DEVELOPMENT, P. 671-682.

NATURAL HISTORY PRESS, N.Y. 1030 P.

NOMADIC PASTORALISM IS AN ADAPTIVE WAY OF LIFE FOR PEOPLES IN THE GREAT ARID AREAS OF THE WORLD: THE INTERIOR ASIAN STEPPES, SOUTHWEST ASIA AND THE ARAB NEAR EAST. SURVEYS IN THE SAHARA INDICATE THAT LIVING STANDARDS OF NOMADS ARE HIGHER THAN THOSE OF SEDENTARY POPULATIONS. NOMADIC STRAINS OF SHEEP, IN IRAN, TEND TO BE LARGER AND MORE PRODUCTIVE THAN SEDENTARY VILLAGE STRAINS. FOR A VARIETY OF POLITICAL REASONS (CONTROL, TAXATION, PROGRESS), MANY GOVERNMENTS HAVE FORCIBLY ATTEMPTED TO SETTLE NOMADS. THIS HAS FREQUENTLY LED TO DRASTIC STOCK LOSSES, OVERGRAZING AROUND SETTLEMENTS, AND A LOSS OF ENERGY AND RESISTANCE TO ENDEMIC DISEASE ON THE PART OF THE NOMADS. DEVELOPMENT SCHEMES ARE CONCEIVED BY ECONOMISTS AND AGRICULTURAL SCIENTISTS RATHER THAN ECOLOGISTS AND NOMADS. NOMADIC PASTORALISM CAN BE A COMPLEX AND EFFICIENT FORM OF LAND USE. YET, IN THE DETERMINATION TO CHANGE A WAY OF LIFE, COUNTRIES HAVE NOT REALIZED THE COMPLEX RELATIONSHIP BETWEEN ECOLOGICAL, CULTURAL AND ECONOMIC FACTORS.

OALS/NOMADS/CARRYING CAPACITY/SOCIAL ASPECTS/ARABIAN DESERT/MIDDLE ASIA/ SAHARA/ECONOMIC IMPACT/POLITICAL ASPECTS/GRAZING/ECONOMIC DEVELOPMENT/ ENVIRONMENTAL EFFECTS/LIVESTOCK/IRAN/ADAPTATION/HUMAN DISEASES/SETTLEMENTS

0042

DAVIS, I.F., JR.

1959

GROUND WATER USE AND IRRIGATED LAND VALUES.

WESTERN FARM ECONOMICS ASSOCIATION, ANNUAL MEETING, 32ND, 1959, PROCEEDINGS, P. 106-117.

USING HYPOTHETICAL SITUATIONS, THIS ARTICLE EXAMINES THE EFFECT OF VARYING RATES OF PUMPING FROM A LIMITED GROUNDWATER SUPPLY ON FARM LAND VALUES. IN AREAS WHERE COMPETITIVE PUMPING IS INVOLVED, DECREASING THE RATE OF PUMPING TO INCREASE LAND VALUES MAY REQUIRE LEGAL CONTROLS. THE AUTHOR ALSO SUGGESTS COOPERATION TO REPLENISH GROUNDWATER SUPPLIES ARTIFICIALLY AS ANOTHER METHOD FOR BOOSTING LAND VALUES.

GROUNDWATER/IRRIGATION PRACTICES/OVERDRAFT/SUBSURFACE WATERS/RECHARGE/ IRRIGATION WATER/ARTIFICIAL RECHARGE/PUMPING/COSTS/WATER MANAGEMENT(APPLIED)/ MANAGEMENT/THEORETICAL ANALYSIS/EVALUATION/MODEL STUDIES/WATER SUPPLY/WELLS/ WATER TABLE/LEGAL ASPECTS/LAND APPRAISALS/FLOW RATES/INSTITUTIONAL CONSTRAINTS/ AGRICULTURAL USE OF WATER

0043

DAVIS, P.N.

1972

WELLS AND STREAMS: RELATIONSHIP AT LAW.

MISSOURI LAW REVIEW 37(2):189-245.

SEE: SWRA W72-14934.

GROUNDWATER/STREAMFLOW/SURFACE-GROUNDWATER RELATIONSHIPS/LEGAL ASPECTS/ WATER LAW/WATER RIGHTS/HYDROLOGY/WELLS/STREAMS/GROUNDWATER MINING/WATER ALLOCATION(POLICY)/REASONABLE USE/TEST WELLS/GROUNDWATER MOVEMENT/WATER MEASUREMENT

0044

DAVIS, S.N.

1974

HYDROGEOLOGY OF ARID REGIONS. IN G.W. BROWN, JR., ED., DESERT BIOLOGY, V. 2, P. 1-30.

ACADEMIC PRESS, NEW YORK, LONDON.

A DISCUSSION OF GROUNDWATER FLOW, RECHARGE, DISCHARGE, WATER QUALITY, LARGE-SCALE GROUNDWATER CIRCULATION, AND IMPACTS OF DEVELOPMENT IN ARID REGIONS. GROUNDWATER DEVELOPMENT IN DESERTS WILL INCREASE RAPIDLY. PROBLEMS ASSOCIATED WITH GROUNDWATER DEVELOPMENT WILL BE DESTRUCTION OF SPRINGS AND PHREATOPHYTIC VEGETATION, CREATION OF PERCHED WATER BODIES, WATERLOGGING OF THE SOIL, AND INCREASE IN SOIL SALINITY. DEPLETION OF GROUNDWATER RESERVOIRS WILL HAVE THE MOST DRASTIC EFFECT ON IRRIGATED AGRICULTURE.

GROUNDWATER/ARID LANDS/HYDROGEOLOGY/IRRIGATION EFFECTS/PUMPING/WELLS/ VEGETATION/SPRINGS/GROUNDWATER MOVEMENT/WATER QUALITY/DARCY'S LAW

0045

DEE, N. ET AL

1973

ENVIRONMENTAL ASSESSMENT: AN AID IN WATER RESOURCE MANAGEMENT. IN WATER FOR THE HUMAN ENVIRONMENT, PROCEEDINGS OF THE FIRST WORLD CONGRESS ON WATER RESOURCES, V. 3: TECHNICAL SESSIONS, P. 124-133.

INTERNATIONAL WATER RESOURCES ASSOCIATION, CHAMPAIGN, ILLINOIS.

THIS PAPER DISCUSSES A FRAMEWORK FOR WATER RESOURCES MANAGEMENT WHICH IDENTIFIES ENVIRONMENTAL PROBLEMS AND ASSESSES THE ENVIRONMENTAL CONSEQUENCES OF ALTERNATIVE SOLUTIONS TO THESE PROBLEMS. IN THIS FRAMEWORK, EMPHASIS IS PLACED ON PERFORMING ENVIRONMENTAL ASSESSMENTS IN THE PLANNING PROCESS INSTALLED AS PART OF AN ENVIRONMENTAL IMPAC STATEMENT. THE IMPACE STATEMENT IS ONLY A FORMAL DECLARATION OF WHAT OCCURRED IN THE PLANNING PROCESS, AND SHOULD BE USED AS SUCH. (AUTHORS)

WATER RESOURCES DEVELOPMENT/WATER MANAGEMENT(APPLIED)/ALTERNATIVE PLANNING/ ENVIRONMENTAL EFFECTS/PLANNING

0046

DEVRIES, R.N.

1971

INVESTIGATION OF THE FEASIBILITY OF THE DEVELOPMENT OF A WATER RESOURCES MANAGEMENT MODEL FOR THE HIGH PLAINS AREA OF OKLAHOMA. COMPLETION REPORT.

OKLAHOMA WATER RESOURCES RESEARCH INSTITUTE, STILLWATER. 86 P.

SEE: SWRA W71-11860.

MANAGEMENT/OKLAHOMA/WATER LAW/GROUNDWATER/MODEL STUDIES/LEGAL ASPECTS/SOCIAL ASPECTS/GROUNDWATER MOVEMENT/COMPUTER PROGRAMS/AQUIFERS/AQUIFER CHARACTERISTICS

0047

DITWILER, C.D.

1968

INSTITUTIONAL CONSTRAINTS AND ECONOMIC OPTIMA, A BASIS FOR MANAGEMENT DECISIONS IN INTRAREGIONAL WATER TRANSFER.

LAND ECONOMICS 44(2):173-184.

THE PHYSICAL, ECONOMIC, INSTITUTIONAL AND POLITICAL FACTORS THAT AFFECT A WATER ECONOMY ARE FREQUENTLY SUCH THAT SOLUTIONS OF WATER TRANSFER AND WATER ALLOCATION PROBLEMS - DERIVED SOLELY FROM ECONOMIC EFFICIENCY CRITERIA THAT ABSTRACT GREATLY FROM REALITY MAY BE OPERATIONALLY UNFEASIBLE AND HAVE LITTLE OR NO VALUE FOR POLICY FORMULATION. THUS ANALYSIS EMPHASIZES THE EVALUATION OF POLITICAL-INSTITUTIONAL PROCESSES, LEGAL STRUCTURES, AND ADMINISTRATIVE TECHNIQUES INSOFAR AS THEY AFFECT WATER POLICY. THE FOCAL POINT OF THE ANALYSIS IS THE GROUNDWATER BASIN IN THE SALINAS VALLEY IN CALIFORNIA WHICH SUFFERS FROM OVERDRAFT AND SEAWATER INTRUSION. AN OPTIMAL WATER MANAGEMENT POLICY OR RATIONALE IS DISCUSSED. EFFICIENCY AND EQUITY IMPLICATIONS OF THE MODERN COUNTERPARTS TO THE TRADITIONAL PRESCRIPTIONS ARE COMPARED TO THE SOLUTION ACTUALLY FOLLOWED.

SALINE WATER INTRUSION/GROUNDWATER/OVERDRAFT/ECONOMIC IMPACT/CALIFORNIA/ LEGAL ASPECTS/POLITICAL ASPECTS/WATER MANAGEMENT(APPLIED)

0048

DOBYNS, H.F.

1952

THIRSTY INDIANS: INTRODUCTION OF WELLS AMONG PEOPLE OF AN ARID REGION.

HUMAN ORGANIZATION 11:33-36.

BRIEF DISCUSSION OF THE PAPAGO CULTURE PRIOR TO THE WELL DIGGING PROGRAM OF THE FEDERAL GOVERNMENT AND THE IMPACT OF THESE WELLS ON THE CULTURE. PROVISION OF WATER HAS DONE MUCH TO RAISE THE STANDARD OF LIVING OF THE PAPAGO AND THIS IS REFLECTED IN THE POSITIVE RELATIONSHIP BETWEEN THE PAPAGO AND THE FEDERAL GOVERNMENT.

PAPAGO INDIAN RESERVATION/WELLS/GROUNDWATER/SOCIAL ASPECTS/ARID LANDS/ SONORAN DESERT/ARIZONA/INSTITUTIONAL ASPECTS/PAPAGOS

0049

DOMENICO, P.A./ANDERSON, D.V./CASE, C.M.

1968

OPTIMAL GROUNDWATER MINING.

WATER RESOURCES RESEARCH 4(2):247-255.

SEE: SWRA W69-03114.

WATER MANAGEMENT(APPLIED)/GROUNDWATER MINING/WATER YIELD/MATHEMATICAL MODELS/ECONOMICS/WITHDRAWAL/GROUNDWATER BASINS/SAFE YIELD/OPTIMUM DEVELOPMENT PLANS

0050

DOMENICO, P.A./STEPHENSON, D.A./MAXEY, G.B.

1964

GROUNDWATER IN LAS VEGAS VALLEY.

DESERT RESEARCH INSTITUTE, RENO, TECHNICAL REPORT 7. 53 P.

INCREASING DEVELOPMENT OF GROUNDWATER IN LAS VEGAS VALLEY, NEVADA HAS RESULTED FROM MUNICIPAL GROWTH IN THE LAS VEGAS METROPOLITAN AREA. GROUNDWATER RESERVOIRS ARE CURRENTLY UNDERGOING DEPLETION AT A RATE OF 30,000 ACRE-FEET/YR OR MORE. DEPLETION IS REFLECTED IN LARGE WATER LEVEL DECLINES, SHALLOW WELL FAILURES, INCREASED PUMPING COSTS, AND LAND SURFACE SUBSIDENCE. THIS REPORT ATTEMPTS TO ANALYZE THE HYDROLOGIC SYSTEM PARTICULARLY THE EFFECT ON WATER LEVELS OF PREDICTED INCREASES IN WATER WITHDRAWAL. THE EFFECT OF INCREASED WITHDRAWALS IS ASCERTAINED WITH AN ELECTRICAL SYSTEM (ANALOG). SEVERAL PROBLEMS ARE ANALYZED AND THE EFFECT OF EACH IS SHOWN. (AFTER AUTHOR)

GROUNDWATER/WITHDRAWAL/WELLS/NEVADA/MODELS/SUBSIDENCE/AQUIFERS/ARID LANDS

0051

DOMMEN, A.J.

1975

THE BAMBOO TUBE WELL: A NOTE ON AN EXAMPLE OF INDIGENOUS TECHNOLOGY.

ECONOMIC DEVELOPMENT AND CULTURAL CHANGE 23(3):483-489.

IN THE STATE OF BIHAR, INDIA, SMALL LANDOWNERS ARE CONSTRUCTING BAMBOO TUBE WELLS AS AN ALTERNATIVE TO IRON PIPE TUBEWELLS AND AS AN ADDITIONAL, MORE DEPENDABLE SOURCE OF WATER THAN THAT SUPPLIED BY PROBLEM-RIDDEN SURFACE-WATER CANALS. MORE THAN 100,000 ACRES HAVE BEEN BROUGHT UNDER BAMBOO TUBE WELL IRRIGATION AND, DURING ONE 6-MONTH PERIOD, GREATER THAN 33,000 OF THEM WERE SUNK IN 10 DISTRICTS OF BIHAR. THESE TUBE WELLS ARE CHEAP AND EASY TO CONSTRUCT AND HAVE PROMOTED GREATER CROPPING INTENSITIES AND ACCELERATED CROPPING SCHEDULES. THE DEVELOPMENT OF THE BAMBOO TUBEWELL HAS DONE MUCH TO PROMOTE EMPLOYMENT, THE USE OF INDIGENOUS RAW MATERIALS, AND THE ECONOMIC DEVELOPMENT OF THE SMALL LANDOWNER.

GROUNDWATER/INDIA/IRRIGATION WELLS/AGRICULTURE/CROPPING PATTERNS/APPROPRIATE TECHNOLOGY/TUBEWELLS

0052

DORFMAN, R./REVELLE, R./THOMAS, H.

1965

WATERLOGGING AND SALINITY IN THE INDUS PLAIN: SOME BASIC CONSIDERATIONS.

PAKISTAN DEVELOPMENT REVIEW 5(3):331-370.

THE INITIAL DRAMATIC POSITIVE RESPONSE TO THE TUBEWELL IRRIGATION AND LAND RECLAMATION PROJECTS IN THE INDUS BASIN IN PAKISTAN HAVE LED TO THE PREMATURE CONCLUSION THAT THE PROGRAMS ALREADY UNDERTAKEN WILL SUFFICE IN OVERCOMING THE PROBLEMS OF THE AGRICULTURAL SECTOR. AUTHORS REITERATE THAT INSUFFICIENT WATER WAS NOT THE ONLY DEFICIENCY IN THE INDUS PLAIN AND THE PROVISION OF MORE WATER WAS NOT THE SOLUTION BUT ONLY THE FIRST STEP TOWARD SOLVING THE AGRICULTURAL PROBLEM. AN APPRAISAL OF WHAT HAS HAPPENED SINCE THE INITIATION OF THE PLAN IS MADE. CRITICAL QUESTIONS ABOUT THE PROJECT ARE DISCUSSED AND PRIVATE VS PUBLIC TUBEWELL PERFORMANCE IS EVALUATED.

PAKISTAN/WATERLOGGING/SALINITY/SALINE WATER/IRRIGATION/AGRICULTURE/WATER TABLE/WITHDRAWAL/SALINE WATER/CANALS/DRAINAGE/ECONOMIC DEVELOPMENT/ INDUS BASIN/CROP PRODUCTION/LAND USE/ECONOMIC IMPACT/FERTILIZERS/SURFACE WATERS/SODIUM/CROP YIELDS/SCARP 1/TUBEWELLS

0053

DUCKSTEIN, L./KISIEL, C.C.

1968

GENERAL SYSTEMS APPROACH TO GROUND-WATER PROBLEMS.

NATIONAL SYMPOSIUM ON ANALYSIS OF WATER RESOURCES SYSTEMS, PROCEEDINGS SER. 5:100-115.

SEE: SWRA W70-01123.

GROUNDWATER/REVIEWS/BIBLIOGRAPHIES/SYSTEMS ANALYSIS/AQUIFERS/OPTIMUM DEVELOPMENT PLANS/MATHEMATICAL ANALYSIS/INPUT-OUTPUT ANALYSIS/ECONOMICS/ DYNAMIC PROGRAMMING/ECOLOGY/GROUNDWATER MINING/NUMERICAL ANALYSIS/GROUNDWATER RECHARGE/OPERATIONS RESEARCH/ECONOMIC JUSTIFICATION/WATER MANAGEMENT(APPLIED)/ MATHEMATICAL MODELS

0054

DUPNICK, F./DUCKSTEIN, L.

1971

COLLECTIVE UTILITY: A SYSTEMS APPROACH FOR THE UTILIZATION OF WATER RESOURCES. IN: HYDROLOGY AND WATER RESOURCES IN ARIZONA AND THE SOUTHWEST, VOL 1.

AMERICAN WATER RESOURCES ASSOCIATION, ARIZONA SECTION/ARIZONA ACADEMY OF SCIENCE, HYDROLOGY SECTION, PROCEEDINGS OF THE 1971 MEETINGS, TEMPE, ARIZONA, P. 367-372.

IN THE SEMIARID SOUTHWESTERN U.S. WHERE COMPETITION FOR WATER IS FIERCE BETWEEN COMPETING USERS, NO REGIONAL AGENCY CONTROLS WATER ALLOCATION, AND AS A RESULT, MUCH COURT LITIGATION ENSUES. THIS PAPER ATTEMPTS TO DEVELOP A MODEL FOR OPTIMAL ALLOCATION OF WATER RESOURCES AND TO APPLY THE MODEL TO A SPECIFIC CASE STUDY. IN NOVEMBER 1969, THE LARGEST FARMING INTEREST IN THE SAHUARITA-CONTINENTAL AREA NEAR TUCSON FILED A COURT SUIT SEEKING FIRST TO REDUCE THE AMOUNT OF GROUNDWATER USED BY 4 NEARBY COPPER MINES, AND THEN TO ALLOCATE THE WATER MORE EVENLY AMONG VARIOUS INTERESTS IN THE AREA. THE FARMING INTEREST MAINTAINED THAT THE MINES DRAWDOWN ON THE GROUNDWATER TABLE WOULD SOON DEPLETE THE SUPPLY TO THE POINT WHERE AGRICULTURE WOULD BECOME IMPOSSIBLE. THE MODEL UTILIZES THE CONCEPT OF COLLECTIVE UTILITY WHICH POSTULATES THE EXISTENCE OF AN ECONOMIC DECISION MAKER (EDP). TO GET AROUND THE PROBLEM OF DETERMINATION OF NET REVENUE FUNCTIONS, THE THEORY COMPARES THE RELATIVE DESIRABILITY OF NEIGHBORING ECONOMIC STATES. THE EDP HAS THE POWER TO IMPOSE GROUNDWATER-USE TAXES IN SUCH A WAY AS TO MAXIMIZE OVERALL GROWTH OF COLLECTIVE UTILITY IN THE SAHUARITA-CONTINENTAL AREA, TAKING INTO ACCOUNT THE EXTERNALITIES OF THE RESOURCE CONSUMPTION. THE MATHEMATICAL ANALYSIS IS PRESENTED IN DETAIL. (OALS)

OALS/WATER UTILIZATION/MATHEMATICAL MODELS/WATER SUPPLY/WATER COSTS/ ARIZONA/GROUNDWATER MINING/WATER RIGHTS/COMPETING USES

0055

EATON, F.M.

1965

WATERLOGGING AND SALINITY IN THE INDUS PLAIN: COMMENT.

PAKISTAN DEVELOPMENT REVIEW 5(3):381-392.

DISCUSSION OF FUTURE WATERLOGGING AND SALINITY PROBLEMS IN THE INDUS PLAIN OF PAKISTAN. LITTLE OF THE SALT DEPOSITED IN THE SOILS AND GROUNDWATER WITH IRRIGATION IS BEING CARRIED TO THE SEA. THIS REPRESENTS A LONG-TIME THREAT TO THE PERMANENCY OF AGRICULTURE IN PAKISTAN UNLESS A WAY IS FOUND TO DISPOSE OF THE SALT RESIDUES OF IRRIGATION WATER. DISCHARGING SALINE DRAINAGE WATER INTO CANALS AND RIVERS WOULD THREATEN DOWNSTREAM AGRICULTURE. PUMPING AND RECYCLING OF GROUNDWATER WILL INCREASE THE SALINITY WITHIN 10 TO 50 YEARS BEYOND USABILITY. PUMPING OF GROUNDWATER WILL ALSO ENCOURAGE THE MOVEMENT OF POOR QUALITY WATER INTO THE FRESHER WATER. WHEN WELLS NO LONGER YIELD GOOD QUALITY WATER, AGRICULTURE WILL BE IN THE SAME POSITION IT WAS BEFORE THE TUBEWELL RECLAMATION PROJECTS. TWO SUGGESTIONS ARE MADE TO ALLEVIATE THE SALINITY PROBLEMS: ON-FARM DRAINAGE (EVAPORATION FLATS), AND LEACHING WITH THE ADDITION OF GYPSUM. AN EQUATION AND A GUIDE FOR COMPUTING THE LEACHING AND GYPSUM REQUIREMENTS OF IRRIGATION WATERS IS PRESENTED.

WATERLOGGING/SALINITY/GROUNDWATER/SALINE WATER INTRUSION/SALINE WATER/SALINE SOILS/IRRIGATION WATER/LAND RECLAMATION/GYPSUM/DRAINAGE/CALCIUM/WATER TABLE/ PUMPING/PAKISTAN/INDUS BASIN

0056

FINKEL, H.

1973

HUMAN OBSTACLES TO THE CONTROL OF THE HYDROLOGICAL CYCLE FOR THE BENEFIT OF MAN.

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, ROME, IRRIGATION AND DRAINAGE PAPER 17:53-69.

SEE: SWRA W75-10866.

HYDROLOGIC CYCLE/ADMINISTRATIVE DECISIONS/WATER LAW/LEGISLATION/WATER RESOURCES DEVELOPMENT/LEGAL ASPECTS/WATER ALLOCATION(POLICY)/WATER RIGHTS/ WATER POLICY/WATER MANAGEMENT(APPLIED)/GOVERNMENT

0057

FREEMAN, V.M.

1968

PEOPLE, LAND, WATER: SANTA CLARA VALLEY AND OXNARD PLAIN, VENTURA COUNTY, CALIFORNIA.

LORRIN L. MORRISON, LOS ANGELES, CALIFORNIA. 227 P.

THE HISTORY OF SOUTHERN CALIFORNIA IS THE STORY OF THE STRUGGLE FOR A DEPENDABLE WATER SUPPLY. AUTHOR DETAILS THE HISTORY FROM 1840-1967 OF THE DEVELOPMENT OF THE MEAGER SURFACE WATER SUPPLIES AND THE ONCE-ABUNDANT GROUND WATER SUPPLIES IN THE SANTA CLARA VALLEY AND OXNARD PLAIN AREAS AND THE PROBLEMS ASSOCIATED WITH EACH: THE DEPLETION OF THE RESOURCE, FLOODS, AND THE INTRUSION OF SALT WATER WHERE PUMPING HAD LOWERED WELL WATER LEVELS BELOW MEAN SEA LEVEL. FIVE PHASES OF WATER DEVELOPMENT ARE NOTED: 1) THE USE OF SURFACE WATERS, 2) THE DEVELOPMENT OF GROUNDWATER, 3) THE CONSTRUCTION OF SURFACE STORAGE RESERVOIRS, 4) THE IMPORTATION OF WATER FROM DISTANT AREAS, 5) THE RECLAMATION OF SEWAGE AND INDUSTRIAL WASTE WATER, AND DESALINIZATION. VARIOUS ORGANIZATIONS FORMED IN RESPONSE TO WATER SUPPLY PROBLEMS ARE DISCUSSED. INCLUDES CHAPTERS ON ESTIMATED RAINFALL AT SANTA PAULA, CALIFORNIA, 1769 TO 1873, AND MEASURED RAINFALL AT SANTA PAULA, 1873 TO 1965.

CALIFORNIA/INJECTION WELLS/ARTIFICIAL RECHARGE/WATER RESOURCES DEVELOPMENT/ WATER SUPPLY/WELLS/GROUNDWATER/SURFACE WATERS/STREAMFLOW/RESERVOIRS/ CATCHMENTS/DAMS/RAINFALL/WATER REUSE/RECLAMATION/SURFACE IMPORTATION/ DESALINATION

0058

FRIEDMAN, A.E.

1971

ECONOMICS OF THE COMMON POOL: PROPERTY RIGHTS IN EXHAUSTIBLE RESOURCES.

UCLA LAW REVIEW 18:855-886.

AN ECONOMIC ANALYSIS OF 'THE COMMON-POOL PROBLEM' IN NATURAL RESOURCE DEVELOPMENT - THE TENDENCY TOWARD PRESENT OVER PRODUCTION THAT ARISES WHEN COMPETITORS SEEK TO EXPLOIT AN EXHAUSTIBLE RESOURCE IN WHICH NO ONE HAS ADEQUATELY DEFINED AND PROTECTABLE RIGHTS. DISCUSSION TOPICS INCLUDE AN OVERVIEW OF THE PROBLEM, THE MEANING OF A SOCIALLY OPTIMAL RATE OF EXPLOITATION OF AN EXHAUSTIBLE RESOURCE, AND THE PROBLEM OF EXTERNALITY IN THE COMMON POOL. AN ECONOMIC ANALYSIS IS DEVELOPED TO EXPLAIN WHY EXHAUSTIBLE RESOURCES ARE EXPLOITED AT DIFFERENT RATES DEPENDING ON HOW THEY ARE OWNED. A GENERAL THEORETICAL SOLUTION IS PROPOSED AND IS ILLUSTRATED THROUGH APPLICATION TO THE PROBLEM OF GROUNDWATER MINING.

GROUNDWATER/GROUNDWATER MINING/NATURAL RESOURCES/ECONOMIC IMPACT/LEGAL ASPECTS/WATER RIGHTS/WATER LAW/OPPORTUNITY COST/PROPERTY RIGHTS/EXHAUSTIBLE RESOURCES/COMMON-POOL PROBLEM/EXTERNALITIES/OPTIMIZATION

0059

GINDLER, B.J./HOLBURT, M.B.

1969

WATER SALINITY PROBLEMS: APPROACHES TO LEGAL AND ENGINEERING SOLUTIONS.

NATURAL RESOURCES JOURNAL 9(3):329-400.

SEE: SWRA W69-08769.

SALINE WATER INTRUSION/GROUNDWATER/ARID LANDS/SALINITY/SALINE WATER/LEGAL ASPECTS/ECONOMICS/ARTIFICIAL RECHARGE/PUMPING/WATER RIGHTS/WATER LAW/SOCIAL ASPECTS/PROPERTY VALUES/COST-BENEFIT ANALYSIS

0060

GLOVER, R.E./BALMER, G.G.

1954

RIVER DEPLETION RESULTING FROM PUMPING A WELL NEAR A RIVER.

AMERICAN GEOPHYSICAL UNION, TRANSACTIONS 35(3):468-470

A WELL ADJACENT TO A RIVER WILL TAKE A PORTION OF ITS SUPPLY FROM THE RIVER. A THEORETICAL FORMULA IS DEVELOPED WHICH PERMITS THE DRAFT ON THE RIVER TO BE COMPUTED IN TERMS OF DISTANCE OF THE WELL FROM THE RIVER, THE PROPERTIES OF THE AQUIFER, AND TIME. THE FORMULA APPLIES WHERE THE RIVER CAN BE CONSIDERED TO FLOW IN A STRAIGHT COURSE WHICH EXTENDS FOR A CONSIDERABLE DISTANCE BOTH UPSTREAM AND DOWNSTREAM FROM THE WELL LOCATION. (AUTHORS).

GROUNDWATER-SURFACE WATER RELATIONSHIPS/GROUNDWATER/SURFACE WATERS/ MATHEMATICAL MODELS/WELLS/STREAMS/DRAWDOWN/STREAMFLOW

0061

GOTSCH, C.H.

1968

REGIONAL AGRICULTURAL GROWTH: THE CASE OF WEST PAKISTAN.

ASIAN SURVEY 8(3):188-205.

RELATIVELY STAGNANT BEFORE 1959, AGRICULTURE IN PAKISTAN EXHIBITED AN ANNUAL GROWTH RATE OF 3.8 PERCENT FROM 1960-1965. MOST OF THIS GROWTH COMPONENT WAS IN THE CROP CATEGORY. GEOGRAPHICAL ANALYSIS INDICATES THAT THERE IS MUCH REGIONAL DISPARITY IN ECONOMIC PERFORMANCE OF THE AGRICULTURAL SECTOR AND THAT THE 'AGRICULTURAL GROWTH IN WEST PAKISTAN' IS REALLY A REMARKABLE RATE OF GROWTH IN A RELATIVELY FEW DISTRICTS. THE SOURCE OF GROWTH IN THESE DISTRICTS WAS USUALLY ADEQUATE WATER SUPPLIES MADE POSSIBLE BY TUBEWELL DEVELOPMENT FOR IRRIGATION. IN A FEW DISTRICTS GROWTH COULD NOT BE

CORRELATED WITH TUBEWELL DEVELOPMENT, THUS THIS INCREASED AVAILABILITY OF WATER IS A SUFFICIENT BUT NOT A NECESSARY CONDITION FOR ECONOMIC GROWTH. REGIONAL VARIATION IN ECONOMIC PERFORMANCE IS EXPECTED TO CONTINUE. PROGRAMS TO MITIGATE OR ELIMINATE THIS DISPARITY MUST BE IMPLEMENTED.

PAKISTAN/WELLS/AGRICULTURE/IRRIGATION/CROPS/ECONOMIC DEVELOPMENT/ECONOMIC IMPACT/PUNJAB/REGIONAL ANALYSIS/MATHEMATICAL MODELS/ANALYTICAL TECHNIQUES/ DEVELOPMENT POLICY/TUBEWELLS

0062

GRACY, D.B.

1970

WINDMILLS, PLAINS AND PEOPLE.

CROSS SECTION 16(9):3-4.

SEE: SWRA W71-12138.

HISTORY/WATER WELLS/WATER SUPPLY/WATER RESOURCES DEVELOPMENT/CULTIVATED LANDS/TEXAS/COSTS/GROUNDWATER/RIPARIAN RIGHTS/ARID LANDS/IRRIGATION PRACTICES

0063

GREEN, D.E.

1973

LAND OF THE UNDERGROUND RAIN: IRRIGATION ON THE TEXAS HIGH PLAINS, 1910-1970.

UNIVERSITY OF TEXAS PRESS, AUSTIN. 295 P.

A HISTORY OF THE RISE AND DECLINE OF GROUNDWATER-IRRIGATED AGRICULTURE ON THE HIGH PLAINS OF TEXAS IS DIVIDED INTO 3 PHASES: PHASE 1, 1910-20, WHEN LARGE SCALE GROUNDWATER PUMPING PLANTS FIRST APPEARED THROUGH THE EFFORTS OF LAND SPECULATORS; PHASE 2, 1934-1950'S, WHEN A COMBINATION OF DROUGHT, INSTITUTIONAL FACTORS, AND AN AVAILABLE TECHNOLOGY GAVE RISE TO THE DEVELOPMENT OF IRRIGATED AGRICULTURE AS A WAY OF LIFE; PHASE 3, THE 1960'S, WHEN A DECLINING GROUNDWATER TABLE GAVE RISE TO A DECLINE IN IRRIGATED AGRICULTURE AND TO THE QUEST FOR WATER FROM DISTANT SOURCES SUCH AS THE MISSISSIPPI RIVER. THIS HISTORY POINTS OUT 3 LESSONS: THE TIME TO CONSERVE IS BEFORE, NOT AFTER, EXPLOITATION; THE TECHNOLOGY THAT AIDS IN THE DEVELOPMENT OF THE RESOURCE IS AN ACCESSORY TO ITS DEPLETION; AND THAT WATER IS ONE OF THE MOST IRREPLACABLE OF ALL RESOURCES WHEN IT IS EXHAUSTED.

TEXAS/GROUNDWATER/IRRIGATION/IRRIGATION WELLS/OGALLALA AQUIFER/SOCIAL ASPECTS/DRY FARMING/WATER SHORTAGE/IRRIGATION EFFECTS/ECONOMIC IMPACT

0064

GREEN, J.H.

1964

THE EFFECT OF ARTESIAN - PRESSURE DECLINE ON CONFINED AQUIFER SYSTEMS AND ITS RELATION TO LAND SUBSIDENCE.

U.S. GEOLOGICAL SURVEY, WATER SUPPLY PAPER 1779-T. 11 P.

GROUNDWATER IN THE SOUTHWESTERN U.S. IS DERIVED CHIEFLY FROM UNCONSOLIDATED TO SEMICONSOLIDATED ALLUVIAL DEPOSITS. WHERE THESE DEPOSITS CONTAIN CONFINED WATER, THEY MAY BE SUSCEPTIBLE TO COMPACTION AND RELATED LAND-SURFACE SUBSIDENCE, IF ARTESIAN PRESSURES ARE REDUCED. COMPACTION OF ARTESIAN-AQUIFER SYSTEMS CAN BE ESTIMATED FROM CORE TESTS IF THE ARTESIAN-PRESSURE DECLINE IS KNOWN. COMPACTION OCCURS CHIEFLY IN THE FINER GRAINED DEPOSITS; POROSITY DECREASE IS GREATER NEAR THE TOP OF THE CONFINED AQUIFER THAN NEAR THE BOTTOM. BECAUSE MOST OF THE COMPACTION OF THESE AQUIFER SYSTEMS IS PERMANENT, THE STORAGE COEFFICIENT DURING THE INITIAL DECLINE OF ARTESIAN PRESSURE GREATLY EXCEEDS THE STORAGE COEFFICIENT DURING A SUBSEQUENT PRESSURE DECLINE THROUGH THE SAME DEPTH RANGE, AFTER AN INTERVENING PERIOD OF PRESSURE RECOVERY. (AUTHOR)

SUBSIDENCE/GROUNDWATER/STORAGE COEFFICIENT/ARTESIAN WELLS

0065

GREENMAN, D.W./SWARZENSKI, W.V./BENNETT, G.D.

1967

GROUND-WATER HYDROLOGY OF THE PUNJAB, WEST PAKISTAN, WITH EMPHASIS ON PROBLEMS CAUSED BY CANAL IRRIGATION.

U.S. GEOLOGICAL SURVEY, WATER SUPPLY PAPER 1608-H. 66 P.

RISING WATER TABLES AND THE SALINIZATION OF LAND AS A RESULT OF CANAL IRRIGATION THREATEN THE AGRICULTURAL ECONOMY OF THE PUNJAB. UNDERLYING THE ENTIRE PUNJAB IS AN UNEXPLOITED AQUIFER OF ENORMOUS ECONOMIC VALUE. SCIENTIFIC MANAGEMENT OF THIS AQUIFER IS THE KEY TO PERMANENT IRRIGATION AGRICULTURE IN THE PUNJAB. GROUNDWATER WITHDRAWALS WILL SERVE THE DUAL PURPOSE OF HELPING TO SUPPLY IRRIGATION REQUIREMENTS AND OF PROVIDING SUBSURFACE DRAINAGE. IT IS INEVITABLE THAT LARGE-SCALE GROUNDWATER WITHDRAWALS WILL DISTURB THE HYDROLOGIC REGIMEN. THE DISTRIBUTION OF WITHDRAWALS AND MAINTENANCE OF A FAVORABLE SALT BALANCE ARE TWO ASPECTS THAT MUST BE CONSIDERED IN THE DESIGN AND MANAGEMENT OF THE TUBEWELL PROJECTS. SEVERAL FACTORS IN THE TUBEWELL SYSTEM WILL TEND TO DEPRECIATE THE QUALITY OF THE GROUNDWATER WITH TIME--THE ADDITION OF SALTS LEACHED FROM SOILS, INCREASED CONCENTRATION OF SALTS DUE TO REPEATED CYCLES OF RECIRCULATION, AND THE POSSIBLE LATERAL AND UPWARD ENCROACHMENT OF SALINE WATER IN RESPONSE TO PUMPING. THESE SHOULD NOT PRESENT SERIOUS PROBLEMS WITHIN THE 40-TO-50-YEAR ECONOMIC LIFETIME OF THE PROJECTS.

GROUNDWATER/IRRIGATION EFFECTS/IRRIGATION CANALS/PAKISTAN/PUNJAB/INDUS BASIN/LAND RECLAMATION/DRAINAGE/SALINITY/WATER QUALITY/SALINE WATER/WATER TABLE/SALINE SOILS/SALINE WATER INTRUSION/IRRIGATION WATER

0066

GRUBB, H.W.

1966

IMPORTANCE OF IRRIGATION WATER TO THE ECONOMY OF THE TEXAS HIGH PLAINS.

TEXAS WATER DEVELOPMENT BOARD, AUSTIN, REPORT 11. 25 P.

FOR LONG-RANGE PLANNING PURPOSES IT IS NECESSARY TO HAVE AN UNDERSTANDING OF THE IMPORTANCE OF HIGH PLAINS IRRIGATED AGRICULTURE TO THE LOCAL, STATE AND NATIONAL ECONOMIES. IRRIGATED AGRICULTURE IN THE HIGH PLAINS IS DEPENDENT ON A GROUNDWATER RESOURCE THAT IS RAPIDLY DIMINISHING. PAPER PRESENTS INFORMATION PERTAINING TO THE CONTRIBUTIONS OF GROUNDWATER TO THE HIGH PLAINS ECONOMY BY ANALYZING PRESENT ECONOMIC IMPORTANCE AND THEN PROJECTING FUTURE IRRIGATION BENEFITS AT 10 YEAR INTERVALS FROM 1970 TO 2020. FINDINGS IMPLY THAT IRRIGATION IS MORE IMPORTANT TO THE HIGH PLAINS ECONOMY THROUGH ITS INDUCED EFFECTS THAN IN DIRECT BENEFITS TO IRRIGATORS - THAT COMMUNITY, STATE AND NATIONAL ECONOMIC INTERESTS OF LARGE MAGNITUDE, DEPENDENT ON HIGH PLAINS IRRIGATION, ARE AT STAKE. IRRIGATED ACREAGE IS EXPECTED TO INCREASE UNTIL 1980 AFTER WHICH TIME CERTAIN QUESTIONS MUST BE CONSIDERED DEALING WITH 1) ALTERNATIVE SUPPLIES OF IRRIGATION WATER, 2) EXPANSION OF EMPLOYMENT IN LOW-WATER-CONSUMING INDUSRIES, AND 3) THE POSSIBILITY OF SIGNIFICANT ECONOMIC CONTRACTION WITHIN THE HIGH PLAINS. KEY TO MAINTAINING A HIGH LEVEL OF ECONOMIC ACTIVITY ON THE HIGH PLAINS IS TO BEGIN WITH PLANS TO AUGMENT PRESENT WATER SUPPLIES COUPLED WITH IMPROVEMENTS IN TECHNICAL AND ECONOMIC EFFICIENCY OF WATER USE.

GROUNDWATER/TEXAS/OGALLALA AQUIFER/IRRIGATED AGRICULTURE/ECONOMIC IMPACT/ WATER SUPPLY/ECONOMICS

0067

HALL, W.A./DRACUP, J.A.

1967

THE OPTIMUM MANAGEMENT OF GROUND WATER RESOURCES. IN INTERNATIONAL CONFERENCE ON WATER FOR PEACE, 1967, WASHINGTON, D.C., WATER FOR PEACE 3:20-27.

U.S. GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C.

THE MANNER IN WHICH GROUNDWATER RESOURCES ARE DEVELOPED AND UTILIZED CAN GREATLY AFFECT THE DEVELOPMENT OF A REGIONAL OR LOCAL WATER SUPPLY SYSTEM AND THE CORRESPONDING LONG TERM ECONOMY WHICH THE SYSTEM CAN SUPPORT, PARTICULARLY IN ARID AND SEMI-ARID REGIONS. CURRENT MANAGEMENT PRACTICES FALL INTO TWO CATEGORIES: SAFE YIELD CONCEPT AND THE MINING STORAGE CONCEPT. FOUR ADDITIONAL GROUNDWATER BASIN RESOURCES OUGHT TO BE INCLUDED IN AN OVERALL MANAGEMENT SCHEME: RESERVOIR FOR LONG TERM STORAGE; A TRANSMISSION SYSTEM;

AN ENERGY RESOURCE IN THAT PUMPING LIFTS ARE MODIFIED BY MANAGEMENT; AND A WATER QUALITY MANAGEMENT FUNCTION. A KNOWLEDGE OF THESE SIX MANAGEABLE RESOURCES OF AN AQUIFER COMBINED WITH THE APPLICATION OF SIMULATION TECHNIQUES WILL HELP DEFINE THE OPTIMUM MANAGEMENT. PHYSICAL PROBLEMS ASSOCIATED WITH POOR MANAGEMENT ARE LAND SUBSIDENCE, SEA WATER INTRUSION INTO COASTAL AQUIFERS, DETERIORATION OF GROUNDWATER QUALITY AND THE PROBLEM OF FINDING AN ALTERNATIVE SUPPLY WHEN THE RESOURCE IS DEPLETED. LEGAL AND INSTITUTIONAL CHANGES GOVERNING GROUNDWATER USAGE ARE NEEDED TO ACHIEVE OPTIMUM MANAGEMENT PRACTICES.

GROUNDWATER/GROUNDWATER MANAGEMENT/MODELS/SUBSIDENCE/LEGAL ASPECTS/ INSTITUTIONAL ASPECTS/GROUNDWATER MINING/ARID LANDS/SALINE WATER INTRUSION/ GROUNDWATER QUALITY/ECONOMIC IMPACT

0068

HARGREAVES, G.H.

1972

ECONOMIC ASPECTS OF IRRIGATION FROM GROUND WATER. PAPER PREPARED FOR PRESENTATION AT

NATIONAL GROUND WATER SYMPOSIUM, SAO CARLOS, SAO PAULO, BRAZIL, NOVEMBER 27-DECEMBER 1, 1972. 21 P.

GROUNDWATER DEVELOPMENT SHOULD BE GIVEN MAJOR CONSIDERATION AS A MEANS OF PROMOTING IRRIGATION EXPERIENCE AND INITIAL INFRASTRUCTURE GROWTH. IN AREAS WITH LIMITED GROUNDWATER RECHARGE IT IS SUGGESTED THAT THE MOST ECONOMICAL USE OF GROUNDWATER WOULD BE MINING IT OVER PERIOD OF 15 TO 20 YEARS. AS RESERVES ARE DEPLETED IT FREQUENTLY BECOMES ECONOMICAL TO DEVELOP SURFACE WATER SUPPLIES TO REPLACE GROUNDWATER USAGE. THE ECONOMIC ANALYSIS BASED UPON THE AREA NEAR SANTA CRUZ, BOLIVIA, APPEARS TO HAVE CONSIDERABLE APPLICATION TO CONDITIONS IN SEMIARID AREAS OF BRAZIL CHARACTERIZED BY FAVORABLE SOIL AND GROUNDWATER CONDITIONS. PLANNED UTILIZATION OF GROUNDWATER, UNDER FAVORABLE CONDITIONS, CAN PRODUCE TWIN BENEFITS, DRAINAGE AND IRRIGATION WATER.

OALS/GROUNDWATER/BRAZIL, NORTHEASTERN/ECONOMICS/IRRIGATION WATER/ GROUNDWATER BASINS/GROUNDWATER MINING/SURFACE WATERS/WATER RESOURCES DEVELOPMENT/DRAINAGE/PUMPING/COST-BENEFIT ANALYSIS/WELLS/SPRINKLER IRRIGATION/KWIC SA 5

0069

HARRISON CHURCH, R.J.

1973

THE DEVELOPMENT OF THE WATER RESOURCES OF THE DRY ZONE OF WEST AFRICA. IN D. DALBY AND R.J. HARRISON CHURCH, EDS., DROUGHT IN AFRICA, REPORT OF THE SYMPOSIUM HELD JULY 19-20, 1973, P. 62-66.

UNIVERSITY OF LONDON, SCHOOL OF ORIENTAL AND AFRICAN STUDIES, CENTRE FOR AFRICAN STUDIES.

EVEN THOUGH THE POPULATION OF THE SAHELIAN ZONE IS SMALL IN NUMBERS, IT IS HIGH IN RELATION TO THE LOW RESOURCES OF THE AREA. EFFORTS TO INCREASE PRODUCTION THROUGH IRRIGATION PROJECTS ALONG THE SENEGAL AND NIGER RIVERS HAVE FAILED DUE TO POOR SOILS AND LOW FARMER EDUCATION. BOREHOLES TO UNDERGROUND AQUIFERS IN THE DRY AREAS HAVE LED TO HIGH CONCENTRATIONS OF PEOPLE AND LIVESTOCK, RESULTING IN ENVIRONMENTAL DETERIORATION. BEST PROSPECTS LIE IN ENCOURAGING TRADITIONAL FLOOD RETREAT AGRICULTURE WITH SIMPLE WEIRS AND EMBANKMENTS TO DISTRIBUTE WATER IN THE RIVER VALLEYS AND IN PROVIDING NUMEROUS SMALL WELLS IN THE DRY ZONE.

OALS/AID/KWIC SS 61/WEST AFRICA/SAHELIAN ZONE/DROUGHTS/WATER ALLOCATION(POLICY)/IRRIGATION PRACTICES/IRRIGATION PROGRAMS/WATER RESOURCES DEVELOPMENT/WATER UTILIZATION/IRRIGATION CANALS/WATER SOURCES/AQUIFERS/ WATER STORAGE/WELLS/LIVESTOCK/PASTURES/NOMADS/ENVIRONMENTAL IMPACT/ AGRICULTURE/MALI/NIGER/UPPER VOLTA/SENEGAL

0070

HARSHBARGER, J.W.

1968

GROUND-WATER DEVELOPMENT IN DESERT AREAS.

GROUND WATER 6(5):2-4. SWRA W69-00366.

A SUMMARY OF GROUNDWATER DEVELOPMENT IN SEVERAL MAJOR WORLD DESERTS, 1958-1968, INCLUDING THE SAHARA, EGYPTIAN, ATACAMA, PERUVIAN, AND NORTH AMERICAN DESERTS. SOME BASIC PRINCIPLES FOR OPTIMUM GROUNDWATER MANAGEMENT ARE CITED, WITH THE INDUS BASIN OF WEST PAKISTAN GIVEN AS AN EXAMPLE OF MODEL SOPHISTICATED WATER MANAGEMENT. IT IS CONCLUDED THAT WHILE PHYSICAL RESOURCES AND KNOWLEDGE ARE AVAILABLE TO DEVELOP DESERT AREAS, AND THE COMPUTER AND WATER SYSTEMS ANALYSIS CAN BE USED IN WATER MANAGEMENT, MAN HIMSELF MUST SUPPLY THE WISDOM AND JUDGMENT TO EXPLOIT THESE TOOLS INTELLIGENTLY.

PAKISTAN/WATER MANAGEMENT/OALS/WATER RESOURCES DEVELOPMENT/HYDROGEOLOGY /GROUNDWATER/SAHARA/ATACAMA/PERUVIAN DESERT /INDUS BASIN/EGYPT/DESERTS/WEST U.S.

0071

HARTMAN, L.M.

1965

ECONOMICS AND GROUND-WATER DEVELOPMENT.

GROUND WATER 3(2):4-8.

THE ECONOMICS OF GROUNDWATER RESEARCH DEVELOPMENT AND USE ARE DISCUSSED. AFTER A CONSIDERATION OF THE WELFARE CRITERIA, PROBLEMS OF DEFINING AND MANAGING PROPERTY RIGHTS ARE PRESENTED. THE INTERRELATED NATURE OF GROUNDWATER USE AND EXTERNAL EFFECTS RESULTING FROM UNCOORDINATED INDIVIDUAL ACTION LEAD TO INEFFICIENCIES IN GROUNDWATER DEVELOPMENT AND USE UNLESS APPROPRIATE INSTITUTIONAL ARRANGEMENTS HAVE BEEN MADE. (AUTHOR).

GROUNDWATER/GROUNDWATER MANAGEMENT/POLITICAL ASPECTS/ECONOMIC IMPACT/COST-BENEFIT ANALYSIS/WATER RIGHTS/WATER UTILIZATION/INSTITUTIONAL CONSTRAINTS/PUBLIC RIGHTS/REGULATION/SUBSURFACE WATERS

0072

HEADY, H.F.

1972

ECOLOGICAL CONSEQUENCES OF BEDOUIN SETTLEMENT IN SAUDI ARABIA. IN M.T. FARVAR AND J. P. MILTON, EDS., THE CARELESS TECHNOLOGY: ECOLOGY AND INTERNATIONAL DEVELOPMENT, P. 683-693.

NATURAL HISTORY PRESS, N.Y. 1030 P.

ONE UNPLANNED AND UNFORESEEN SIDE EFFECT OF THE OIL INDUSTRY IN SAUDI ARABIA HAS BEEN SETTLEMENT OF MANY BEDOUINS. THIS PAPER TRACES THE RECENT DEVELOPMENT OF WATER AND GRAZING FOR DOMESTIC ANIMALS. BASIC GEOGRAPHIC CONSIDERATIONS ARE OUTLINED. THE GRAZING HISTORY IS REVIEWED, INCLUDING THE EFFECT OF WATER DEVELOPMENT BY OIL INTERESTS AND THE DROUGHT OF 1955-63 ON INTENSIFICATION OF SETTLEMENT. THE AUTHOR REPORTS ON NUMBERS OF GRAZING ANIMALS AND CONDITIONS OF THE RANGE. HYDROLOGICAL DEVELOPMENT OF WELLS WAS OFTEN POORLY CARRIED OUT, RESULTING IN EXCESS WATER, HIGH SALINITY AND POOR DRAINAGE. RECENTLY WATER MANAGEMENT PRACTICES HAVE BEEN IMPROVED. THE AUTHOR QUESTIONS THE USEFULNESS OF WATER-SPREADING SYSTEMS IN WADIS. DEPLETION OF WILDLIFE IS RELATED TO THE INTRODUCTION OF FOUR-WHEEL DRIVE VEHICLES. THE AUTHOR FEELS THAT MANY BEDOUINS CAN EASILY MOVE INTO MODERN SOCIETY, BUT THAT THEIR WAY OF LIFE IS THE BEST FOR EXPLOITATION OF THE RANGE RESOURCES. FOR THOSE THAT RETAIN THEIR NOMADIC EXISTENCE, HE SUGGESTS THAT MODERNIZATION OF BEDOUIN LIFE IN SITU WITH ALL THE SERVICES AVAILABLE FROM TECHNOLOGICAL AGRICULTURE AND OTHER ASPECTS OF MODERN SOCIETY SHOULD BE BROUGHT TO BEAR ON THE PROBLEMS OF LIVESTOCK PRODUCTION IN ARID REGIONS.

OALS/SAUDI ARABIA/ARABIAN DESERT/NOMADS/ENVIRONMENTAL EFFECTS/SOCIAL ASPECTS/ECONOMIC DEVELOPMENT/OIL FIELDS/WATER RESOURCES DEVELOPMENT/WATER SPREADING/SALINITY/DROUGHTS/LIVESTOCK/GRAZING/REGIONAL GEOGRAPHY /WELLS/SETTLEMENTS/WILDLIFE

0073

HEINDL, L. ED.

1975

HIDDEN WATERS IN ARID LANDS. REPORT OF A WORKSHOP ON GROUNDWATER RESEARCH NEEDS IN ARID AND SEMI-ARID ZONES, NOVEMBER 25, 1974, PARIS.

INTERNATIONAL DEVELOPMENT RESEARCH CENTRE, OTTAWA. 18 P.

SEE: SWRA W76-06585.

GROUNDWATER/ARID LANDS/WATER RESOURCES DEVELOPMENT/WATER SUPPLY/DROUGHTS/ GROUNDWATER RESOURCES/WATER QUALITY/SEMIARID CLIMATE/WATER SHORTAGE/ ENVIRONMENTAL EFFECTS/SOCIAL ASPECTS/HYDROGEOLOGY/HYDROLOGIC DATA/WATER MANAGEMENT(APPLIED)

0074

HELWEG, O.J.

1977

A NONSTRUCTURAL APPROACH TO CONTROL SALT ACCUMULATION IN GROUNDWATER.

GROUND WATER 15(1):51-56.

ONE OF THE MORE SUBTLE AND DANGEROUS AREAS OF POLLUTION IS THAT OCCURRING IN GROUNDWATER FROM NORMAL IRRIGATION PRACTICES. THE POLLUTION FROM SALT BUILDUP IS ONE OF THE UNSOLVED PROBLEMS IN MANAGING STREAM-AQUIFER SYSTEMS. THIS PAPER PRESENTS SEVERAL STRATEGIES THAT OFFER A POSSIBILITY OF CONTROLLING THIS SALT BUILDUP. FOR EXAMPLE, INSTEAD OF APPLYING IRRIGATION GROUNDWATER NEAR THE SITE OF THE WELL, THE ASTRAN METHOD TRANSFERS IT DOWNSTREAM TO BE APPLIED ON LAND WHEN THE GROUNDWATER IS A LOWER QUALITY THEREBY CONTROLLING THE INCREASE IN SALT CONCENTRATION. INSTEAD OF PREVENTING SEEPAGE LOSS IN DELIVERY CANALS, THE PERCOLATING WATER IS USED TO MAINTAIN GROUNDWATER QUALITY. FINALLY, TIMED RELEASES OF RETURN FLOW REMOVE SALTS WITHOUT EXCEEDING SURFACE-WATER QUALITY CONSTRAINTS. (AUTHOR).

GROUNDWATER/IRRIGATION PRACTICES/IRRIGATION EFFECTS/SALINE WATER/EVAPORATION/ EVAPOTRANSPIRATION/MODELS/WATER QUALITY/SALINE SOILS/SALINITY/SALTS

0075

HENNIGHAUSEN, F.H.

1970

CHANGE OF CHLORIDE CONTENT OF WATER IN RESPONSE TO PUMPING IN THE ARTESIAN AQUIFER IN THE ROSWELL-EAST GRAND PLAINS AREA, CHAVES COUNTY, NEW MEXICO. IN R.B. MATTOX, ED., SALINE WATER, P. 71-86.

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, SOUTHWESTERN AND ROCKY MOUNTAIN DIVISION, COMMITTEE ON DESERT AND ARID ZONES RESEARCH, CONTRIBUTION 13. 105 P.

SALINE WATER IN THE ARTESIAN AQUIFER IN THE ROSEWELL-EAST GRAND PLAIN AREA HAS ENCROACHED INTO THE FRESH WATER PORTION OF THE AQUIFER SINCE 1952 AND HAS RETREATED IN SOME PARTS SINCE 1965 IN RESPONSE TO FLUCTUATIONS IN ARTESIAN HEAD CAUSED BY PUMPAGE OF WATER FROM THE AQUIFER. THE MOVEMENT OF THE SALINE WATER, WHICH IS BOTH VERTICAL AND LATERAL, IS RESPONSIVE BOTH TO SEASONAL DECLINES IN ARTESIAN HEAD AND TO ACCUMULATIVE OVERDRAFT OF THE WHALE BASIN. IT IS PROBABLE THAT THE RECENT OVERALL TREND TOWARDS IMPROVEMENT OF WATER QUALITY WILL CONTINUE IF PUMPING IS MAINTAINED AT APPROXIMATELY THE SAME RATE THAT HAS OCCURRED FOR THE PAST 3 YEARS AND IF SEVERE SEASONAL DECLINES OF ARTESIAN HEAD ARE INFREQUENT.

GROUNDWATER/NEW MEXICO/GROUNDWATER MINING/ARTESIAN WELLS/WATER QUALITY/ SALINE WATER INTRUSION

0076

HOCK, K.J.

1973

AGRICULTURAL ADJUSTMENTS TO A FALLING GROUNDWATER TABLE IN CENTRAL ARIZONA.

UNIVERSITY OF ARIZONA (PH.D. DISSERTATION). 152 P.

LEVELS OF FUTURE AGRICULTURAL PRODUCTION IN MARICOPA COUNTY WERE PROJECTED USING LINEAR PROGRAMMING MODELS INCORPORATING DECLINING LAND AND WATER BASES, INCREASING WATER COSTS, AND TRANSFER OF COTTON ALLOTMENTS. TWO MODEL REGIONS ARE CONSIDERED: AREA A WITH LOW-COST POOR QUALITY WATER TO GROW ONLY COTTON, AND AREA B WITH HIGH-COST GOOD QUALITY WATER FOR GROWTH OF VEGETABLES AND CITRUS AS WELL AS COTTON. 9 FARM SIZES, 10 CROPS, AND 18 WATER COST AND AVAILABILITY SITUATIONS ARE INCLUDED IN THE MODEL. PROJECTIONS COVER 1967 TO 2015. AGGREGATE LAND AND WATER USE DECLINE MORE THAN 20 PERCENT AND TOTAL NET REVENUES DECLINE 13 PERCENT IN THE PROJECTED PERIOD, DUE TO EXPANDING URBAN AREAS AND ABANDONED LOW-VALUE CROPS. IN AREA A CULTIVATED LAND DROPS 7 PERCENT, WATER USE DROPS 13 PERCENT, YET NET REVENUES RISE 7 PERCENT BECAUSE OF INCREASED COTTON GROWTH. IN AREA B LAND USE, WATER USE, AND NET REVENUES ALL FALL, 30, 30, AND 23 PERCENT, RESPECTIVELY. A COMPREHENSIVE LAND USE PLAN, ZONING URBAN AREAS AWAY FROM LOW-COST WATER, WOULD HELP MAINTAIN URBAN ENVIRONMENTAL QUALITY AS WELL AS AGRICULTURAL RESOURCE USE AND INCOMES AT HIGHER LEVELS.

OALS/AGRICULTURE/GROUNDWATER/WATER TABLE/MARICOPA COUNTY/CROP PRODUCTION/ MATHEMATICAL MODELS/LAND USE/WATER COSTS/WATER SUPPLY/WATER QUALITY/WATER UTILIZATION/URBAN PLANNING/ENVIRONMENT/ARIZONA/MEIGS SA13/GOSSYPIUM/ ECONOMICS/ECONOMIC IMPACT/ANALOG SIMULATION/ZONING/COMPETING USES/PLANNING

0077

HOLZER, T.L./DAVIS, S.N.

1976

EARTH FISSURES ASSOCIATED WITH WATER-TABLE DECLINES.

GEOLOGICAL SOCIETY OF AMERICA, ABSTRACTS WITH PROGRAMS 8(6):923-924.

MANY EARTH FISSURES ARE ASSOCIATED WITH LAND SUBSIDENCE IN AREAS OF EXCESSIVE EXTRACTION OF GROUNDWATER. FIELD EVIDENCE APPEARS TO BE INCOMPATIBLE WITH MECHANISMS MOST COMMONLY USED TO EXPLAIN FISSURES. ANY PROPOSED MECHANISM SHOULD BE CONSISTENT WITH THE FOLLOWING OBSERVATIONS: FISSURES APPEAR TO BE RESTRICTED TO AREAS OF WATER-TABLE DECLINES; YOUTHFUL FISSURES EXAMINED IN THE FIELD APPEAR TO BE PROPAGATING UPWARDS FROM DEPTH; AND, MANY FISSURES ARE DEEP, APPEARING TO EXTEND FROM THE DRAINED ZONE TO THE GROUND SURFACE. AUTHORS PROPOSE A MECHANISM OF HORIZONAL SEDIMENT SHRINKAGE ACCOMPANIED BY TENSILE FAILURE WITHIN THE ZONE WHICH IS DRAINED WHEN THE WATER TABLE IS LOWERED TO EXPLAIN FISSURES. ALTHOUGH THIS MAY NOT BE THE ONLY MECHANISM ACTING, IT MAY DOMINATE IN THE REGIONS STUDIED. (AFTER AUTHOR)

GROUNDWATER/SUBSIDENCE/WATER TABLE/GROUNDWATER MINING

0078

HOOD, J.W.

1963

SALINE GROUND WATER IN THE ROSWELL BASIN, CHAVES AND EDDY COUNTIES, NEW MEXICO, 1958-59.

U.S. GEOLOGICAL SURVEY, WATER-SUPPLY PAPER 1539-M. 46 P.

THE RESULTS OF ANALYSIS OF WATER SAMPLES FROM WELLS AND SPRINGS SHOW THAT IN THE ROSWELL BASIN SALINE-WATER ENCROACHMENT IS A REAL OR POTENTIAL THREAT TO THE PRODUCTIVITY OF THE IRRIGATED LANDS IN THE BASIN. IN GENERAL, THE QUALITY OF WATER AT A GIVEN LOCATION DECREASES WITH DEPTH AND, IN A GIVEN ZONE DETERIORATES EASTWARD. THE ENCROACHMENT OF SALINE WATER INTO FRESH WATER IS DUE TO LARGE SCALE GROUNDWATER DEVELOPMENT.

GROUNDWATER/NEW MEXICO/WATER QUALITY/SALINE WATER INTRUSION/ARTESIAN WELLS/ WATER TABLE/CHLORIDE

0079

HOSKIN, G.K.

1965

WHO PAYS WHEN THE WELL RUNS DRY.

UNIVERSITY OF COLORADO LAW REVIEW 37:402-414.

IN THE DEVELOPMENT OF SUBSURFACE WATER IN THE WESTERN U.S., CONSIDERATIONS OF CERTAINTY OF ESTABLISHED USES AND OF FULL DEVELOPMENT HAVE PULLED IN OPPOSITE DIRECTIONS. THIS ARTICLE CONCERNS THE CONFLICT WHICH DOES NOT CENTER AROUND THE AVAILABILITY OF WATER FOR ALL PERSONS CONCERNED, BUT RATHER AROUND THE PAYMENT FOR THE ALTERATION OR REPLACEMENT OF DIVERSION WORKS MADE OBSOLETE WHEN SUBSEQUENT USERS LOWER THE WATER LEVEL.

WITHDRAWAL/WATER UTILIZATION/DIVERSION/GROUNDWATER/JUDICIAL DECISIONS/ GROUNDWATER MINING/WATER LEVEL FLUCTUATIONS/WATER RIGHTS/COMPENSATION/ SUBSURFACE WATERS/HYDROSTATIC PRESSURE

0080

HOWE, C.W.

1976

THE EFFECTS OF WATER RESOURCE DEVELOPMENT ON ECONOMIC GROWTH: THE CONDITIONS FOR SUCCESS.

NATURAL RESOURCES JOURNAL 16(3):939-955.

IN THE POST-WAR PERIOD, THE WESTERN WORLD HAS PURSUED THE ISSUE OF WATER DEVELOPMENT IN THE THIRD WORLD BY TRYING TO TRNASPLANT TECHNOLOGIES, SUCCESSFUL IN THE WEST, INTO THE SOCIAL SYSTEMS OF THESE COUNTRIES. ANY HOPE FOR THE SUCCESS OF SUCH TRANSPLANTS RESTS UPON THE FOLLOWING CONDITIONS: A) THAT WATER IS THE REAL BOTTLENECK TO GROWTH, B) THAT CAPITAL IS AVAILABLE FOR THE WATER SYSTEM UNDER DEVELOPMENT AND FOR THE RELATED, COMPLIMENTARY USES, C) THAT INSTITUTIONS CAPABLE OF MANAGING THE TECHNOLOGY EXIST, AND D) THAT THE TECHNOLOGY FITS THE SOCIAL STRUCTURE AND VALUES OR THAT THE LATTER WILL CHANGE TO ACCOMMODATE THE TECHNOLOGY. THESE CONDITIONS EXIST IN RELATIVELY FEW CASES. THIS PAPER INVESTIGATES THE NECESSARY AND/OR SUFFICIENT CONDITIONS FOR SUCCESSFUL GROWTH INITIATION BY WATER PROJECTS THROUGH BOTH A CONCEPTUAL FRAMEWORK AND EMPIRICAL CASE STUDIES. CASE STUDIES ARE GIVEN ON IRRIGATION, DRAINAGE, NAVIGATION, AND MULTIPLE-PURPOSE PROJECTS. SOME OBSERVATIONS ARE OFFERED TO BE USED AS GUIDES TO FUTURE POLICY FORMULATION.

WATER RESOURCES DEVELOPMENT/IRRIGATION/NAVIGATION/WATER MANAGEMENT(APPLIED)/ ECONOMIC DEVELOPMENT

0081

HUGHES, W.F./HARMAN, W.L.

1969

PROJECTED ECONOMIC LIFE OF WATER RESOURCES, SUBDIVISION #1, HIGH PLAINS UNDERGROUND WATER RESERVOIR.

TEXAS AGRICULTURAL EXPERIMENT STATION, TECHNICAL MONOGRAPH 6. 81 P.

GROUNDWATER DEPLETION TRENDS INDICATE CHANGE IN THE MAJOR IRRIGATED AREAS OF THE TEXAS HIGH PLAINS. PROGRAMMED RESULTS IN 1966 INDICATE THAT THE LIFE OF THE GROUNDWATER RESOURCES RANGES FROM 5 TO MORE THAN 50 YEARS, THAT IRRIGATED ACREAGE WILL DECLINE FROM 3.5 MILLION ACRES IN 1966 TO 125,000 ACRES IN 2015. THAT THE AMOUNT OF WATER PUMPED WILL DECLINE FROM 4.13 MAF IN 1966 TO 95,000 AF IN 2015. SUBSTANTIAL DECLINES IN THE VOLUME OF AGRICULTURAL PRODUCTION AND FARM INCOME WILL ACCOMPANY THESE DECLINES. AT 1966 COMMODITY PRICES THE AGGREGATE ANNUAL VALUE OF AGRICULTURAL PRODUCTION IS PROJECTED TO DECLINE FROM 432 MILLION DOLLARS IN 1966 TO 128 MILLION DOLLARS, OR 70 PERCENT, BY 2015. AGGREGATE ANNUAL NET FARM RETURNS WILL DECLINE FROM 194 MILLION DOLLARS TO 50.5 MILLION DOLLARS, 68 PERCENT, DURING THE SAME TIME PERIOD. THESE PROJECTIONS HAVE FAR-REACHING INDIVIDUAL, AREA, STATE, NATIONAL, AND EVEN INTERNATIONAL IMPLICATIONS.

GROUNDWATER/PUMPING/GROUNDWATER MINING/TEXAS/WATER SUPPLY/ECONOMIC IMPACT

0082

HUGHES, W.F./MAGEE, A.C.

1960

SOME ECONOMIC EFFECTS OF ADJUSTING TO A CHANGING WATER SUPPLY.

TEXAS AGRICULTURAL EXPERIMENT STATION, BULLETIN 966. 27 P.

REGIONAL STATIC WATER LEVELS HAVE DECLINED FROM A FEW FEET TO 100 FEET IN THE AQUIFER UNDERLYING THE TEXAS HIGH PLAINS DURING THE PERIOD 1937-58. PRINCIPAL SHORT RUN PHYSICAL EFFECT IS A DECLINE IN WELL CAPACITY. LONG-RUN EFFECT IS A DEPLETED WATER SUPPLY. ADJUSTMENTS TO THIS DECLINE INCLUDE: 1) INCREASING HOURS OF PUMP OPERATION, 2) LOWERING PUMPS, 3) INSTALLING ADDITIONAL WELL, 4) INSTALLING CLOSED WATER DISTRIBUTION SYSTEMS, 5) INSTALLING SMALLER PUMPS IN OLD WELLS, 6) DECREASING ACREAGE OF SUMMER-IRRIGATED CROPS AND INCREASING ACREAGE OF FALL AND WINTER-IRRIGATED CROPS, 7) STAGGERING GRAIN SORGHUM PLANTING DATES, 8) CONCENTRATING WATER SUPPLY ON COTTON, 9)IRRIGATING ALTERNATE ROWS, AND 10) REDUCING NUMBER OF ACRES IRRIGATED PER FARM. THE EFFECTS OF ADJUSTING TO DECLINING WATER SUPPLIES ARE REFLECTED IN INCREASED PER-ACRE INVESTMENT IN IRRIGATION FACILITIES AND INCREASED OPERATING COSTS PER ACRE.

GROUNDWATER/TEXAS/IRRIGATED AGRICULTURE/IRRIGATION WELLS/GROUNDWATER MINING/ WITHDRAWAL/ECONOMIC IMPACT/IRRIGATION EFFECTS/CROP PRODUCTION/ CULTIVATED LANDS

0083

ISKANDAR, W.

1972

GROUND WATER IN THE SUDAN. IN MAN - ENVIRONMENT - DEVELOPMENT, ARAB REGIONAL SYMPOSIUM ON ENVIRONMENTAL ASPECTS AND DEVELOPMENT IN THE ARAB COUNTRIES, KHARTOUM, FEBRUARY 5-12, 1972, PROCEEDINGS P. 281-285.

ARAB LEAGUE EDUCATIONAL, CULTURAL AND SCIENTIFIC ORGANIZATION (ALECSO), KHARTOUM. 413 P.

SUDAN IS THE LARGEST COUNTRY IN AFRICA. AVERAGE ANNUAL RAINFALL VARIES FROM TRACE AMOUNTS IN THE NORTHERN SAHARA TO GREATER THAN 1500 MM IN SOUTHERN TROPICAL ZONES. ECONOMY IS MAINLY AGRICULTURAL AND DEVELOPMENT OF RURAL AREAS DEPENDS UPON THE AVAILABILITY OF LARGE ENOUGH AMOUNTS OF GROUNDWATER AND ITS SUITABILITY FOR DOMESTIC AND IRRIGATION USE. DIFFERENT SOURCES OF GROUNDWATER SUPPLIES ARE DISCUSSED. PROBLEMS ARE: A SHORTAGE OF TECHNICAL STAFF AND EQUIPMENT; LOW SUCCESS RATES WITH WELLS DRILLED IN CERTAIN GEOLOGIC FORMATIONS; LACK OF DATA TO ASSESS GROUNDWATER POTENTIAL; OVERDRAFT OF AQUIFER LEADING TO GREATER DEPTHS TO WATER, LOWER WELL YIELDS AND DETERIORATING QUALITY; AND LACK OF WATER QUALITY DATA.

GROUNDWATER/SUDAN/SAHARA/GROUNDWATER MINING/IRRIGATED AGRICULTURE/WATER QUALITY

0084

JENKINS, C.T.

1968

TECHNIQUES FOR COMPETING RATE AND VOLUME OF STREAM DEPLETION BY WELLS.

GROUND WATER 6(2):37-46.

THE EFFECTS ON FLOW OF A NEARBY STREAM FROM PUMPING A WELL CAN BE CALCULATED READILY USING DIMENSIONLESS CURVES AND TABLES. COMPUTATIONS CAN BE MADE OF 1) THE RATE OF STREAM DEPLETION AT ANY TIME DURING THE PUMPING PERIOD OR AFTER THE CESSATION OF PUMPING, 2) THE VOLUME INDUCED FROM THE STREAM DURING OR AFTER PUMPING, 3) THE EFFECTS, BOTH IN RATE AND VOLUME OF STREAM DEPLETION, OF ANY SELECTED PATTERN OF INTERMITTENT PUMPING. SAMPLE PROBLEMS AND CALCULATIONS ILLUSTRATE THE USE OF THE CURVES AND TABLES. THE EFFECTS AFTER THE CESSATION OF PUMPING ON STREAMFLOW MAY EASILY BE GREATER THAN THE EFFECTS DURING THE PUMPING PERIOD. WITH INCREASING FREQUENCY, PROBLEMS OF WATER ADMINISTRATION WILL REQUIRE THE EVALUATION OF THE IMPACT OF GROUND WATER DEVELOPMENT ON STREAMFLOW. (AFTER AUTHOR).

SURFACE-GROUNDWATER RELATIONSHIPS/GROUNDWATER/STREAMFLOW/MATHEMATICAL MODELS/ COLORADO/HYDROLOGIC DATA/SURFACE WATERS/WELLS/ANALYTICAL TECHNIQUES

0085

JENTSCH, C.

1970

KAREZES IN AFGHANISTAN (IN GERMAN).

ERDKUNDE 24(2):112-120.

SEE: SWRA W71-10484.

GROUNDWATER/SOCIAL ASPECTS/ARID LANDS/IRRIGATION SYSTEMS/WATER DISTRIBUTION/ POTABLE WATER/SURVEYS/TOPOGRAPHY/SALINITY/WATER CONTROL/WATER DELIVERY

0086

JONES, L.L./LARSON, J.

1975

ECONOMIC EFFECTS OF LAND SUBSIDENCE DUE TO EXCESSIVE GROUNDWATER WITHDRAWAL IN THE TEXAS GULF COAST AREA.

TEXAS A AND M UNIVERSITY, COLLEGE STATION, WATER RESOURCES INSTITUTE, TECHNICAL REPORT 67. 33 P.

SEE: SWRA W76-03099.

SUBSIDENCE/GROUNDWATER/WITHDRAWAL/ECONOMIC IMPACT/ WATER TRANSFER/TEXAS

0087

JONES, L.L./WARREN, J.

1976

LAND SUBSIDENCE COSTS IN THE HOUSTON-BAYTOWN AREA OF TEXAS.

AMERICAN WATER WORKS ASSOCIATION, JOURNAL 68(11):597-599.

PUMPING OF GROUNDWATER HAS CAUSED SUBSIDENCE OF AS MUCH AS 9 FEET IN THE HOUSTON AREA. COSTS FOR THIS WATER HAVE NOT INCLUDED DAMAGES CAUSED BY SUBSIDENCE. AUTHORS DEVELOP AN ECONOMIC MODEL BASED ON DAMAGES REPORTED IN A SURVEY. THE MODEL REVEALS THAT THE SUBSTITUTION OF SURFACE FOR GROUNDWATER USE IN THE AREA WOULD PROVIDE A LOWEST-COST ALTERNATIVE FOR WATER SUPPLY. (AUTHORS)

GROUNDWATER/SUBSIDENCE/MODELS/COSTS/ECONOMIC IMPACT/TEXAS/WITHDRAWAL/ SURFACE WATERS

0088

JUDD, B.I. ET AL.

1971

THE LETHAL DECLINE OF MESQUITE ON THE CASA GRANDE NATIONAL MONUMENT.

GREAT BASIN NATURALIST 31(3):153-159. SWRA W72-07051.

DEAD MESQUITE(PROSOPIS JULIFLORA)TREES ARE THE RULE THROUGHOUT CASA GRANDE NATIONAL MONUMENT IN CENTRAL ARIZONA. IN AN ENDEAVOR TO DETERMINE THE YEAR OF DEATH AND AGE, 10 CROSS-SECTIONAL SPECIMENS WERE CUT FROM VARIOUS MESQUITE TREES ON THE MONUMENT. THREE OF THEM PROVED TO BE SATISFACTORY DENDROCHRONOLOGICAL MATERIAL. THEIR AGES WERE 110, 137 AND 111 YEARS. ALL 3 SPECIMENS EXHIBITED SERIES OF GOOD AND BAD GROWTH YEARS, BUT ATTEMPTS TO CORRELATE THESE WITH PRECIPITATION DATA OR TO CROSSDATE BETWEEN TREES PROVED INEFFECTIVE. NO EVIDENCE OF INFESTATION BY INSECTS OR DISEASE PRIOR TO DEATH WAS DISCOVERED. MISTLETOE INFECTIONS MAY HAVE BEEN IMPORTANT, JUDGING FROM PHOTOGRAPHS FROM 1878 AND 1930; POSSIBLY THEY LOWERED THE TREE RESISTANCES ENOUGH TO INTERFERE WITH THEIR CAPABILITIES TO ADAPT TO CHANGING CONDITIONS. THE ONLY OTHER FACTOR WHICH MAY BE IMPORTANT IS WATER TABLE DECLINE. THE RECORDS OF WATER TABLE LEVELS AND MESQUITE DEATHS INDICATE CORRELATIONS. AGE OF TREES, INSECT INFESTATION AND NATURAL SUCCESSIONAL PROCESSES MAY HAVE BEEN SECONDARY FACTORS.

OALS/PROSOPIS JULIFLORA/TREES/ARIZONA/WATER TABLE/PHORADENDRON/PLANT POPULATIONS/DROUGHTS/CLIMATIC DATA/MORTALITY/DEATH/WATER LEVELS/PINAL COUNTY

0089

KAHANA, Y.

1968

THE ROLE OF GROUNDWATER IN THE DEVELOPMENT OF WATER RESOURCES. IN INTERNATIONAL CONFERENCE ON WATER FOR PEACE, 1967, WASHINGTON, D.C., WATER FOR PEACE 2:809-820.

U.S. GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C.

SEE: SWRA W69-06054.

GROUNDWATER/ARID LANDS/GROUNDWATER MANAGEMENT/AQUIFERS/SYSTEMS ANALYSIS/ COMPUTERS/ARTIFICIAL RECHARGE/WATER DEMAND/WATER RESOURCES/WATERSHED MANAGEMENT/STORAGE

0090

KAM, W.

1965

EARTH CRACKS: A CAUSE OF GULLYING.

U.S. GEOLOGICAL SURVEY, PROFESSIONAL PAPER 525-B:122-125.

THE DEVELOPMENT OF EARTH CRACKS ACCOMPANYING LAND-SURFACE SUBSIDENCE THAT RESULTS FROM DIFFERENTIAL COMPACTION OF HETEROGENEOUS UNCONSOLIDATED SEDIMENTS FAVORS GULLYING. WHERE NEWLY FORMED EARTH CRACKS TRANSECT DRAINAGEWAYS, LOWER BASE LEVELS ESTABLISHED AT POINTS OF TRANSECTION FAVOR MORE RAPID EROSION AND THE FORMATION OF GULLIES UPSTREAM FROM THE CRACKS. AT OTHER PLACES NEW GULLIES FORM UPSLOPE FROM EARTH CRACKS WHERE NO DRAINAGE WAY EXISTED BEFORE. WHERE THE MATERIAL BENEATH THE CRACKS DOES NOT ABSORB THE WATER TRANSMITTED BY THESE GULLIES, DIVERSION OF THE GULLY STREAMS ALONG THE CRACKS MAY LEAD TO CHANGES IN DRAINAGE PATTERN. (AUTHOR)

SUBSIDENCE/GULLY EROSION/DRAINAGE PATTERNS

0091

KANEDA, H./GHAFFAR, M.

1970

OUTPUT EFFECTS OF TUBEWELLS ON THE AGRICULTURE OF THE PUNJAB: SOME EMPIRICAL RESULTS.

PAKISTAN DEVELOPMENT REVIEW 10(1):68-87.

RESULTS OF A STATISTICAL STUDY AND REGRESSION ANALYSIS DONE TO DETERMINE THE OUTPUT EFFECTS OF TUBEWELLS FROM EMPIRICAL DATA COLLECTED PRIOR TO THE INFLUENCE OF THE GREEN REVOLUTION IN PAKISTAN ARE DISCUSSED. DATA ARE PRESENTED ON EFFECTS OF TUBEWELLS ON CROPPING PATTERN AND CROPPING INTENSITIES, CROP YIELDS, AND TYPE AND PRODUCTIVITY OF INPUTS. THREE REGRESSION MODELS ARE DEVELOPED AND SUBJECTED TO VARIANCE - COVARIANCE ANALYSIS FOR TESTING EMPIRICAL VALIDITY OF THE ALTERNATIVE ASSUMPTIONS CONTAINED IN EACH MODEL. WITHIN THE LIMITS OF THE STUDY THE FOLLOWING CONCLUSIONS EMERGE: 1) WATER FROM TUBEWELLS NOT ONLY INCREASE THE INPUTS OF LABOR AND CROPPED ACREAGE, BUT ALSO INCREASE THE EFFICIENCY IN WHICH THESE INPUTS ARE TRANSFORMED INTO OUTPUT; 2) THE OUTPUT - AUGMENTING EFFECT OF TUBEWELL WATER IS MOST PRONOUNCED IN THE FARMS HOLDING BETWEEN 12, 5 AND 50 ACRES; 3) THE PATTERN OF INCREASES IN TUBEWELL INSTALLATIONS REVEALS THAT FARMS IN THESE SIZE CLASSES HAVE RESPONDED MOST CONSPICTOUSLY TO THE EXPANDED ECONOMIC OPPORTUNITIES MADE AVAILABLE.

GROUNDWATER/IRRIGATION WELLS/WELLS/IRRIGATION PRACTICES/CROP PRODUCTION/ECONOMIC DEVELOPMENT/ECONOMIC IMPACT/FERTILIZERS/PAKISTAN/CROPS/LAND USE/CULTIVATION/REGRESSION ANALYSIS/MATHEMATICAL MODELS/ANALYTICAL TECHNIQUES/AGRICULTURE/PRODUCTION FUNCTION/GREEN REVOLUTION/TUBEWELLS/CROP YIELDS/CROPPING PATTERNS

0092

KASHEF, A.-A.I.

1973

POLLUTION OF GROUNDWATER BY SALT INVASION. IN GROUNDWATER POLLUTION CONFERENCE, PROCEEDINGS, P. 72-89.

UNDERWATER RESEARCH INSTITUTE, ST. LOUIS, MISSOURI.

SEE: SWRA W74-09594.

SALINE WATER INTRUSION/GROUNDWATER PUMPING/WELLS/SALINE WATER-FRESHWATER INTERFACES/WATER MANAGEMENT(APPLIED)/RECHARGE WELLS/RECHARGE/ARTIFICIAL RECHARGE/SALINE WATER

0093

KELSO, M.M./MARTIN, W.E./MACK, L.E.

1973

WATER SUPPLIES AND ECONOMIC GROWTH IN AN ARID ENVIRONMENT: AN ARIZONA CASE STUDY.

UNIVERSITY OF ARIZONA PRESS, TUCSON. 327 P.

THE AUTHORS STATE THAT WATER SUPPLIES IN THE STATE ARE ADEQUATE FOR CONTINUOUS GROWTH OF THE STATE S ECONOMY. POLICY ACTIONS ARE NEEDED TO FACILITATE CHANGING THE STRUCTURE OF THE STATE S ECONOMY AND THE TRANSFERABILITY OF WATER AMONG USES AND LOCATIONS OF USE. THE CURRENT WATER PROBLEM IS A MANAGEMENT, INSTITUTIONAL, AND POLICY PROBLEM OF DEMAND MORE THAN ONE OF SUPPLIES WHERE RESTRAINTS ARE MAN-MADE RATHER THAN NATURE-MADE. THE STUDY POINTS OUT THAT MOST OF ARIZONA S WATER IS USED TO GROW AGRICULTURAL CROPS THAT PRODUCE RELATIVELY LITTLE ECONOMIC RETURN. A SENSIBLE, ECONOMICAL APPROACH TO MANAGING ARIZONA S WATER RESOURCES IS THE GRADUAL PHASING OUT OF MARGINAL AGRICULTURE TO PROVIDE WATER FOR USES THAT ARE FAR MORE IMPORTANT TO OUR ECONOMY.

OALS/WATER SUPPLY/WATER RESOURCES/ECONOMICS/ARIZONA/EVALUATION/WATER MANAGEMENT/WATER SHORTAGE/WATER YIELD/AGRICULTURE/IRRIGATION

0094

KOMIE, F.E.

1969

THE CHANGING ROLE OF THE GROUNDWATER RESERVOIR IN ARID LANDS. PAPER PRESENTED AT INTERNATIONAL CONFERENCE ON ARID LANDS IN A CHANGING WORLD, TUCSON, JUNE 1969.

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, COMMITTEE ON ARID LANDS/UNIVERSITY OF ARIZONA, TUCSON. PROCESSED. 5 P.

SEE: SWRA W69-07351.

GROUNDWATER/WATER RESOURCES PLANNING/ARID LANDS/GROUNDWATER MINING/SUBSIDENCE/OVERDRAFT/UNDERGROUND STORAGE/COMPETING USES/WATER USERS/REASONABLE USE/WATER CONSERVATION/WATER QUALITY/WATER RESOURCES PLANNING

0095

LACEWELL, R.D./JONES, L.L./OSBORN, J.E.

1976

ADJUSTMENTS DUE TO A DECLINING GROUNDWATER SUPPLY: HIGH PLAINS OF NORTHERN TEXAS AND WESTERN OKLAHOMA.

TEXAS WATER RESOURCES INSTITUTE, TECHNICAL REPORT 74. 42 P.

THE DECLINING GROUNDWATER SUPPLY IN THE NORTHERN HIGH PLAINS IS A REGIONAL PROBLEM AFFECTING THE REGIONAL AND STATE ECONOMIES IN TEXAS AND OKLAHOMA. PAPER SUMMARIZES THE WORK THAT HAS BEEN DONE ON PROJECTING THE ECONOMIC, AGRICULTURAL AND INDUSTRIAL PRODUCTION AND COMMUNITY SERVICES EFFECTS OF A DECLINING GROUNDWATER RESOURCE. DECLINING GROUNDWATER SUPPLY WILL RESULT IN REDUCED AGRICULTURAL OUTPUT WHICH WILL BE REFLECTED THROUGHOUT THE REGION IN TERMS OF POPULATION, EMPLOYMENT, GROSS OUTPUT OF NON-AGRICULTURAL SECTORS, AND COMMUNITY SERVICE EXPENDITURES, RESULTING IN AN OVERALL DOWNWARD ECONOMIC TREND.

GROUNDWATER/OGALLALA AQUIFER/TEXAS/OKLAHOMA/ECONOMIC IMPACT/IRRIGATION/AGRICULTURE/CROP PRODUCTION

0096

LAL, D.

1972

WELLS AND WELFARE, AN EXPLORATORY COST-BENEFIT STUDY OF THE ECONOMICS OF SMALL-SCALE IRRIGATION IN MAHARASHTRA.

OECD, PARIS, DEVELOPMENT CENTRE STUDIES, SERIES ON COST-BENEFIT ANALYSIS, CASE STUDY 1. 162 P.

THE AHMEDNAGAR DISTRICT IN THE MAHARASHTRA STATE IN INDIA LIES IN THE DECCAN FAMINE BELT AND RECEIVES AN AVERAGE OF 60 CENTIMETERS PER YEAR RAINFALL. GROUNDWATER HAS BEEN AND WILL CONTINUE TO BE THE MAJOR SOURCE OF IRRIGATION WATER. WHEN A FARMER HAS ACCESS TO AN ASSURED SUPPLY OF WATER: 1) VARIABILITY OF YIELD OF EXISTING DRY FARM CROPS IS REDUCED, 2) HE IS ABLE TO USE FERTILIZER AND BETTER SEEDS WHICH SHIFT THE PRODUCTION FUNCTION FOR THE CROPS, 3) CROPPING PATTERNS ARE CHANGED. THE IMPACT ON THE FARMER'S INCOME IS DRAMATIC. PROFIT/ACRE ON UNIRRIGATED LAND IN RUPEES IS RS. 7.9/ACRE. WHEN 75-99% OF THE LAND IS IRRIGATED THE PROFIT RISES TO RS. 100.6/ACRE. THIS STUDY ATTEMPTS TO DETERMINE THE SOCIAL RATES OF RETURN OF ALTERNATIVE CROPPING PATTERNS, EXTENSIVE VS INTENSIVE APPLICATION OF IRRIGATION WATER, AND THE RANDOM SITING OF WELLS VS SITING WELLS BASED ON HYDROGEOLOGIC STUDIES. POLICY IMPLICATIONS FOR INDIA ARE DRAWN.

WELLS/GROUNDWATER/SOCIAL ASPECTS/ECONOMIC IMPACT/INDIA/IRRIGATION/SORGHUM/SUGAR CANE/SOIL-WATER-PLANT RELATIONSHIPS/DRY FARMING/CROP PRODUCTION/IRRIGATION PRACTICES/FERTILIZERS/LAND USE

0097

LOF, G.

1960

POTENTIAL APPLICATIONS OF NEW WATER TECHNOLOGY IN THE WEST. IN F.S. POLLAK, ED., RESOURCES DEVELOPMENT, FRONTIERS FOR RESEARCH, P. 39-48.

UNIVERSITY OF COLORADO PRESS, BOULDER.

SEE: SWRA W69-08089.

TECHNOLOGY/INDUSTRIAL USE/WATER REUSE/WATER DEMAND/WATER SUPPLY/SEA WATER/ATMOSPHERE/GROUNDWATER/EVAPORATION

0098

LOFGREN, B.E.

1975

LAND SUBSIDENCE DUE TO GROUND-WATER WITHDRAWAL, ARVIN-MARICOPA AREA, CALIFORNIA.

U.S. GEOLOGICAL SURVEY, PROFESSIONAL PAPER 437-D. 55 P.

IN THE ARVIN-MARICOPA AREA IN THE SAN JOAQUIN VALLEY, CALIFORNIA, 700 SQUARE MILES, ROUGHLY 60 PERCENT OF THE AREA, HAD SUBSIDED AS OF 1970 DUE TO INTENSIVE GROUNDWATER PUMPING. MAXIMUM SUBSIDENCE EXCEEDS 9 FEET AND LOCALLY SUBSIDENCE RATES ARE AS MUCH AS 0.5 FEET/YR. BEGINNING IN THE MID 1960'S, THE IMPORTATION OF SURFACE WATER INTO THE AREA BEGAN TO MITIGATE SUBSIDENCE BY INCREASING RECHARGE TO THE AQUIFER AND DECREASING GROUNDWATER PUMPAGE. BY 1970 RATES OF DECLINING WATER LEVELS AND RATES OF SUBSIDENCE WERE DECREASING. BY 1972 MEASURED COMPACTION AT ONE SITE WAS LESS THAN ONE QUARTER THE RATE OF 3 YEARS EARLIER.

SUBSIDENCE/CALIFORNIA/GROUNDWATER/PUMPING/IRRIGATION/ARTESIAN WELLS/WITHDRAWAL/WATER TRANSFER/ARID LANDS

0099

LOFGREN, B.E./KLAUSING, R.L.

1969

LAND SUBSIDENCE DUE TO GROUND-WATER WITHDRAWAL, TULARE-WASCO AREA, CALIFORNIA.

U.S. GEOLOGICAL SURVEY, PROFESSIONAL PAPER 437-B. 101 P.

SEE: SWRA W70-01013.

SUBSIDENCE/CALIFORNIA/GROUNDWATER/IRRIGATION/ARTESIAN WELLS/PUMPING/WITHDRAWAL/COMPACTION/HYDROGEOLOGY

0100

MACK, L.E.

1969

ECONOMIC IMPLICATIONS OF A DYNAMIC LAND AND WATER BASE FOR AGRICULTURE IN CENTRAL ARIZONA.

UNIVERSITY OF ARIZONA (PH.D. DISSERTATION). 136 P.

IRRIGATED AGRICULTURE'S FUTURE IN CENTRAL ARIZONA IS DEPENDENT UPON THE AVAILABILITY OF TWO RELATIVELY FIXED AND LIMITED RESOURCES: LAND AND WATER. STUDY EXPLORES THE AGRICULTURAL USE OF THESE TWO FACTORS OF PRODUCTION AND ADJUSTMENTS THAT WILL FOLLOW FROM THEIR CHANGING AVAILABILITY AND COST OVER A 53-YEAR PERIOD FROM 1967-2020. MODELLING AND LINEAR PROGRAMMING WERE USED TO PROJECT FUTURE IMPACTS.

GROUNDWATER/WATER SUPPLY/AGRICULTURE/ECONOMIC IMPACT/ECONOMICS/LAND USE/LAND MANAGEMENT/CROP PRODUCTION/IRRIGATED AGRICULTURE/MODELS/ARIZONA

0101

MAHONEY, F.

1966

RANGE MANAGEMENT IN THE SOMALI REPUBLIC. IN A.H. NIEHOFF, ED., A CASEBOOK OF SOCIAL CHANGE, P. 155-163.

ALDINE PUBLISHING COMPANY, CHICAGO.

DISCUSSES THE PROBLEMS OF IMPOSING TECHNOLOGICAL SOLUTIONS TO DEVELOPMENT PROBLEMS WITHOUT CONSIDERATION OF CULTURAL FACTORS THAT MAY NEGATE THE SUCCESS OF THE NEW TECHNOLOGY. CASE HISTORY PRESENTED ON THE INTRODUCTION OF WATER TANKS AND WELLS IN SOMALI REPUBLIC TO IMPROVE RANGE MANAGEMENT. NOMAD'S RESPONSE TO ADDITIONAL WATER IS TO INCREASE HERD SIZE AND OVERGRAZE FORAGE. EDUCATION SEEN AS PART OF THE SOLUTION.

NOMADS/SOMALIA/WELLS/WATER RESOURCES DEVELOPMENT/RANGE MANAGEMENT/ARID LANDS/ ECONOMIC DEVELOPMENT/WATERSHED MANAGEMENT/WATER STORAGE

0102

MALMBERG, G.T.

1975

RECLAMATION BY TUBEWELL DRAINAGE IN RECHNA DOAB AND ADJACENT AREAS, PUNJAB REGION, PAKISTAN.

U.S. GEOLOGICAL SURVEY, WATER-SUPPLY PAPER 1608-O. 72 P.

SURFACE WATER IRRIGATION SINCE THE TURN OF THE CENTURY IN THE ARID RECHNA DOAB REGION OF THE PUNJAB PAKISTAN HAS GIVEN RISE TO THE PROBLEMS OF WATERLOGGING AND SALINITY WHICH, BY THE 1930'S, HAD REDUCED THE AGRICULTURAL PRODUCTIVITY OF THE AREA TO ONE OF THE LOWEST IN THE WORLD. IN 1960 CONSTRUCTION BEGAN ON A PROGRAM TO ALLEVIATE THESE PROBLEMS WHICH UTILIZED A NETWORK OF DEEP WELLS FOR THE DUAL PURPOSE OF LOWERING THE WATER TABLE AND FOR PROVIDING SUPPLEMENTAL IRRIGATION WATER. BY THE LATE 1960'S 66 PERCENT OF THE DAMAGED AREA (400,000 ACRES) HAD BEEN WHOLLY OR PARTIALLY RECLAIMED. PUMPING HAS DECREASED THE GROUNDWATER DISCHARGE FROM THE AREA BY 25000 AF/YEAR, INCREASED THE GROUNDWATER INFLOW BY 1700 AF/YEAR, AND DEPLETED STORAGE BY 1.7 MAF. PUMPING HAS ALSO CAUSED WIDESPREAD CHANGES IN CHEMICAL QUALITY OF THE WATER BY CHANGING THE RATE AND DIRECTION OF FLOW, INDUCING INFILTRATION FROM CANALS, AND MIXING OF INDIGENOUS WATER OF DIFFERENT CHEMICAL QUALITY.

GROUNDWATER/PAKISTAN/PUNJAB/WATER BALANCE/WATER QUALITY/IRRIGATION CANALS/ EVAPORATION/SALINITY/IRRIGATION WATER/WELLS/SALINE SOILS/SALINE WATER/DRAINAGE/ ARABLE LAND/HYDROLOGIC BUDGET/LAND RECLAMATION/WATER TABLE/INDUS BASIN/ TUBEWELLS

0103

MANDEL, S.

1977

THE OVER-EXPLOITATION OF GROUNDWATER RESOURCES IN DRY REGIONS. IN Y. MUNDLAK AND S.F. SINGER, EDS., ARID ZONE DEVELOPMENT: POTENTIALITIES AND PROBLEMS, PROCEEDINGS OF A SYMPOSIUM COSPONSORED BY THE AMERICAN ACADEMY OF ARTS AND SCIENCES AND THE HEBREW UNIVERSITY OF JERUSALEM, OCTOBER 1975, P. 31-51.

BALLINGER PUBLISHING COMPANY, CAMBRIDGE, MASSACHUSETTS. 293 P.

SEE: SWRA W76-09479.

GROUNDWATER MINING/OVERDRAFT/AQUIFERS/WATER MANAGEMENT(APPLIED)/WITHDRAWAL/ SURFACE-GROUNDWATER RELATIONSHIPS/AQUIFER MANAGEMENT/SAFE YIELD/DESALINATION/ SUBSIDENCE/SOCIAL ASPECTS/ECONOMIC IMPACT/ARID LANDS

0104

MANDEL, S./MERO, F.

1961

PLANNED EXPLOITATION OF THE AQUIFER FEEDING THE NA'AMAN SPRING. IN GROUNDWATER IN ARID ZONES, SYMPOSIUM OF ATHENS, 1961.

INTERNATIONAL ASSOCIATION OF SCIENTIFIC HYDROLOGY, PUBLICATION 57(2):645-650.

DURING THE PERIOD 1950/51 TO 1953/54 THE NA'AMAN SPRING IN NORTHERN ISRAEL YIELDED AN AVERAGE OF 43 MILLION CUBIC METERS/YEAR (MCM/YR) WITH A SALINITY OF 700 PPM CL ION (1600 PPM TOTAL DISSOLVED SOLIDS). THE AQUIFER FEEDING THIS SPRING EXTENDS OVER ABOUT 220 SQUARE KILOMETERS OF HILLY COUNTRY, COMPOSED MAINLY OF LIMESTONE AND DOLEMITE. AVERAGE RAINFALL IS 650 MM/YEAR. WELLS EXPLOIT THIS AQUIFER AT A RATE OF 25 MCM/YEAR. AS A CONSEQUENCE THE SPRING DRIED UP DURING THE SUMMER MONTHS 1959 AND 1960 AFTER A PERIOD OF EXTREMELY LOW RAINFALL AND FULL EXPLOITATION OF WELLS.

GROUNDWATER/WELLS/AQUIFERS/SPRINGS/SALINE WATER/SALINITY/WATER BALANCE/ CHLORIDE/PUMPING/WATER MANAGEMENT(APPLIED)/SAFE YIELD/ISRAEL

0105

MARTIN, W.A./ERICKSON, G.H.

1976

SUMMARY OF SELECTED COURT CASES IN WATER CONSERVATION AND GROUNDWATER LITIGATION.

U.S. WATER CONSERVATION LABORATORY, PHOENIX, ARIZONA, REPORT 10. 23 P.

SUMMARY OF COURT CASES DEALING WITH LEGAL ASPECTS OF WATER CONSERVATION AND GROUNDWATER PUMPING AND USE. CASES ARE ORGANIZED TO ANSWER NINE GENERAL QUESTIONS WHICH INCLUDE: IF A FARMER CLEARS PHREATOPHYTES FROM A FLOOD PLAIN, WHO HAS THE RIGHT TO THE WATER SAVED; CAN AQUIFERS BE USED AS TRANSMISSION FACILITIES; IF A STREAM AND AQUIFER ARE IN DIRECT HYDRAULIC CONNECTION, CAN A SURFACE-WATER APPROPRIATOR CHANGE HIS POINT OF DIVERSION TO A WELL; MUST THE OWNER OF A FREE-FLOWING WELL BE COMPENSATED WHEN IT CEASES TO FLOW FREELY; MUST THE OWNER OF A PUMPED WELL BE COMPENSATED WHEN THE CAPACITY IS REDUCED BECAUSE OF PUMPING FROM WELLS INSTALLED LATER?

GROUNDWATER/WATER LAW/WATER CONSERVATION/LEGAL ASPECTS/SURFACE-GROUNDWATER RELATIONSHIPS/PHREATOPHYTES/WATER REUSE/WATER RIGHTS/SURFACE WATERS/STREAMFLOW/ WELLS/ARTESIAN WELLS/IRRIGATION CANALS/SEWAGE EFFLUENT/WATERSHED MANAGEMENT/ GROUNDWATER RECHARGE

0106

MARTIN, W.E./ARCHER, T.

1971

COST OF PUMPING IRRIGATION WATER IN ARIZONA: 1891 TO 1967.

WATER RESOURCES RESEARCH 7(1):23-31. GA 71C-1527. SWRA W71-04851: SWRA W71-07501.

THE HISTORICAL RECORD OF THE COST OF PUMPING GROUNDWATER IN ARIZONA IS EXAMINED. MEASURES USED ARE THE COST PER ACRE-FOOT PER FOOT OF LIFT, THE COST PER ACRE-FOOT, THE WATER COST PER ACRE FOR IMPORTANT CROPS, AND THE TOTAL WATER COST PER FARM FOR REPRESENTATIVE GENERAL CROP FARMS. COSTS ARE PRESENTED IN ACTUAL DOLLARS AND DOLLARS ADJUSTED BY GNP IMPLICIT PRICE DEFLATORS. WHEREAS PUMPING DEPTHS HAVE BEEN RISING RAPIDLY, COSTS PER ACRE-FOOT PER FOOT OF LIFT HAVE BEEN FALLING, ADJUSTED COSTS PER ACRE-FOOT HAVE BEEN ALMOST CONSTANT, AND PER ACRE COSTS AND TOTAL FARM COSTS RELATIVE TO BOTH TOTAL COSTS AND TOTAL RETURNS HAVE FLUCTUATED THROUGHOUT THE TIME PERIOD EXAMINED, SOMETIMES BEING LOWER BUT OFTEN BEING HIGHER THAN COSTS AT THE PRESEENT TIME. (AUTHOR)

SONORAN DESERT/OALS/PUMPING/IRRIGATION WATER/ARIZONA/COSTS/GROUNDWATER MINING

0107

MARTIN, W.E./BURDAK, T.G./YOUNG, R.A.

1969

PROJECTING HYDROLOGIC AND ECONOMIC INTERRELATIONSHIPS IN GROUNDWATER BASIN MANAGEMENT. PAPER PRESENTED AT INTERNATIONAL CONFERENCE ON ARID LANDS IN A CHANGING WORLD, TUCSON, JUNE 1969.

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, COMMITTEE ON ARID LANDS, UNIVERSITY OF ARIZONA, TUCSON. PROCESSED. 15 P.

SEE: SWRA W69-07353.

GROUNDWATER/ECONOMIC IMPACT/ANALOG MODELS/ARID LANDS/HYDROLOGIC DATA/ IRRIGATION PRACTICES/INTER-BASIN TRANSFERS/DRAWDOWN/GROUNDWATER MINING/WELLS/ PUMPING/WATER DEMAND/WATER MANAGEMENT(APPLIED)

0108

MARTIN, W.E./YOUNG, R.A.

1969

THE NEED FOR ADDITIONAL WATER IN THE ARID SOUTHWEST: AN ECONOMIST'S DISSENT.

ANNALS OF REGIONAL SCIENCE 3(1):22-31.

THIS PAPER CHALLENGES THE NOTION THAT WATER IN THE ARID SOUTHWEST IS A LIMITING RESOURCE ON ECONOMIC GROWTH. ALTHOUGH ECONOMIC GROWTH IN THE WEST MAY ORIGINALLY HAVE BEEN BASED ON A LIBERAL WATER SUPPLY, ADDITIONAL WATER IS NO LONGER NECESSARY (AT LEAST IN THE FORESEEABLE FUTURE) AND MAY IN FACT BE 'DETREMENTAL TO OUR HEALTH'. DATA IS PRODUCED TO SUPPORT THIS THEORY. IRRIGATION DEVELOPMENT, ITS MATURATION AND ITS ULTIMATE DECLINE ARE NATURAL PHENOMENA IN AN ECONOMICALLY DEVELOPING REGION AND IRRIGATION DECLINE SHOULD NOT IN ITSELF BE A SUBJECT FOR GENERAL ALARM.

WATER RESOURCES DEVELOPMENT/ARIZONA/CENTRAL ARIZONA PROJECT/IRRIGATION/ AGRICULTURE/ECONOMIC IMPACT/ARID LANDS/SURFACE WATER IMPORTATION/WATER SHORTAGE

0109

MATLOCK, W.G.

1976

SEGMENTS OF A VICIOUS CIRCLE: LAND DEGRADATION AND WATER RESOURCES. IN P. PAYLORE AND R.A. HANEY, JR., EDS., DESERTIFICATION: PROCESS, PROBLEMS, PERSPECTIVES; PAPERS PRESENTED DURING A 14-WEEK SEMINAR SERIES NOVEMBER 1975-APRIL 1976, P. 45-50.

UNIVERSITY OF ARIZONA, TUCSON. 125 P.

DISCUSSES THE VICIOUS CIRCLE BETWEEN LAND DEGRADATION AND WATER RESOURCES: THE RELATIONSHIP BETWEEN THE DEVELOPMENT OF WATER RESOURCES AND THE CONSEQUENT LAND DEGRADATION, AND THE EFFECT OF LAND DEGRADATION ON WATER RESOURCES. THE EFFECT OF LAND DEGRADATION ON SURFACE WATER RESOURCES IS TO INCREASE THE SEDIMENT YIELD AND TO CHANGE THE FLOOD REGIME. WITH RESPECT TO GROUNDWATER, LAND DEGRADATION REDUCES DIRECT RECHARGE. WATER RESOURCES DEVELOPMENT ENHANCES LAND DEGRADATION BY CHANGING THE VEGETATION IN A MANNER THAT LEADS TO INCREASED EROSION. AUTHOR IS OPTIMISTIC THAT GOOD PLANNING AND ADEQUATE DATA WILL HELP MITIGATE THESE PROBLEMS.

WATER RESOURCES DEVELOPMENT/DESERTIFICATION/GROUNDWATER/SURFACE WATERS/ SEDIMENT YIELD/VEGETATION

0110

MATLOCK, W.G./FOGEL, M.M./BUSCH, C.D.

1966

UTILIZATION OF WATER RESOURCES IN A COASTAL GROUNDWATER BASIN.
II: GROUNDWATER SUPPLY AND INCIPIENT SALT WATER INTRUSTION.

JOURNAL OF SOIL AND WATER CONSERVATION 21(5):166-169.

ON THE COASTAL PLAIN OF HERMOSILLO, MEXICO GROUNDWATER IS THE SOLE SOURCE OF WATER AND PUMPING FOR IRRIGATION HAS DRASTICALLY LOWERED THE WATER LEVELS WHICH HAS CAUSED SALT WATER INTRUSION. PAPER IS THE RESULT OF RESEARCH DONE TO DETERMINE THE EXISTING GROUNDWATER SUPPLY AND THE QUANTITY OF WATER THAT CAN BE PUMPED WITHOUT EXCESSIVE SALTWATER INTRUSION. FRESHWATER RECHARGE TO THE BASIN WAS DETERMINED TO BE LESS THAN HALF THE WATER PUMPED. MORE THAN ONE THIRD OF THE WATER PUMPED IS INFLOW FROM THE SEA COAST. SALT WATER IS ENCROACHING ON THE FARMING AREA AT A RATE OF ABOUT 70 FEET/YEAR. IMPROVED IRRIGATION PRACTICES, A REDUCTION IN CULTIVATED ACREAGE, A CHANGE IN CROPPING PATERNS, THE IMPORTATION OF WATER FROM OTHER DRAINAGE BASINS AND A CAPTURE OF A GREATER PERCENTAGE OF PRECIPITATION ARE SUGGESTED AS METHODS TO DECREASE THE GROUNDWATER OVERDRAFT.

GROUNDWATER/MEXICO/IRRIGATION/IRRIGATION WELLS/OVERDRAFT/GROUNDWATER RECHARGE/ AQUIFERS/SALINE WATER INTRUSION/WATER LEVELS/SALINE WATER/TRANSMISSIVITY/ GROUNDWATER MOVEMENT/DARCY'S LAW/GROUNDWATER MINING/WATER LEVEL FLUCTUATIONS/ HYDROLOGIC BUDGET/SONORA/COASTAL PLAINS

0111

MAXEY, G.B.

1968

HYDROGEOLOGY OF DESERT BASINS.

GROUND WATER 6(5):10-22. ANAG (1968)04268. SWRA 2(3)-W69 C1013: 2(8) W69-02924; 2(9) W69-03238.

GROUNDWATER FLOW PATTERNS OF DESERT BASINS, WHICH USUALLY INVOLVE RECHARGE IN MOUNTAINS AND DISCHARGE IN LOWLANDS, ARE REVIEWED AND ILLUSTRATED BY SOME DETAILED STUDIES IN THE GREAT BASIN OF NEVADA. ALTHOUGH DELINEATION OF MOST FLOW SYSTEMS IN NEVADA HAS NOT BEEN ACCOMPLISHED, INTEGRATION OF HYDROLOGIC, GEOLOGIC, AND CHEMICAL METHODS ALLOW APPROXIMATE PORTRAYAL OF MANY SYSTEMS, BOTH LOCAL AND REGIONAL. ADEQUATE METHODS UPON WHICH TO BASE PLANNING FOR OPTIMUM DEVELOPMENT OF WATER RESOURCES IN DESERT BASINS ARE NOW AVAILABLE.

GREAT BASIN/HYDROGEOLOGY/NEVADA/BASINS/GROUNDWATER BASINS/DESERTS/WATER MANAGEMENT/WATER CHEMISTRY/DRAINAGE PATTERNS/GROUNDWATER MOVEMENT/FLOW/OALS

0112

MAXEY, G.B./DOMENICO, P.

1967

OPTIMUM DEVELOPMENT OF WATER RESOURCES IN DESERT BASINS. IN NATIONAL SYMPOSIUM ON GROUND-WATER HYDROLOGY, PROCEEDINGS, P. 84-90.

AMERICAN WATER RESOURCES ASSOCIATION, PROCEEDING SER. 4, URBANA, ILLINOIS.

GROUNDWATER HAS BEEN IGNORED BY PLANNERS BECAUSE LACK OF KNOWLEDGE OF PHYSICAL ASPECTS OF GROUNDWATER AND BECAUSE OF OVERSENSITIVITY TO CONCEPT OF 'SAFE YIELD'. GROUNDWATER CAN BE USED IN EXCESS OF SAFE YIELD TO DEVELOP AN ECONOMY CAPABLE OF UTILIZING HIGHER COST WATER FROM OTHER SOURCES. CONCEPTUAL MODEL OF HOW GROUNDWATER RESERVOIRS MAY BE MANAGED IS PRESENTED ALONG WITH AN OPTIMIZATION FORMULA WHICH CAN BE USED TO DETERMINE THE AMOUNT OF WITHDRAWAL FROM STORAGE THAT IS OPTIMAL: H'=(E/MC)-(R/Y)K WHERE H'=THE LEVEL IN THE BASIN AT WHICH IT IS MOST PROFITABLE TO CEASE MINING AND PUMP ONLY PERENNIAL RECHARGE, E=DOLLARS PER ACRE FOOT PROFIT WHEN PUMPING FROM H, MC=COST OF LIFTING ONE ACREFOOT OF WATER ONE FOOT, K=WATER LEVEL DECLINE PER ACRE FOOT OF INTEREST: THIS PROCEDURE WOULD RESULT IN THREE TYPES OF GROUNDWATER RIGHTS: 1) RIGHTS IN PERPETUITY BASED ON PERENNIAL YIELD; 2) 'TEMPORARY' OR STORAGE RIGHTS BASED ON THE VOLUME OF WATER FROM STORAGE THAT MAY BE DEVELOPED UNDER AN OPTIMAL SCHEME, 3) TRANSFER RIGHTS BASED UPON IMPORTED WATER. ASSESSMENT AND UNDERSTANDING OF PHYSICAL CHARACTERISTICS OF A GIVEN AREA IS REQUIRED TO ACCOMPLISH SUCH PLANNING.

GROUNDWATER/ARID LANDS/DESERTS/MODELS/HYDROGEOLOGY/LEGAL ASPECTS/GROUNDWATER RECHARGE/GROUNDWATER MINING/WATER MANAGEMENT(APPLIED)/WATER YIELD/ECONOMICS/ COSTS/PUMPING/WATER RIGHTS

0113

MCCAULEY, C.A.

1973

MANAGEMENT OF SUBSIDING LANDS: AN ECONOMIC EVALUATION.

UNIVERSITY OF ARIZONA (M.S. THESIS). 70 P.

ANNUAL DAMAGE DUE TO SUBSIDENCE FROM GROUNDWATER WITHDRAWAL IN WESTERN PINAL COUNTY, ARIZONA IS CALCULATED TO BE 184,200 DOLLARS. ANNUAL GROUNDWATER WITHDRAWAL IS 970,000 ACRE FEET. ANNUAL COST OF SUBSIDENCE/ACRE FOOT OF WATER IS 19 CENTS. WATER IMPORTATION AND CONTROLLED PUMPAGE ARE TWO ALTERNATIVES FOR MITIGATING SUBSIDENCE (ASSUMING A 25 PERCENT REDUCTION IN GROUNDWATER PUMPING WILL HALT SUBSIDENCE). THE BENEFIT-COST RATIO FOR WATER IMPORTATION IS 0.0325, AND 0.2 FOR CONTROLLED PUMPAGE. THEREFORE NO STEPS CAN BE RECOMMENDED TO HALT SUBSIDENCE BECAUSE OF EXCESSIVE COST OF CONTROLLED PUMPAGE AND WATER IMPORTATION.

SUBSIDENCE/GROUNDWATER/WITHDRAWAL/ECONOMIC IMPACT/WATER TRANSFER/ ARIZONA/PINAL COUNTY/CENTRAL ARIZONA PROJECT/ARID LANDS/IRRIGATION

0114

MCCAULEY, C.A./GUM, R.

1972

SUBSIDENCE DAMAGE IN SOUTHERN ARIZONA. IN HYDROLOGY AND WATER RESOURCES IN ARIZONA AND THE SOUTHWEST, 2:87-94.

AMERICAN WATER RESOURCES ASSOCIATION, ARIZONA SECTION/ARIZONA ACADEMY OF SCIENCE, HYDROLOGY SECTION, PROCEEDINGS OF THE 1972 MEETINGS, PRESCOTT, ARIZONA.

SEE SWRA W73-10825.

SUBSIDENCE/GROUNDWATER/WITHDRAWAL/WELLS/ECONOMIC IMPACT/ARIZONA/ PINAL COUNTY/ARID LANDS

0115

MECKELEIN, W.

1976

DESERTIFICATION CAUSED BY LAND RECLAMATION IN DESERTS: THE EXAMPLE OF THE NEW VALLEY, EGYPT. IN PROBLEMS IN THE DEVELOPMENT AND CONSERVATION OF DESERT AND SEMIDESERT LANDS, PRE-CONGRESS SYMPOSIUM K26, WORKING GROUP ON DESERTIFICATION IN AND AROUND ARID LANDS, ASHKHABAD, USSR, JULY 20-26, 1976, P. 151-154

INTERNATIONAL GEOGRAPHICAL CONGRESS, 23RD, MOSCOW, 1976, WITH THE SUPPORT OF UNESCO, THE INTERNATIONAL GEOGRAPHICAL UNION, AND THE UNIVERSITY OF NEW SOUTH WALES, AUSTRALIA. 216 P.

DEEP GROUNDWATER WELLS WERE DRILLED IN THE KHARGA AND DAKHLA OASES (THE NEW VALLEY) AS PART OF AN EXTENSIVE DESERT LAND RECLAMATION PROGRAM STARTED BY THE EGYPTIAN GOVERNMENT IN 1952. BY 1974 19000 HA OF LAND HAD BEEN BROUGHT UNDER CULTIVATION BUT MORE THAN ONE THIRD OF THE TOTAL CULTIVATED LAND SUFFERED FROM SALINIZATION AND/OR MOVING SANDS. SALINIZATION OF THE SOILS, THE RESULT OF THE APPLICATION OF WATER TO POORLY DRAINED SOILS IN AN ARID CLIMATE, HAS RESULTED IN LOSS OF AGRICULTURAL PRODUCTIVITY AND IN THE DESTRUCTION OF WALLS AND HOUSE FOUNDATIONS. SHIFTING SANDS HAVE DESTROYED FIELDS, HOUSES, ROADS, AND COMMUNICATION LINES. AUTHOR SUGGESTS BOTH PROBLEMS COULD BE SOLVED BY FIXING THE DUNES BY A VEGETATIVE COVER WATERED WITH WASTE DRAINAGE WATER.

WELLS/DESERTIFICATION/SAND DUNES/SALINE SOILS/LAND RECLAMATION/EGYPT/ DAKHLA OASIS/KHARGA OASIS

0116

MEYER, W.R.

1976

DIGITAL MODEL FOR SIMULATED EFFECTS OF GROUND-WATER PUMPING IN THE HUECO BOLSON, EL PASO AREA, TEXAS, NEW MEXICO, AND MEXICO.

U.S. GEOLOGICAL SURVEY, WATER-RESOURCES INVESTIGATIONS 58-75. 31 P.

THE HUECO BOLSON PROVIDES A SUBSTANTIAL PART OF THE MUNICIPAL AND INDUSTRIAL WATER SUPPLY OF THE EL PASO AREA OF TEXAS, NEW MEXICO, AND MEXICO. ALTHOUGH THE SUPPLY IS LARGE, ABOUT 10.6 MILLION ACRE-FEET (MAF) CU 1973, IN THE TEXAS PART OF THE BOLSON ALONE, THE SUPPLY IS BEING DEPLETED. THE MODEL STUDY SHOWED THAT A PROPOSED PLAN OF DEVELOPMENT FOR 1973-91, IN WHICH PUMPING COULD BE INCREASED BY 29 PERCENT IN THE TEXAS PART OF THE BOLSON AND BY 34 PERCENT IN CIUDAD JUAREZ, WOULD CAUSE ADDITIONAL WATER-LEVEL DECLINES BE AS MUCH AS 45 FEET IN THE VICINITY OF EL PASO AND 70 FEET IN CIUDAD JUAREZ. THE STUDY ALSO SHOWED THAT NEARLY 60 PERCENT OF THE WATER WOULD COME FROM STORAGE IN THE WATER-TABLE PART OF THE BOLSON AQUIFER, AND 28 PERCENT FROM LEAKAGE FROM THE ALLUVIUM. BY THE END OF THE PERIOD, 9.48 MAF OF FRESH WATER WOULD BE IN STORAGE IN THE TEXAS PART OF THE BOLSON, AS COMPARED TO 10.6 MAF IN STORAGE IN 1973. (AFTER AUTHOR)

GROUNDWATER/GROUNDWATER BASINS/TEXAS/NEW MEXICO/MEXICO/GROUNDWATER MINING/ WATER SUPPLY/MODELS/DIGITAL COMPUTERS/WATER LEVEL DECLINES

0117

MILNE, C.

1968

THE HYDROGEOLOGIC SETTING IN LOS ANGELES COUNTY, CALIFORNIA. IN LIMITED PROFESSIONAL SYMPOSIUM ON SALT-WATER ENCROACHMENT INTO AQUIFERS, PROCEEDINGS, P. 127-151.

LOUISIANA WATER RESOURCES RESEARCH INSTITUTE, BATON ROUGE.

OVER 80 PERCENT OF THE WATER LEVELS IN THE PRINCIPAL AQUIFERS UNDERLYING THE 470-SQUARE MILE COASTAL PLAIN AREA OF LOS ANGELES COUNTY, CALIFORNIA ARE BELOW SEA LEVEL. AS A RESULT, HAVE BEEN INTRUDED BY SEA WATER. THE VOLUME OF THIS INTRUSION IS ESTIMATED TO BE 700,000 ACRE FEET. COSTLY STEPS ARE UNDERWAY TO CORRECT THE PROBLEM. ARTIFICIAL REPLENISHMENT IS BEING ACCOMPLISHED BY THE SPREADING OF LOCAL STORM RUNOFF AND THE INJECTIOON OF BOTH IMPORTED COLORADO RIVER WATER AND WATER RECLAIMED FROM SEWAGE EFFLUENT. IN THE FUTURE, OTHER SOURCES POSSIBLY WILL BE UTILIZED FOR REPLENISHMENT. THE PLANNED MANAGEMENT OF THE GROUND-WATER BASINS WILL MAINTAIN BELOW SEA LEVEL THE WATER TABLES UNDERLYING MOST OF THE COASTAL PLAIN. HOWEVER, SEA-WATER INTRUSION BECAUSE OF THESE LOW LEVELS WILL BE PREVENTED BY THE INJECTION OF FRESH WATER, WHICH WILL ALSO PROVIDE A MAJOR PORTION OF THE GROUND-WATER REPLENISHMENT. (AUTHOR)

SALINE WATER INTRUSION/AQUICLUDES/WATER MANAGEMENT(APPLIED)/AQUIFERS/ HYDROGEOLOGY/FAULTS(GEOLOGY)/GROUNDWATER BARRIERS/NATURAL RECHARGE/PIT RECHARGE/INJECTION/DRAWDOWN/CALIFORNIA/COASTAL PLAINS

0118

MOHAMMAD, G.

1964

SOME STRATEGIC PROBLEMS IN AGRICULTURAL DEVELOPMENT IN PAKISTAN.

PAKISTAN DEVELOPMENT REVIEW 10(2):223-253.

CROP YIELDS IN PAKISTAN ARE AMONG THE LOWEST IN THE WORLD. FOOD INTAKE IS LESS THAN 2000 CALORIES PER CAPITA PER DAY. THE MAJOR PROBLEM IS TO INCREASE THE YIELDS OF MAIN FOOD AND CASH CROPS. THE MAIN PROPOSALS UNDER DISCUSSION SO FAR HAVE INVOLVED 2 ELEMENTS: 1) THE PROVISION OF INCREASED WATER SUPPLIES THROUGH LARGE-SCALE GOVERNMENT PROJECTS; AND 2) THE INCREASED PROVISION OF ALL INPUTS TO THE AGRICULTURE SECTION. PAPER ARGUES THAT THE IMMEDIATE NEED IS TO MAKE AVAILABLE TO FARMERS LARGE QUANTITIES OF THOSE LOW-PRICED INPUTS THAT CAN BRING ABOUT LARGE INCREASES IN CROP PRODUCTION IN RELATION TO COST INCURRED. INPUTS MOST EFFECTIVE IN BRINGING THIS ABOUT WOULD BE INCREASED AVAILABILITY OF FERTILIZERS AND INCREASED AVAILABILITY OF WATER. BOTH CAN BE ACCOMPLISHED WITHOUT RADICAL STRUCTURAL REORGANIZATION OF THE GOVERNMENT, THROUGH GREATER USE OF THE PRIVATE SECTOR AND OF THE INCENTIVES FOR GAIN OF THE FARMERS. DATA IS PRESENTED TO SHOW THE RELATIVE ECONOMIC EFFICIENCY OF PRIVATE OVER PUBLIC TUBEWELL DEVELOPMENT. PROBLEMS CRITICAL TO THE EXECUTION OF SUCH A PROGRAM ARE DISCUSSED.

WELLS/GROUNDWATER/IRRIGATION/COSTS/WATER RESOURCES DEVELOPMENT/PUMPING/ AGRICULTURE/PAKISTAN/FERTILIZERS/CANALS/WATER TABLE/SALINE WATER/CROP PRODUCTION/ECONOMIC DEVELOPMENT/PUNJAB/BANGLADESH/TUBEWELLS/CREDIT/ ELECTRICITY

0119

MOHAMMAD, G.

1965 A

PRIVATE TUBEWELL DEVELOPMENT AND CROPPING PATTERNS IN WEST PAKISTAN.

PAKISTAN DEVELOPMENT REVIEW 5(1):1-53.

A SIGNIFICANT PHENOMENA IN AGRICULTURAL DEVELOPMENT IN PAKISTAN IS THE INSTALLATION OF PRIVATE TUBEWELLS BY FARMERS AT EXCEEDINGLY FAST RATES, ENABLING THE FARMER TO INTENSIFY IRRIGATION AND MAKE IMPORTANT CHANGES IN CROPPING PATTERNS TO MAXIMIZE INCOME. THIS ARTICLE PRESENTS RESULTS OF 2 SURVEYS AND CROPPING PATTERNS FOLLOWED WHERE TUBEWELLS ARE INSTALLED. EVIDENCE PRESENTED LEADS TO 5 INFERENCES: 1) PROVISION OF ELECTRICITY TO RURAL AREAS HAS BEEN ONE OF THE MAIN CAUSES OF RAPID INCREASE IN TUBEWELL INSTALLATION; 2) PRIVATE TUBEWELL DRILLERS HAVE RAPIDLY MOVED WHEREVER DEMAND WAS CREATED CONSEQUENT UPON THE PROVISION OF ELECTRICITY, 3) ADDITIONAL WATER PUMPED FROM TUBEWELLS IN NON-SALINE AREAS ALLOWS FARMERS TO GET HIGH RETURNS, 4) AREAS UNDER SUMMER CROPS HAVE INCREASED MUCH MORE RAPIDLY THAN AREAS UNDER WINTER CROPS WHEN ADEQUATE WATER SUPPLY IS AVAILABLE THROUGH TUBEWELL DEVELOPMENT, 5) HIGH RETURNS FROM INVESTMENT IN TUBEWELLS IS ACTING AS A CATALYST IN MODERNIZING AGRICULTURE.

GROUNDWATER/INDUS BASIN/PAKISTAN/IRRIGATION WELLS/IRRIGATION PRACTICES/ IRRIGATION EFFECTS/CROP PRODUCTION/LAND USE/FERTILIZERS/CROPS/COSTS/PUMPING/ AGRICULTURE/DRAINS/WATER REQUIREMENTS/PUNJAB/TUBEWELLS/CROPPING PATTERNS/ BULLOCKS/SUGAR CANE/RICE/MAIZE/WHEAT/COTTON

0120

MOHAMMAD, G.

1965 B

WATERLOGGING AND SALINITY IN THE INDUS PLAIN: REJOINDER.

PAKISTAN DEVELOPMENT REVIEW 5(3):393-407.

CRITIQUE OF RECOMMENDATIONS MADE IN THE REVELLE REPORT. THE AUTHOR FEELS THE MOST DAMAGING RECOMMENDATION WAS THE PROPOSAL TO PUMP WATER IN THE SALINE GROUNDWATER AREAS TO MIX WITH CANAL WATER AND TO USE THE MIXED WATER WITH AN AVERAGE SALINITY OF 2000 PPM FOR IRRIGATION: DETERIORATION OF THE LAND DUE TO SODIUM DAMAGE WOULD RESULT AND LARGE, UNECONOMIC QUANTITIES OF GYPSUM WOULD BE NECESSARY TO KEEP THE SOILS IN GOOD CONDITION. ANOTHER POINT OF DISAGREEMENT IS ON WHETHER THERE SHOULD BE HORIZONTAL OR VERTICAL DRAINAGE. AUTHOR FEELS A HORIZONTAL DRAINAGE SYSTEM TO INTERCEPT THE INFILTRATED IRRIGATION WATER BELOW THE ROOT ZONE BEFORE IT REACHES THE WATER TABLE IS MORE EFFICIENT THAN PUMPING TUBEWELLS FROM GREATER DEPTHS FOR DRAINAGE. PRIVATE TUBEWELLS ARE MORE DESIRABLE BECAUSE: 1) THEY UTILIZE DOMESTIC RESOURCES;CH 2) THEY REQUIRE MUCH LESS FOREIGN EXCHANGE; 3) THEY CONTRIBUTE TO THE DEVELOPMENT OF LOCAL INDUSTRIES; AND 4) THEY DEVELOP A STRONG CLASS OF ENERGETIC FARMERS WHO ACT AS LEADERS IN MODERNIZING AGRICULTURE. IN GENERAL THE AUTHOR THINKS THE PLAN ADVOCATED BY THE REVELLE REPORT IS TEMPORARILY EXPEDIENT AND SELF-DESTRUCTIVE.

PAKISTAN/INDUS BASIN/GROUNDWATER/IRRIGATION/LEACHING/WELLS/IRRIGATION WELLS/ IRRIGATION PRACTICES/AGRICULTURE/DRAINAGE/SALINE WATER INTRUSION/SALINE WATER/ LAND USE/LAND RECLAMATION/SURFACE WATERS/CANALS/GYPSUM/SODIUM/TUBEWELLS/REVELLE REPORT/LINKAGES

0121

MOHAMMAD, G./BERINGER, C.

1963

WATERLOGGING AND SALINITY IN WEST PAKISTAN: AN ANALYSIS OF THE REVELLE REPORT.

PAKISTAN DEVELOPMENT REVIEW 3(2):250-275.

AN ANALYSIS OF THE REVELLE REPORT WHICH INCLUDES THE BACKGROUND OF THE REPORT, AN HISTORICAL PERSPECTIVE OF THE FIGHT AGAINST WATERLOGGING AND SALINITY, THE PRINCIPAL PROPOSALS OF THE REPORT, AND ITS RELEVANCE TO PAKISTAN'S ECONOMIC DEVELOPMENT EFFORT. ALTERNATIVES TO THE PLAN ARE DISCUSSED AND A CRITIQUE OF THE REVELLE REPORT'S TECHNICAL ASSUMPTIONS IS MADE. GENERAL CONCLUSION IS THAT SOME OF THE KEY ASSUMPTIONS ABOUT GROUNDWATER AVAILABILITY AND QUALITY ARE TOO LIBERAL. AUTHORS BELIEVE MAIN HURDLE TO IMPLEMENTATION OF THE REVELLE PLAN IS THE PROBLEM OF ADMINISTRATION, EDUCATION AND EXTENSION.

WATERLOGGING/SALINITY/PAKISTAN/INDUS BASIN/FERTILIZERS/IRRIGATION/HISTORY/PUMPING/GROUNDWATER/AQUIFERS/WATER TABLE/COSTS/COST-BENEFIT ANALYSIS/ECONOMIC DEVELOPMENT/ECONOMIC IMPACT/LAND USE/CROP PRODUCTION/IRRIGATION PRACTICES/CANALS/DRAINAGE/PUNJAB/REVELLE REPORT/ADMINISTRATION/EDUCATION/TUBEWELLS/CROP YIELDS

0122

MOORE, C.V./SNYDER, J.H.

1967

ECONOMIC PROBLEMS OF SEA WATER INTRUSION: A CASE STUDY OF THE SALINAS VALLEY, CALIFORNIA. IN WATER RESOURCES AND ECONOMIC DEVELOPMENT OF THE WEST, CONFERENCE PROCEEDINGS, P. 39-53.

WESTERN AGRICULTURAL ECONOMICS RESEARCH COUNCIL, SAN FRANCISCO, CALIFORNIA, COMMITTEE ON THE ECONOMICS OF WATER RESOURCES DEVELOPMENT, REPORT 16.

BETWEEN 1930 AND 1940 SEAWATER INTRUSION INTO THE EXTENSIVELY EXPLOITED 180 FOOT AQUIFER HAD BEGUN IN THE SALINAS VALLEY OF CALIFORNIA. THIS WAS THE RESULT OF 2 CONDITIONS: 1) A HYDRAULIC CONTINUITY BETWEEN THE AQUIFER AND THE OCEAN, 2) THE DROP OF THE WATER LEVEL TO BELOW SEA LEVEL. BY THE 1960'S THE 180 FOOT AQUIFER CONTAMINATED AREA UNDERLAY 8000 ACRES OF VEGETABLE-PRODUCING LAND, AND THE 400 FOOT AQUIFER CONTAMINATED AREA UNDERLAY 500 ACRES. BECAUSE SALTWATER IS HEAVIER THAN FRESH WATER, IT INTRUDES AS A WEDGE WITH LITTLE MIXING AND DIFFUSION OF THE 2 WATER BODIES. CONSEQUENTLY CROPPING ADJUSTMENTS ARE NOT PRACTICABLE. FARMERS NEAREST THE COAST BEAR THE FINANCIAL BURDEN OF THIS PROBLEM, ALTHOUGH ALL USERS OF THE AQUIFER ARE TO BLAME. METHODS OF HALTING THE INTRUSION ARE DISCUSSED.

SALINE WATER INTRUSION/GROUNDWATER/ECONOMIC IMPACT/CALIFORNIA/ARID LANDS/GROUNDWATER RECHARGE/RECHARGE WELLS/INTER-BASIN TRANSFERS

0123

MOORE, C.V./SYNDER, J.H.

1969

SOME LEGAL AND ECONOMIC IMPLICATIONS OF SEA WATER INTRUSION: A CASE STUDY OF GROUND WATER MANAGEMENT.

NATURAL RESOURCES JOURNAL 9(3):401-419.

PAPER DESCRIBES SOME OF THE PHYSICAL CHARACTERISTICS OF SEAWATER INTRUSION INTO A GROUNDWATER BASIN AND DEFINES AND EVALUATES LEGAL AND ECONOMIC PROBLEMS THAT CAN ARISE, USING THE SALINAS VALLEY IN CALIFORNIA AS AN EXAMPLE. SIX ALTERNATIVES TO STOP SEAWATER INTRUSION ARE PROPOSED AND ANALYZED WITHIN BOTH THE FRAMEWORK OF WELFARE ECONOMICS AND THE LEGAL SETTING OF PROPERTY RIGHTS. PAPER CONCLUDES THAT OPTIMAL POLICY IS ONE WHERE THE PUMPERS IN THE CONTAMINATED AREA WOULD CONTRIBUTE TO COST OF A FRESH WATER CANAL; THIS SOLUTION WOULD MAXIMIZE THE AGGREGATE PROFIT LEVEL OF THE ENTIRE GROUNDWATER AREA.

SALINE WATER INTRUSION/GROUNDWATER/ECONOMIC IMPACT/RECHARGE WELLS/CALIFORNIA/ARID LANDS/GROUNDWATER RECHARGE/INTER-BASIN TRANSFERS/WATER QUALITY/LEGAL ASPECTS/SALINAS VALLEY

0124

MOORE, J.E./WOOD, L.A.

1969

INTERPRETATION OF HYDROGEOLOGIC DATA FOR GROUNDWATER MANAGEMENT.

ANNALS OF ARID ZONE 8(2):225-230. SWRA W71-00150.

THE ARKANSAS VALLEY OF SOUTHEASTERN COLORADO OVERLAYS A VALLEY FILL AQUIFER CONSISTING OF SAND, GRAVEL, CLAY AND SILT, AVERAGING 3 MILES IN WIDTH. THE ARKANSAS RIVER IS HYDRAULICALLY CONNECTED WITH THE AQUIFER SO THAT THE SURFACE WATER AND GROUNDWATER OF THE AREA CONSTITUTE A COMMON WATER SUPPLY. DURING THE DRY MONTHS RIVER FLOW IS OFTEN INADEQUATE FOR IRRIGATION NEEDS AND ABOUT 234,000 ACRE-FEET OF GROUNDWATER ARE THEREFORE PUMPED FROM WELLS. THE PHYSICAL LIMITS AND CHARACTER OF THE AQUIFER WERE DESCRIBED AND MAPPED AND QUANTITATIVE DATA WERE OBTAINED ON GROUNDWATER LEVELS, PRECIPITATION, EVAPOTRANSPIRATION, AND RIVER GAINS AND LOSSES. RIVER LOSSES WERE GREATEST IN THOSE AREAS OF GREATEST PUMPING, INDICATING THAT AREAL GROUNDWATER MOVEMENTS WERE GREATLY AFFECTED BY GROUNDWATER WITHDRAWAL. WITH THE DATA FROM FIELD STUDIES AN EXTENSIVE ANALOG MODEL OF THE ARKANSAS VALLEY HYDROLOGIC SYSTEM WAS BUILT IN AN EFFORT TO PREDICT VARIOUS WITHDRAWAL EFFECTS ON THE REGIONAL WATER ECONOMY. INITIAL RESULTS OF TWO CHANNEL GAIN AND CHANNEL LOSS ANALOG ANALYSES COMPARED CLOSELY WITH FIELD MEASUREMENTS AND FURTHER WATER ANALYSIS PROJECTS ARE DISCUSSED. (OALS)

SURFACE WATERS/GROUNDWATER/COLORADO/SUBSURFACE WATERS/AQUIFERS/WELLS/ IRRIGATION WELLS/SURFACE-GROUNDWATER RELATIONSHIPS/STREAMFLOW/NATURAL RECHARGE/ANALOG MODELS/HYDROLOGY/PRECIPITATION(ATMOSPHERIC)/PUMPING/ DRAWDOWN/GROUNDWATER MINING/OALS

0125

MOORTI, T.V.

1971

A COMPARATIVE STUDY OF WELL IRRIGATION IN ALIGARH DISTRICT, INDIA.

CORNELL UNIVERSITY, ITHACA, NEW YORK, INTERNATIONAL AGRICULTURAL DEVELOPMENT BULLETIN 19. 64 P.

THE INTRODUCTION OF NEW TECHNOLOGY TO INDIAN AGRICULTURE HAS RESULTED IN THE INCREASED USE OF FERTILIZER AND WATER. TUBEWELLS CAN MEET THIS INCREASED WATER DEMAND. THIS STUDY ATTEMPTS 1) TO ESTIMATE RETURNS TO WATER USE AT DIFFERENT LEVELS OF APPLICATION AND UNDER VARYING FARM OPERATING CONDITIONS; 2) TO ANALYZE THE DIFFERENCES IN CROPPING PATTERNS, YIELDS, AND LEVELS OF TECHNOLOGY ACCOMPANYING DIFFERENT SYSTEMS OF WELL IRRIGATION, AND 3) TO COMPARE COSTS AND NET RETURNS TO DIFFERENT SYSTEMS OF WELL IRRIGATION. FOUR DIFFERENT IRRIGATION SOURCES ARE STUDIED: STATE TUBEWELLS, PRIVATE TUBEWELLS, THE PERSIAN WHEEL, AND THE CHARSA. PRIVATE TUBEWELL FARMS HAVE MORE INTENSIVE CROPPING PATTERNS, GROW A GREATER PROPORTION OF HIGH YIELDING VARIETIES, OPERATE AT MUCH HIGHER LEVELS OF INPUT USE AND ARE THE MOST PROFITABLE OF THE FOUR IRRIGATION SOURCES. SUGGESTIONS FOR IMPROVING STATE TUBEWELLS PERFORMANCE ARE OFFERED.

GROUNDWATER/INDIA/IRRIGATION/WELLS/ECONOMIC IMPACT/IRRIGATION PRACTICES/ FERTILIZERS/CROP PRODUCTION/IRRIGATION EFFECTS/IRRIGATION WATER/WATER COSTS/ DEVELOPING COUNTRIES/TUBEWELLS

0126

MOSES, R.J.

1966

THE LAW OF GROUND WATER: DOES MODERN BURIED TREASURE CREATE A NEW BREED OF PIRATES.

ROCKY MOUNTAIN MINERAL LAW INSTITUTE, 11TH, 1966, PAPERS, P. 277-309.

THIS PAPER EXAMINES THE EXISTING LAW OF GROUNDWATER IN THE WESTERN STATES. TRENDS TOWARD GREATER CONTROLS AND MORE EFFICIENT USE ARE OBSERVED. THESE TRENDS ARE DICTATED BY ECONOMIC PRESSURES AND THE GROWING SCARCITY OF ALL WATER, BOTH SURFACE AND GROUNDWATER. SINCE THERE IS NO INTERSTATE REGULATION BY COMPACT OR OTHERWISE, MODERN-DAY PIRATES, IN WELL-DRILLER'S DUNGAREES, RACE TO DRAW THE WATER FROM THE RESERVOIR ACROSS THE STATE LINE BEFORE SOME CONTROL IS IMPOSED. THE AUTHOR CONCLUDES IF STATES DO NOTHING THEMSELVES, FEDERAL CONTROLS SEEM IMMINENT. IT IS FOR THOSE INTERESTED IN THE LAW TO TAKE THE LEAD IN NEGOTIATION OF UNDERSTANDINGS BETWEEN THE STATES WHICH WILL AVOID BOTH FEDERAL DOMINATION AND COSTLY INTERSTATE LITIGATION.

WATER LAW/GROUNDWATER/GROUNDWATER BASINS/PUMPING/OVERDRAFT/FEDERAL JURISDICTION/STATE JURISDICTION/LEGAL ASPECTS/INTERSTATE/WATER SHORTAGE/ SURFACE WATERS/DRILLING

0127

MUNDORFF, M.J. ET AL

1976

HYDROLOGIC EVALUATION OF SALINITY CONTROL AND RECLAMATION PROJECTS IN THE INDUS PLAIN, PAKISTAN: A SUMMARY.

U.S. GEOLOGICAL SURVEY, WATER-SUPPLY PAPER 1608-Q. 59 P.

THE SALINITY CONTROL AND LAND RECLAMATION PROJECTS BY PUMPING FROM TUBEWELLS, HAS BEEN NOTABLY SUCCESSFUL IN LOWERING THE WATER TABLE, IN PROVIDING SUPPLEMENTAL WATER FOR IRRIGATION AND FOR LEACHING OF SALINIZED SOILS, AND IN IMPROVING CROP PRODUCTION IN THE INDUS PLAIN REGION OF PAKISTAN. PROBLEMS ASSOCIATED WITH RECLAMATION INCLUDE CONTROL OF DETERIORATION IN PERFORMANCE OF TUBEWELLS AND THEIR REHABILITATION, LOCAL BRACKISH OR SALINE-WATER ENCROACHMENT, AND MAINTENANCE OF A FAVORABLE SALT BALANCE IN THE GROUNDWATER SYSTEM. RAPID AND UNREGULATED GROWTH OF SHALLOW PRIVATE TUBEWELL DEVELOPMENT RECENTLY HAS INTRODUCED COMPLICATING FACTORS TO THE RECLAMATION PLANNING OF THE EARLY 1960'S WHICH EMPHASIZED PUBLIC TUBEWELL DEVELOPMENT. CONTINUED MONITORING OF THE HYDROLOGIC SYSTEM AND RESEARCH ON PROBLEMS ENGENDERED BY RECLAMATION ARE ESSENTIAL TO THE VIABILITY OF THE PROGRAM AND RELATED WATER-RESOURCES DEVELOPMENT.

GROUNDWATER/PAKISTAN/INDUS BASIN/LAND RECLAMATION/DRAINAGE/SALINITY/WATER QUALITY/WATER BALANCE/IRRIGATION CANALS/SALINE SOILS/SALINE WATER/BRACKISH WATER/SALINITY/WELLS/IRRIGATION EFFECTS/ARABLE LAND/WATER TABLE/TUBEWELLS

0128

NACE, R.L.

1969

HUMAN USE OF GROUNDWATER. IN R. CHORLEY, ED., WATER, EARTH AND MAN, P. 285-294.

METHUEN AND CO., LTD., LONDON.

SEE: SWRA W70-03095.

GROUNDWATER/WATER SOURCES/WATER UTILIZATION/WATER RESOURCES DEVELOPMENT/HISTORY/SALINE WATER INTRUSION/WATER POLLUTION

0129

NULTY, I.

1972

THE GREEN REVOLUTION IN WEST PAKISTAN: IMPLICATIONS OF TECHNOLOGICAL CHANGE.

PRAEGER, NEW YORK. 150 P.

STUDY ANALYZES THE GROWTH AND DEVELOPMENT OF WEST PAKISTAN'S AGRICULTURAL SECTOR FROM 1948 TO 1970 AND DISCUSSES THE ROLE OF THIS SECTOR IN ECONOMIC DEVELOPMENT. AUTHOR ARGUES FROM EMPIRICAL DATA THAT THE AGRICULTURAL SECTOR IN WEST PAKISTAN CONTRIBUTED MORE TO ECONOMIC DEVELOPMENT THAN THE EXISTING BODY OF ECONOMIC THEORY WOULD PREDICT. AN ECONOMIC STANDARD BY WHICH TO JUDGE THE PERFORMANCE OF THIS SECTOR IS DEVELOPED AND THEN USED TO EVALUATE THE PERFORMANCE OF THE AGRICULTURAL SECTOR IN WEST PAKISTAN. THE SUCCESS OF THE AGRICULTURAL SECTOR IS THE RESULT OF THE INTRODUCTION OF TUBEWELL TECHNOLOGY WHICH MADE GROUNDWATER AVAILABLE TO THE FARMERS. THUS ADDITIONAL, CERTAIN SUPPLY OF WATER ACTED AS A CATALYST ENABLING THE FARMERS TO TAKE UP OTHER INGREDIENTS OF THE GREEN REVOLUTION. THOUGH THE AGRICULTURAL SECTOR FULFILLED MOST OF ITS FUNCTIONS WITH RESPECT TO ECONOMIC DEVELOPMENT, THE AUTHOR CONCLUDES THAT ITS POTENTIAL WILL BE FRUSTRATED BY THE PREVAILING DISTRIBUTION OF ECONOMIC AND POLITICAL POWER WHICH PERMITS A FEW TO REAP THE LARGER SHARE.

PAKISTAN/ECONOMIC DEVELOPMENT/GROUNDWATER/IRRIGATION WELLS/LAND USE/FERTILIZERS/CROP PRODUCTION/IRRIGATION PRACTICES/IRRIGATION EFFECTS/ECONOMIC IMPACT/POLITICAL ASPECTS/INSTITUTIONAL ASPECTS/AGRICULTURE/WATER SUPPLY/GREEN REVOLUTION/TUBEWELLS

0130

ORTIZ, T.S.

1967

SUBSIDENCE IN MEXICO CITY IN RELATION TO GROUNDWATER OVERDRAFT. IN HYDROLOGY OF FRACTURED ROCKS, PROCEEDINGS OF THE DUBROVNIK SYMPOSIUM, OCTOBER 1965, VOL. 2.

INTERNATIONAL ASSOCIATION OF SCIENTIFIC HYDROLOGY, PUBLICATION 74:665-671.

SEE: SWRA W69-09297.

MEXICO/SUBSIDENCE/GROUNDWATER/WITHDRAWAL/ARTESIAN WELLS/PUMPING/ AQUIFERS

0131

OSBORN, J.E./HOLLOWAY, M./WALKER, N.

1972

IMPORTANCE OF IRRIGATED CROP PRODUCTION TO A SEVENTEEN-COUNTY AREA IN THE TEXAS HIGH PLAINS.

TEXAS TECH UNIVERSITY, LUBBOCK, WATER RESOURCES CENTER. 38 P.

OBJECTIVE OF STUDY WAS TO DETERMINE THE IMPORTANCE OF INCOME FROM MAJOR IRRIGATED CROPS TO A 17-COUNTY AREA IN THE TEXAS HIGH PLAINS. SOURCE OF IRRIGATION WATER IS GROUNDWATER WHICH IS BEING DEPLETED. IRRIGATED LAND ACCOUNTED FOR 93 PERCENT OF TOTAL REVENUE FROM CROP PRODUCTION IN THIS AREA. EFFECTS OF A DECLINING GROUNDWATER SUPPLY WERE ESTIMATED. TOTAL REVENUE IS ESTIMATED TO DECLINE FROM 431 MILLION DOLLARS IN 1964 TO 158 MILLION DOLLARS IN 2015. DRYLAND CROP PRODUCTION WILL INCREASE AS IRRIGATED CROP PRODUCTION DECREASES. CROPS AND CROPPING PATTERNS WILL CHANGE. LAND WILL BE REASSESSED AND SCHOOL, COUNTY AND STATE LAND TAXES ARE ESTIMATED TO DECLINE FROM 6 MILLION DOLLARS IN 1964 TO 2.5 MILLION DOLLARS IN 2015.

GROUNDWATER/TEXAS/OGALLALA AQUIFER/IRRIGATION/ECONOMIC IMPACT/CROP PRODUCTION/ DRY FARMING/IRRIGATED AGRICULTURE/IRRIGATION PRACTICES

0132

OSTERHOUDT, F.H.

1972

IMPACT OF THE DECLINING WATER SUPPLY ON THE ECONOMY OF CURRY AND ROOSEVELT COUNTIES.

NEW MEXICO AGRICULTURAL EXPERIMENT STATION, RESEARCH REPORT 222. 80 P.

SEE: SWRA W72-13078.

IRRIGATION/GROUNDWATER/GROUNDWATER RECHARGE/WATER TABLE/ECONOMIC IMPACT/ FORECASTING/NEW MEXICO

0133

OTTAWAY, D.B.

1973

AFRICANS SEEK MORE LASTING AID.

WASHINGTON POST, SEPTEMBER 11, P. A16.

MANY AFRICAN LEADERS THINK WELL DRILLING IS THE ANSWER TO DROUGHT AND DESERTIFICATION OF THE SAHEL. MUCH MONEY HAS ALREADY BEEN SPENT ON WELL DRILLING BY INTERNATIONAL AID AGENCIES. THE COMMON MARKET FUND HAS SPENT 45 MILLION DOLLARS ON DRILLING WELLS IN WEST AFRICA. THE AGENCY FOR INTERNATIONAL DEVELOPMENT PUT IN 1400 WELLS DURING THE 1960'S MANY OF WHICH WENT DRY OR FELL INTO DISREPAIR. THEY ALSO SERVED TO EXPAND THE DESERT BY ATTRACTING NOMADS AND THEIR ANIMALS, WHICH LED TO OVERGRAZING.

SAHELIAN ZONE/WELLS/GROUNDWATER/NIGER/NOMADS/DROUGHTS/DESERTIFICATION/ OVERGRAZING

0134

PASHLEY, E.F., JR.

1961

SUBSIDENCE CRACKS IN ALLUVIUM NEAR CASA GRANDE, ARIZONA.

ARIZONA GEOLOGICAL SOCIETY DIGEST 4:95-101.

AUTHOR REVIEWS LITERATURE ON EARTH CRACKS, DISCUSSES HIS OBSERVATIONS ON CRACKS NEAR CASA GRANDE, AND CONCLUDES THAT THEY FORMED DUE TO NEAR-SURFACE SUBSIDENCE ABOVE THE WATER TABLE AFTER THE INITIAL APPLICATION OF LARGE AMOUNTS OF WATER.

SUBSIDENCE/ARIZONA/PINAL COUNTY/IRRIGATION/ARID LANDS

0135

PETERSON, D.F.

1968

GROUND WATER IN ECONOMIC DEVELOPMENT.

GROUND WATER 6(3):33-41.

GROUNDWATER DEVELOPMENT PROVIDES A MEANS WHEREBY NEW ECONOMIC OPPORTUNITIES ARE MADE AVAILABLE. CASE HISTORIES ARE PRESENTED ON GROUNDWATER DEVELOPMENT IN ISRAEL AND PAKISTAN. GROUNDWATER DEVELOPMENT IN ISRAEL HAS PERMITTED THE MOST EFFECTIVE UTILIZATION OF ALL THE WATER RESOURCES. IN PAKISTAN GROUNDWATER DEVELOPMENT HAS MITIGATED THE DRAINAGE AND SALINITY PROBLEMS WHILE STIMULATING AGRICULTURAL PRODUCTION AND THE REGIONAL ECONOMY. IN BOTH AREAS, GROUNDWATER IS BEING OVERDRAWN. AUTHOR FEELS THE DEVELOPMENT OF GROUNDWATER WILL BUILD AN ECONOMIC BASE THAT CAN AFFORD MORE COSTLY TECHNOLOGICAL SOLUTIONS TO THE PROBLEMS OF CONTINUED OVERDRAFT WHEN THE TIME COMES.

GROUNDWATER/ECONOMIC IMPACT/ECONOMIC DEVELOPMENT/ISRAEL/PAKISTAN/AGRICULTURE/IRRIGATION/ARID LANDS/WATER RESOURCES DEVELOPMENT/WATER QUALITY/WELLS/DRAINAGE WELLS/SALINE WATER INTRUSION/GROUNDWATER MINING/WATER MANAGEMENT(APPLIED)/WATER POLICY/WASTE WATER DISPOSAL/CROP PRODUCTION/IRRIGATION PRACTICES

0136

PETERSON, D.F.

1970

WATER IN THE DESERTS. IN H.E. DREGNE, ED., ARID LANDS IN TRANSITION, P. 15-30.

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, WASHINGTON, D.C., PUBLICATION 90.

SEE: SWRA W70-08689; W71-08134.

ARID LANDS/WATER RESOURCES DEVELOPMENT/SOCIAL ASPECTS/WATER USERS/GROUNDWATER/RIVER BASINS/ECOLOGY/DESERTS/ENVIRONMENTAL EFFECTS/GROUNDWATER RECHARGE/ECOSYSTEMS/GRAZING/IRRIGATION/SALINITY/HYDROELECTRIC POWER/NAVIGATION/FLOODS/TECHNOLOGY

0137

PICARD, L.

1953

THE HISTORY OF GROUNDWATER EXPLORATION IN ISRAEL. IN DESERT RESEARCH, PROCEEDINGS, INTERNATIONAL SYMPOSIUM HELD IN JERUSALEM, MAY 7-14, 1952.

RESEARCH COUNCIL OF ISRAEL, SPECIAL PUBLICATION 2:583-591.

WITHIN A DECADE THE TECHNIQUE OF WELL CONSTRUCTION CHANGED RAPIDLY FROM THE ROMAN SHAFT DIGGING AND THE PRIMITIVE HAND-DRILLING TO THE PERCUSSION AND ROTARY SYSTEM. AUTHOR DISCUSSES THE THREE PHASES OF GROUNDWATER EXPLORATION AND RESEARCH IN ISRAEL THAT PARALLELED THIS TECHNICAL DEVELOPMENT. THESE THREE PERIODS ARE: 1923-29, DURING WHICH ATTENTION WAS FOCUSED ON YOUNGER, LESS CONSOLIDATED FORMATIONS AND THE 'STRATIGRAPHIC TRAP' WAS RECOGNIZED; 1929-42, DURING WHICH TECHNOLOGY MADE POSSIBLE DRILLING IN HARDER FORMATIONS,

WHICH INSTIGATED DEVELOPMENT IN THE MOUNTAINOUS REGIONS AND LED TO THE RECOGNITION OF THE STRUCTURAL CONTROL-PARTICULARLY THE 'FAULT TRAP'-ON GROUNDWATER; AND 1942-1952, DURING WHICH THE DRILLING OF DEEP BOREHOLES WAS MADE POSSIBLE AND THE STATISTICS AND DYNAMICS OF GROUNDWATER BECAME MORE UNDERSTOOD. THIS LED TO THE DISCOVERY OF A SECOND STRUCUTRAL TYPE OF GROUNDWATER BASIN-THE 'FOLD-BASIN (SYNCLINORIAL) TRAP'.

GROUNDWATER/ISRAEL/GROUNDWATER TECHNOLOGY/HISTORY/FAULTS(GEOLOGY)/GEOLOGIC STRUCTURES

0138

PIFER, J.

1969

WATER TABLE DECLINE AND RESULTANT AGRICULTURAL PATTERNS IN THE SALT RIVER VALLEY OF ARIZONA.

JOURNAL OF GEOGRAPHY 68(9):545-549.

SEE: SWRA W71-04065.

WATER TABLE/ARIZONA/GROUNDWATER/WITHDRAWAL/IRRIGATION PRACTICES/AGRICULTURE/CROP PRODUCTION/ECONOMIC FEASIBILITY/ARID LANDS/IRRIGATION WELLS/GROUNDWATER MINING/GROUNDWATER RECHARGE/GROUNDWATER BASINS/PUMPING/IRRIGATION DISTRICTS/WATER COSTS/ALFALFA/COTTON/CITRUS FRUITS/FORAGES/POTATOES/LEGAL ASPECTS/WELLS

0139

POLAND, J.F.

1969A

STATUS OF PRESENT KNOWLEDGE AND NEEDS FOR ADDITIONAL RESEARCH ON COMPACTION OF AQUIFER SYSTEMS. IN LAND SUBSIDENCE, VOL. 1.

INTERNATIONAL ASSOCIATION OF SCIENTIFIC HYDROLOGY, PUBLICATION 88:11-21.

THE DEPOSITS THAT ARE COMPACTING IN AREAS OF MAJOR SUBSIDENCE ARE RELATIVELY UNCONSOLIDATED, CHIEFLY ALLUVIAL AND LACUSTRINE SEDIMENTS. OF LATE CENOZOIC AGE. IN CONFINED AQUIFERS OF HETEROGENEOUS TEXTURE. ALL SUBSIDING AREAS ARE TOPPED BY WATER WELLS TO DEPTHS OF 200-900 METERS. POROSITY AVERAGES 40 PERCENT, SPECIFIC GRAVITY OF GRAINS 2.7. MONTMORILLONITE IS THE PREDOMINANT CLAY MINERAL IN SUBSIDING AREAS OF TEXAS, CENTRAL ARIZONA, CENTRAL CALIFORNIA, AND MEXICO CITY. HEAD DECLINE RANGES FROM 30 METERS IN MEXICO CITY AND LAS VEGAS, NEVADA TO 150 METERS ON THE WEST SIDE OF SAN JOAQUIN VALLEY. PARAMETERS NEEDED TO PREDICT COMPACTION INCLUDE COMPRESSIBILITY; INITIAL STRESS AND CHANGE IN STRESS; NUMBER AND THICKNESS OF COMPRESSIBLE BEDS, AND VERTICAL HYDRAULIC CONDUCTIVITY. METHODS USED FOR ESTIMATING AND MEASURING COMPACTION, AND ADDITIONAL RESEARCH NEEDS ARE DISCUSSED. (AFTER AUTHOR)

SUBSIDENCE/GROUNDWATER/WITHDRAWAL/AQUIFERS/ARTESIAN WELLS/IRRIGATION

0140

POLAND, J.F.

1969 B

LAND SUBSIDENCE AND AQUIFER SYSTEM COMPACTION, SANTA CLARA VALLEY, CALIFORNIA, U.S.A. IN LAND SUBSIDENCE, VOL. 1.

INTERNATIONAL ASSOCIATION OF SCIENTIFIC HYDROLOGY, PUBLICATION 88:285-294.

INTENSIVE WITHDRAWAL OF GROUNDWATER FROM THE CONFINED AQUIFER SYSTEM, 240 METERS THICK, IN THE SAN JOSE AREA - SANTA CLARA VALLEY, CALIFORNIA, HAS DRAWN DOWN THE ARTESIAN HEAD AS MUCH AS 75 METERS SINCE 1912. RESULTING LAND SUBSIDENCE, WHICH BEGAN ABOUT 1915, WAS 3.9 METERS IN 1967. PERIODIC RELEVELING OF BENCH MARKS, CORE-HOLE DATA AND CONTINUOUS MEASUREMENTS OF WATER-LEVEL CHANGE AND AQUIFER SYSTEM COMPACTION HAVE FURNISHED QUANTITATIVE EVIDENCE ON THE RESPONSE OF THE SYSTEM TO CHANGE IN APPLIED STRESS. THE ADJUSTED SUBSIDENCE-HEAD DECLINE RATIO IN SAN JOSE FOR 1920-38 WAS ABOUT 1:10; THIS RATIO CAN BE USED TO ESTIMATE ULTIMATE SUBSIDENCE FROM SUBSEQUENT HEAD DECLINES. COMPACTION RECORDS AT SOME SITES DEFINE THE MAGNITUDE OF EXCESS PORE PRESSURES IN AQUITARDS; AT ONE SITE, INCREASING ARTESIAN HEAD BY 14 METERS SHOULD STOP THE SUBSIDENCE. (AUTHOR)

SUBSIDENCE/GROUNDWATER/WITHDRAWAL/CALIFORNIA/AQUIFERS/ARTESIAN WELLS/IRRIGATION/PUMPING/WATER LEVELS

0141

POLAND, J.F.

1972

LAND SUBSIDENCE IN THE WESTERN STATES DUE TO GROUNDWATER OVERDRAFT.

WATER RESOURCES BULLETIN 8(1):118-131.

SEE: SWRA W72-06003.

SUBSIDENCE/WITHDRAWAL/GROUNDWATER/WATER TABLE/IRRIGATION WELLS/
WATER WELLS/ARTIFICIAL RECHARGE

0142

POLAND, J.F.

1973

SUBSIDENCE IN THE UNITED STATES DUE TO GROUNDWATER OVERDRAFT. A REVIEW.

AMERICAN SOCIETY OF CIVIL ENGINEERS, IRRIGATION AND DRAINAGE DIVISION,
PROCEEDINGS OF THE SPECIALTY CONFERENCE...FT. COLLINS, COLORADO, P. 11-38.

SEE: SWRA W75-01159.

SUBSIDENCE/WITHDRAWAL/GROUNDWATER/LOUISIANA/TEXAS/ARIZONA/NEVADA/
CALIFORNIA/COMPACTION

0143

POLAND, J.F. ET AL

1975

LAND SUBSIDENCE IN THE SAN JOAQUIN VALLEY, CALIFORNIA, AS OF 1972.

U.S. GEOLOGICAL SURVEY, PROFESSIONAL PAPER 437-H. 78 P.

LAND SUBSIDENCE, WHICH BEGAN IN THE MID 1920'S DUE TO GROUNDWATER
WITHDRAWAL IN THE SAN JOAQUIN VALLEY HAD EXCEEDED 28 FEET IN SOME AREAS BY
1970 AND AFFECTED 5200 SQUARE MILES OF VALLEY LAND. WITHDRAWALS OF
WATER FOR IRRIGATION INCREASED FROM 3 MAF IN 1942 TO 10 MAF IN 1966.
PUMPING LIFTS BECAME INORDINANTLY HIGH, WELL CASINGS FAILED, AND
DIFFERENTIAL SETTLEMENT POSED FARMING AND ENGINEERING PROBLEMS. BY
THE 1960'S CANAL IMPORTATION OF SURFACE WATER HAD REPLACED MUCH OF THE
GROUNDWATER PUMPAGE IN SOME AREAS, WATER LEVELS BEGAN RISING AND
ELEVATIONS OF SUBSIDING LANDS BEGAN STABILIZING.

SUBSIDENCE/CALIFORNIA/ARTESIAN WELLS/IRRIGATION/GROUNDWATER/AQUIFERS/
WATER TRANSFER/ARID LANDS

0144

POLAND, J.F./DAVIS G.H.

1969

LAND SUBSIDENCE DUE TO WITHDRAWAL OF FLUIDS.

REVIEWS IN ENGINEERING GEOLOGY 2:187-269.

PAPER REVIEWS THE KNOWN EXAMPLES OF LAND SUBSIDENCE DUE TO WITHDRAWAL OF
OIL AND GAS AND GROUNDWATER. SUBSIDENCE OCCURS AS THE RESULT OF COMPACTION
OF SEDIMENTS DUE TO A DECREASE IN HYDROSTATIC PRESSURE IN A CONFINED SYSTEM.
DAMAGE FROM SUBSIDENCE AND COMPACTION HAS TOTALED HUNDREDS OF MILLIONS OF
DOLLARS AND TAKES MANY FORMS. SUBSIDENCE CAN BE MEASURED BY PRECISE
LEVELING FROM STABLE REFERENCE POINTS. THE RATIO OF SUBSIDENCE TO HEAD
CHANGE DEPENDS ON THICKNESS AND LITHOLOGIC CHARACTER OF COMPACTING
SEDIMENTS. CONTINUOUS MEASUREMENTS OF COMPACTION INDICATE QUICK
RESPONSE TO PRESSURE CHANGES ALTHOUGH LAG DUE TO SLOW DRAINAGE OF CLAY MAY
CONTINUE AFTER PRESSURE DECLINE HAS CEASED. SUBSIDENCE PROBLEMS CAN BE
ALLEVIATED THROUGH: 1) CESSATION OF FLUID WITHDRAWAL DUE TO DEPLETION,
LEGAL ACTION OR REPLACEMENT WITH SUBSTITUTE REPLY; 2) INCREASE OR
RESTORATION OF RESERVOIR PRESSURE DUE TO REDUCTION IN PRODUCTION RATE OR
TO INCREASE IN RECHARGE; AND 3) REPRESSURING BY WATER INJECTION.

SUBSIDENCE/WITHDRAWAL/ARTESIAN WELLS/INJECTION WELLS

0145

POLAND, J.F./DAVIS, G.H.

1956

SUBSIDENCE OF THE LAND SURFACE IN THE TULARE-WASCO (DELANO) AND LOS BANOS-KETTLEMAN CITY AREA, SAN JOAQUIN VALLEY, CALIFORNIA.

AMERICAN GEOPHYSICAL UNION, TRANSACTIONS 37(3):287-296.

RELEVELING OF BENCH MARKS IN 1953 AND 1954 INDICATES THAT SUBSIDENCE OF THE LAND SURFACE HAS NOW EXCEEDED 10 FEET IN TWO AREAS OF THE SAN JOAQUIN VALLEY. IN THE DELANO AREA SUBSIDENCE WHICH WAS AS MUCH AS 5 FEET IN 1940 NOW HAS ABOUT DOUBLED. THE MAXIMUM RATE OF SUBSIDENCE IN RECENT YEARS HAS BEEN ABOUT 0.8 FEET/YEAR. IN THE LOS BANOS-KETTLEMAN AREA MAJOR SUBSIDENCE EXTENDS A DISTANCE OF 70 MILES OR MORE. THE MAXIMUM RATE THERE APPROACHES 1 FOOT/YEAR. PLOTS OF SUBSIDENCE AGAINST DECLINE IN ARTESIAN PRESSURE SUGGEST THAT PRESSURE DECLINE IS A MAJOR CAUSE OF SUBSIDENCE COMPACTION OF SOIL AFTER IRRIGATION IS KNOWN TO HAVE CAUSED SUBSTANTIAL LOCAL SUBSIDENCE IN THE LOS BANOS-KETTLEMAN AREA, AND TECTONIC ADJUSTMENT AND OTHER CAUSES ALSO MAY HAVE CONTRIBUTED TO SUBSIDENCE. (AFTER AUTHORS)

SUBSIDENCE/GROUNDWATER/WITHDRAWAL/CALIFORNIA/AQUIFERS/ARTESIAN WELLS/IRRIGATION/ARID LANDS

0146

POLAND, J.F./GREEN, J.H.

1962

SUBSIDENCE IN THE SANTA CLARA VALLEY, CALIFORNIA: A PROGRESS REPORT.

U.S. GEOLOGICAL SOCIETY, WATER-SUPPLY PAPER 1619-C. 16 P.

SUBSIDENCE OF THE LAND SURFACE IN SANTA CLARA VALLEY, CALIFORNIA HAS BEEN OBSERVED SINCE 1933. MAXIMUM SUBSIDENCE TO 1954 WAS 7.75 FEET. THE RATE OF SUBSIDENCE VARIES WITH THE RATE OF FLUCTUATION OF ARTESIAN PRESSURE INDICATING THAT EXCESSIVE GROUNDWATER PUMPAGE IS THE CAUSE.

SUBSIDENCE/GROUNDWATER/CALIFORNIA/ARTESIAN WELLS/IRRIGATION/ARID LANDS

0147

QUINN, F.

1968

WATER TRANSFERS: MUST THE AMERICAN WEST BE WON AGAIN.

GEOGRAPHICAL REVIEW 58(1):108-132. MAPS. SWRA W69-09325.

THE PAPER HAS TWO OBJECTIVES: (1) TO DEVELOP SOME PERSPECTIVE ON WATER TRANSFERS RELATIVE TO THE GROWTH OF TOTAL, AND URBAN, DEMANDS IN THE WEST AND ON ALTERNATIVE MEANS FOR SATISFYING THEM; AND (2) TO DISCUSS THE RANGE OF LEGAL AND POLITICAL IMPEDIMENTS THAT BEAR ON THE FLOW OF WATER AMONG DIFFERENT USERS AND REGIONS. THE EVOLUTION OF COMPETITIVE DEMAND FOR WATER RIGHTS IS TRACED; HISTORICALLY AND CURRENTLY, A MUNICIPAL-INDUSTRIAL WATER SUPPLY HAS LOW PRIORITY. LEGAL AND POLITICAL RESTRICTIONS ON THE TRANSFER OF EXISTING WATER RIGHTS MAKE IT DIFFICULT FOR GROWING CITIES TO PURCHASE AGRICULTURAL WATER SUPPLIES. STATES HAVE ADOPTED A HANDS OFF POLICY ON TRANSFERRING WATER TO OTHER STATES. NEGATIVE ASPECTS OF WATER TRANSFER ARE SUMMARIZED, BUT LEGAL AND POLITICAL ACCOMMODATIONS TO TRANSFER ARE RECOMMENDED. EXTENSIVE RESEARCH ON ALTERNATIVE SOLUTIONS TO THE WATER CRISIS SHOULD BE UNDERTAKEN. (OALS)

WATER TRANSFER/INTER-BASIN TRANSFERS/WATER SUPPLY/WATER RESOURCES DEVELOPMENT/SOUTHWEST U.S./OALS

0148

RAHN, P.H.

1968

THE HYDROGEOLOGY OF AN INDUCED STREAMBED INFILTRATION AREA.

GROUND WATER 6(3):21-32.

THE UNIVERSITY OF CONNECTICUT WELL FIELD IS LOCATED IN A SAND AND GRAVEL ICE-CONTACT STRATIFIED DRIFT AQUIFER WHICH FILLS THE FENTON RIVER VALLEY TO A DEPTH OF 60 FEET. THE WATER THAT SUPPLIES THESE WELLS CONSISTS OF CAPTURED GROUNDWATER UNDERFLOW WHICH NORMALLY WOULD DISCHARGE INTO THE FENTON RIVER, AND WATER INDUCED DIRECTLY INTO THE AQUIFER FROM RIVER FLOW BY PUMPING. MEASUREMENTS OF STREAMFLOW MADE AT 3 WEIRS INSTALLED ON THE RIVER ADJACENT TO 2 OF THESE PUMPED WELLS SHOW THE INFLUENCE OF WELLS ON STREAMFLOW. APPROXIMATELY 34 PERCENT OF THE WATER PUMPED FROM THE WELLS WAS STOLEN FROM THE RIVER VIA INDUCED STREAMBED INFILTRATION, ALTHOUGH THIS FIGURE VARIES WITH PUMPING. INDUCED INFILTRATION OF STREAMFLOW INTO THE GROUNDWATER WILL AFFECT GROUNDWATER QUALITY. BACTERIALLY POLLUTED SURFACE WATER CAN BE PURIFIED THROUGH INFILTRATION THROUGH ALLUVIUM BUT CHEMICALLY POLLUTED STREAMFLOW THAT INFILTRATES TO THE AQUIFER POSES A THREAT TO THE WATER QUALITY BECAUSE OF THE EASE WITH WHICH DISSOLVED CHEMICALS TRAVEL THROUGH ALLUVIUM. (AFTER AUTHOR)

SURFACE-GROUNDWATER RELATIONSHIPS/GROUNDWATER/SURFACE WATERS/STREAMFLOW/INFILTRATION/WATER POLLUTION/WATER QUALITY/WELLS/PUMPING/CONNECTICUT

0149

REVELLE, R. ED.

1964

REPORT ON LAND AND WATER DEVELOPMENT IN THE INDUS PLAIN.

WHITE HOUSE-DEPARTMENT OF INTERIOR PANEL ON WATERLOGGING AND SALINITY IN WEST PAKISTAN, WASHINGTON, D.C. 454 P.

THIS PAPER, OFTEN CALLED THE REVELLE REPORT, IS THE RESULT OF A COOPERATIVE EFFORT BETWEEN THE U.S. AND WEST PAKISTAN GOVERNMENTS TO TACKLE THE PROBLEM OF THE LOW AGRICULTURAL PRODUCTIVITY IN PAKISTAN. IN A COUNTRY OF FARMERS FOOD MUST BE IMPORTED. THE PROBLEM OF AGRICULTURE IS BOTH A PHYSICAL AND A HUMAN ONE. WATERLOGGING AND SALINITY OF SOILS DUE TO SURFACE WATER IRRIGATION IS ONE OF THE MAJOR CAUSES OF LOW PRODUCTIVITY. OTHER CAUSES INCLUDE: A SHORTAGE OF IRRIGATION WATER; THE SYSTEM OF LAND HOLDING; PRIMITIVE METHODS OF CULTIVATION; AND INADEQUATE SERVICES IN RURAL AREAS. AN INTEGRATED PROGRAM IS RECOMMENDED FOR THE PROVISION OF DRAINAGE AND ADDITIONAL WATER BY TUBEWELL PUMPING, MORE FERTILIZER, PURE SEED OF IMPROVED VARIETIES, PEST AND DISEASE CONTROL, BETTER CULTIVATION PRACTICES AND A SHIFT FROM ADMINISTRATION BASED ON FUNCTION TO ONE BASED ON AREA.

WATERLOGGING/SALINITY/SALINE SOILS/GROUNDWATER/PAKISTAN/INDUS BASIN/CANALS/FERTILIZERS/DRAINAGE/PUMPING/DRAWDOWN/HYDROLOGY/SOILS/ECONOMIC DEVELOPMENT/ECONOMIC IMPACT/POLITICAL ASPECTS/IRRIGATION PRACTICES/IRRIGATION EFFECTS/CROP PRODUCTION/LAND USE/PRODUCTIVITY/WATER REQUIREMENTS/WATER RESOURCES DEVELOPMENT/WATER ALLOCATION(POLICY)/WATER MANAGEMENT(APPLIED)/LIVESTOCK/MODELS/AQUIFERS/RUNOFF/WATER BUDGET/WATER TABLE/COSTS/PUNJAB/CROP YIELDS/TUBEWELLS/SOCIOECONOMIC RESEARCH/AGRICULTURAL RESEARCH/ADMINISTRATION/CROP YIELDS/AGRICULTURAL CREDIT

0150

ROHDY, D.D. ET AL

1970

PUMP IRRIGATION ON THE COLORADO HIGH PLAINS.

COLORADO AGRICULTURAL EXPERIMENT STATION, BULLETIN 543S. 41 P. SWRA W71-12175.

THE NORTHERN PART OF THE COLORADO HIGH PLAINS IS CHANGING FROM DRYLAND TO IRRIGATED AGRICULTURE. ECONOMIC IMPACT OF IRRIGATION DEVELOPMENT AND LONG-TERM EFFECTS ARE IMPORTANT ISSUES EXAMINED UNDER SPECIFIC IRRIGATION PROBLEMS. LINEAR PROGRAMMING WAS USED TO DETERMINE THE ECONOMIC LIFE OF WATER RESOURCES AND THE OPTIMUM ORGANIZATION AND INCOME. THE STUDY AREA DEPENDS ON THE OGALLALA AQUIFER FOR IRRIGATION WATER. FARM AND IRRIGATION MODELS WERE DEVELOPED ASSUMING HIGH-QUALITY MANAGEMENT. THREE FARM MODELS OR AREAS WERE CONSIDERED WHERE THE NET RETURN TO MANAGEMENT IS POSITIVE FOR 85 YEARS FOR AREA I, 185 YEARS FOR AREA II, AND 150 YEARS FOR AREA III, ASSUMING RESTRICTED DEVELOPMENT. GREATEST RETURN IS BY THE MAXIMUM ALLOWABLE ACRES IN HIGH YIELDS ON SUGAR BEETS. ASSUMPTIONS OF THE ANALYSIS ARE DISCUSSED IN DETAIL. (OALS)

OALS/DRY FARMING/IRRIGATION PRACTICES/PUMPING/ECONOMIC IMPACT/MODELS/COLORADO/WATER RESOURCES DEVELOPMENT/GROUNDWATER BASINS/AQUIFERS/CROP PRODUCTION/MATHEMATICAL MODELS/IRRIGATION PROGRAMS/IRRIGATION EFFECTS/WATER MANAGEMENT

0151

ROLL, J.R.

1967

EFFECT OF SUBSIDENCE ON WELL FIELDS.

AMERICAN WATER WORKS ASSOCIATION, JOURNAL 59(1):80-88.

SUBSIDENCE DUE TO GROUNDWATER WITHDRAWAL IN THE SANTA CLARA VALLEY, CALIFORNIA, HAS HAD CONSIDERABLE EFFECT ON THE DRAINAGE WAYS AND WELLS. CHANGES IN DRAINAGE GRADIENT RESULT IN GREATER EROSION UPSTREAM FROM SUBSIDING AREA AND GREATER DEPOSITION IN AREA OF SUBSIDENCE, BOTH OF WHICH CONTRIBUTE TO AN INCREASE IN FLOODING IN SUBSIDING AREA. FLATTENING OF GRADIENTS IN SUBSIDING AREA OF SEWAGE LINES AND STORM SEWERS HAS REDUCED THEIR CARRYING CAPACITY AND NECESSITATED THE BUILDING OF LARGER LINES OR EXTRA LINES PARALLELING OLD LINES. SUBSIDENCE HAS CAUSED WELL CASING PROTRUSION ABOVE LAND SURFACE, AND MORE SERIOUS, WELL CASING COLLAPSE. IT IS ESTIMATED THAT 80 PERCENT OF THE 5000 WELLS IN VALLEY HAVE HAD TO BE REPAIRED AT 2,000 DOLLARS/REPAIR. THESE PROBLEMS HAVE LED RESIDENTS TO SEEK SOLUTION IN THE IMPORTATION OF WATER FROM SOURCES OUTSIDE THE VALLEY, AND TO CONSTRUCT DAMS AND RESERVOIRS TO CATCH SURFACE WATER.

SUBSIDENCE/GROUNDWATER/WITHDRAWAL/WELLS/ECONOMIC IMPACT/WATER TRANSFER/ CALIFORNIA/ARID LANDS

0152

SANGHI, A.K./KLEPPER, R.

1976

AN ECONOMIC ANALYSIS OF IRRIGATED FARMING WITH DIMINISHING GROUND WATER RESERVES.

WASHINGTON UNIVERSITY, ST. LOUIS, MISSOURI, CENTER FOR THE BIOLOGY OF NATURAL SYSTEMS. 50 P. AVAILABLE NTIS AS PB-255 433.

THE RAPID EXPANSION OF GROUNDWATER IRRIGATED FARMING IN THE GREAT PLAINS HAS CAUSED WATER TABLES TO FALL IN MANY AREAS. AS THE SATURATED THICKNESS OF AN AQUIFER DECLINES, NET RETURNS TO IRRIGATED FARMING ARE AFFECTED BY TWO WAYS: THE INCREASED COST OF PUMPING WATER AND THE DECREASE IN EXPECTED CROP YIELDS. AN ECONOMIC EVALUATION OF IRRIGATION FROM GROUNDWATER REQUIRES CAREFUL SPECIFICATION OF THE PRODUCTION FUNCTION FOR A CROP. A METHOD OF ECONOMIC ANALYSIS IS PROPOSED THAT RESTS ON A PRODUCTION FUNCTION THAT INCORPORATES THE AVAILABILITY OF WATER IN CRITICAL PERIODS OF PLANT GROWTH AND ITS EFFECT ON YIELDS. HYPOTHETICAL EXAMPLES OF CORN UNDER CENTER PIVOT IRRIGATION WITH DECLINING WATER TABLES ARE USED TO DEMONSTRATE THE USEFULNESS OF THIS APPROACH.

GROUNDWATER/GROUNDWATER MINING/ECONOMIC IMPACT/PRODUCTION FUNCTION/CORN/ IRRIGATED AGRICULTURE/PUMPING/WATER COSTS/WATER REQUIREMENTS/CROP RESPONSE/ TIMING/IRRIGATION EFFECTS

0153

SCHAMP, H.

1967

KHARGA, VON DER OASIS MAGNA ZUM NEUEN TAL (KHARGA, FROM THE OASIS MAGNA TO THE NEW VALLEY).

ERDE 98(3):173-202. SWRA W70-04412.

KHARGA, ONE OF THE LARGEST OF THE EGYPTIAN OASES, WAS INCLUDED IN THE AREA OF THE WESTERN DESERT SELECTED BY EGYPTIAN GOVERNMENT'S GENERAL DESERT DEVELOPMENT ORGANIZATION FOR LAND RECLAMATION AND RESETTLEMENT. THE FIRST 5-YEAR PROGRAM (1960-1965) PROVIDED APPROXIMATELY 100 DEEP WELLS, FURNISHING IRRIGATION WATER FOR THE CULTIVATION OF SOME 45,000 FEDDANS (1 FEDDAN= 1.04 ACRES) AS COMPARED WITH ONLY 6,000 FORMERLY. ALTHOUGH THE ORIGIN OF THE GROUNDWATER IN THE KHARGA OASIS AREA IS NOT YET IDENTIFIED, CURRENT ESTIMATES FROM KNOWN SUPPLIES INDICATE THAT EVEN LARGER ACREAGE MAY BE BROUGHT UNDER CULTIVATION. TOPICS DISCUSSED INCLUDE GROUNDWATER, SOILS, A HISTORY OF THE OASIS DETAILING RECURRING DESERTIFICATION, THE COST OF FINANCING THE NEW VALLEY PROJECT, AND SETTLEMENT PROBLEMS. THE LATTER TOPIC SEEKS TO COMPARE THE OLD OASIS VILLAGES WITH THE NEW SETTLEMENTS, CHARACTERIZED BY AN INFLUX OF NEW POPULATION TYPES: TECHNICIANS, ENGINEERS, AND THE LIKE. THE EXTREME DESERTIC CONDITIONS OF THE SURROUNDING ENVIRONMENT MAKE THE KHARGA OASIS DEVELOPMENT ONE OF GREAT GENERAL INTEREST, SINCE ITS SUCCESS COULD PROVIDE A PILOT FOR SIMILAR WATER-SHORT AREAS THROUGHOUT THE ARID WORLD. THE ELEMENT OF ITS WATER POTENTIAL IS THE CRITICAL FACTOR. (OALS)

IRRIGATION PROGRAMS/DESERTS/EGYPT/OASES/WATER RESOURCES DEVELOPMENT/GROUNDWATER BASINS/WELLS/SOCIAL ASPECTS/WESTERN DESERT/ECONOMIC DEVELOPMENT/LAND RECLAMATION/SAHARA/KHARGA OASIS/OALS

0154

SCHMORAK, S.

1967

SALT WATER ENCROACHMENT IN THE COASTAL PLAIN OF ISRAEL. IN ARTIFICIAL RECHARGE AND MANAGEMENT OF AQUIFERS, SYMPOSIUM OF HAIFA, MARCH 19-26, 1967.

INTERNATIONAL ASSOCIATION OF SCIENTIFIC HYDROLOGY, PUBLICATION 72:305-318.

SEE: SWRA W70-04613.

SALINE WATER INTRUSION/GROUNDWATER/ISRAEL/SALINE WATER-FRESHWATER INTERFACES/OBSERVATION WELLS/MONITORING/GROUNDWATER MOVEMENT/ARID LANDS/ELECTRIC WELL LOGGING/WATER LEVELS/RECHARGE/AQUIFERS/DISCHARGE(WATER)

0155

SCHRAMM, G.

1976

HUMAN-INSTITUTIONAL FACTORS.

NATURAL RESOURCES JOURNAL 16(3):923-937.

MORE AND MORE IN DEVELOPING COUNTRIES WATER RESOURCES DEVELOPMENT AND MANAGEMENT IS CONCEIVED IN BROAD, SOCIO-ECONOMIC OBJECTIVES RATHER THAN IN THE NARROWER CONTEXT OF SINGLE PROJECTS THAT ARE DESIGNED TO PROVIDE FOR SPECIFIC WATER NEEDS FOR A SPECIFIC AREA. WITHIN THESE OBJECTIVES PROJECTS ARE CONCEIVED, DESIGNED, AND EVALUATED ON THE BASIS OF FEASIBILITY CRITERIA SUCH AS BENEFIT-COST RATIO, TARGET LEVELS OF INTERNAL RATES OF RETURN, OR SOME FORM OF COST-EFFECTIVENESS ANALYSIS. DESPITE THE EFFORTS THAT HAVE BEEN DIRECTED TOWARD THE DEVELOPMENT AND APPLICATION OF SOPHISTICATED EVALUATION CRITERIA AND METHODOLOGIES, PRACTICAL RESULTS OF COMPLETED PROJECTS HAVE FREQUENTLY BEEN DISAPPOINTING. A MAJOR CONTRIBUTING FACTOR TO THIS DISCREPANCY BETWEEN EXPECTATIONS AND RESULTS HAS BEEN THE HUMAN AND HUMAN-INSTITUTIONAL ELEMENTS, WHICH EXIST ON THE SIDE OF THE BENEFACTORS AND THE BENEFICIARIES. SOME OF THESE FACTORS ARE THE UNPREDICTIBILITY OF BEHAVIOR OF THE BENEFICIARY, LACK OF COMMUNICATION AND COORDINATION BETWEEN AGENCIES, LOW LEVEL OF PROFESSIONAL TRAINING, HIGH TURNOVER RATES OF PROFESSIONALS, AND INSTITUTIONAL RIVALRIES. AUTHOR ILLUSTRATES THESE CONSTRAINTS FROM HIS EXPERIENCE IN WATER RESOURCES PLANNING IN MEXICO.

WATER MANAGEMENT(APPLIED)/MEXICO/INSTITUTIONAL ASPECTS/POLITICAL ASPECTS/WATER RESOURCES DEVELOPMENT/ECONOMIC DEVELOPMENT

0156

SCHUMANN, H.H./POLAND, J.F.

1969

LAND SUBSIDENCE, EARTH FISSURES AND GROUNDWATER WITHDRAWAL IN SOUTH-CENTRAL ARIZONA, U.S.A. IN LAND SUBSIDENCE, VOL. 1.

INTERNATIONAL ASSOCIATION OF SCIENTIFIC HYDROLOGY, PUBLICATION 88:295-302.

LAND SUBSIDENCE IN WESTERN PINAL COUNTY: SOUTH-CENTRAL ARIZONA, IS RELATED TO GROUNDWATER WITHDRAWAL AND WATER LEVEL DECLINES. SUBSIDENCE WAS FIRST DETECTED IN 1948. MAXIMUM DOCUMENTED SUBSIDENCE FROM 1948-1967 IS 2.30 METERS. PUMPING OF WATER HAS LOWERED WATER LEVELS AS MUCH AS 61 METERS. NET WATER LEVEL DECLINES CORRESPOND WITH SUBSIDENCE AND WATER-LEVEL FLUCTUATIONS CORRELATE WITH SEDIMENT COMPACTION AND EXPANSION. MEASURED COMPACTION IN UPPER 253 METERS ACCOUNTS FOR ONLY 65 PERCENT OF MEASURED SUBSIDENCE. NUMEROUS EARTH FISSURES AS MUCH AS 12.8 KILOMETERS LONG IN ALLUVIUM PARALLEL THE LAND CONTOUR AND INTERCEPT DRAINAGES. SUBSIDENCE AND FISSURES HAVE DAMAGED IRRIGATION SYSTEMS, INTERSTATE HIGHWAYS AND RAILROADS AND HAVE RESULTED IN THE REROUTING OF A PROPOSED AQUEDUCT.

SUBSIDENCE/GROUNDWATER MINING/ARIZONA/PINAL COUNTY/WELLS/GROUNDWATER

0157

SHEAHAN, N.T.

1977

INJECTION/EXTRACTION WELL SYSTEM: A UNIQUE SEAWATER BARRIER.

GROUND WATER 15(1):32-50.

SEE: SWRA W77-04088.

SALINE WATER INTRUSION/AQUIFERS/GROUNDWATER/GROUNDWATER MINING/WITHDRAWAL/MODELS/WELLS/INJECTION WELLS/WATER QUALITY/SALINE WATER/WATER REUSE/COMPUTERS

0158

SIMPSON, E.

1968

GENERAL SUMMARY OF THE STATE OF RESEARCH ON GROUND-WATER HYDROLOGY IN DESERT ENVIRONMENTS. IN W.G. MCGINNIES, B.J. GOLDMAN, AND P. PAYLORE, EDS., DESERTS OF THE WORLD, P. 727-744.

UNIVERSITY OF ARIZONA PRESS, TUCSON. 788 P.

SEE: SWRA W69-08688.

GROUNDWATER/ARID LANDS/DESERTS/ANALOG MODELS/EVALUATION/HYDROLOGY/AQUIFERS/ARTIFICIAL RECHARGE MANAGEMENT/GEOHYDROLOGY/HYDROGEOLOGY/GROUNDWATER RECHARGE/WATER TABLE/HYDROLOGIC BUDGET/WATER RESOURCES PLANNING/RESEARCH AND DEVELOPMENT/WATER POLICY/DATA COLLECTIONS/SUBSURFACE MAPPING/WATER STORAGE

0159

SKIBITZKE, H.E. ET AL

1961

SYMPOSIUM ON HISTORY OF DEVELOPMENT OF WATER SUPPLY IN AN ARID AREA IN SOUTHWESTERN UNITED STATES SALT-RIVER VALLEY, ARIZONA. IN GROUNDWATER IN ARID ZONES, SYMPOSIUM OF ATHENS, 1961.

INTERNATIONAL ASSOCIATION OF SCIENTIFIC HYDROLOGY, PUBLICATION 57(2):706-742.

PAPER DESCRIBES THE HISTORY OF DEVELOPMENT OF WATER SUPPLY IN AN ARID AREA, THE SALT RIVER VALLEY OF ARIZONA, AN AREA OF RAPID POPULATION GROWTH AND ACCOMPANYING EXTENSIVE DEVELOPMENT OF BOTH GROUND-AND SURFACE-WATER SUPPLIES. FIVE SECTIONS ARE PRESENTED: HISTORICAL REVIEW; THE EARLY PERIOD--SURFACE WATER DEVELOPMENT; THE INTERMEDIATE PERIOD--THE INTERRELATIONSHIP BETWEEN SURFACE WATER AND GROUNDWATER; THE MODERN PERIOD--GROUNDWATER DEVELOPMENT; AND A SUMMARY.

GROUNDWATER/SURFACE WATERS/SURFACE-GROUNDWATER RELATIONSHIPS/ARIZONA/IRRIGATION/WATERLOGGING/SALT RIVER VALLEY/HISTORY/DRAINAGE/CROPS/PUMPING

0160

SMITH, C.L./HOGG, T.C.

1971

BENEFITS AND BENEFICIARIES: CONTRASTING ECONOMIC AND CULTURAL DISTINCTIONS.

WATER RESOURCES RESEARCH 7(2):254-263.

A CONCERN WITH RELATIONS AMONG PEOPLE IN WATER RESOURCE DEVELOPMENT MEANS THAT THE VALUES THEY HOLD REGARDING EFFECTIVE DEVELOPMENT MUST BE CONSIDERED IN DECISION MAKING. COMPARATIVE OBSERVATIONS OF PEOPLES OF THE SALT RIVER VALLEY IN ARIZONA, THE PACIFIC NORTHWEST, AND THE KALAHARI DESERT OF AFRICA SUGGEST THAT TRADITIONAL METHODS OF WATER DEVELOPMENT EVALUATION DEVELOPED IN THE WESTERN WORLD ARE NOT APPLICABLE TO UNDERDEVELOPED AREAS. THESE OBSERVATIONS SHOW INTERESTING DIFFERENCES IN THE NATURE OF ROLE PERFORMANCE RELATIVE TO RECEIVING WATER RESOURCE DEVELOPMENT BENEFITS AND REPAYING THE COST OF CREATING THESE BENEFITS, AND SIGNIFICANT DIFFERENCES IN THE CULTURAL VALUES FOR OBTAINING WATER RESOURCES DEVELOPMENT.

WATER RESOURCES DEVELOPMENT/COST-BENEFIT ANALYSIS/WATER MANAGEMENT(APPLIED)/ BENEFITS/ECONOMIC ASPECTS/KALAHARI/ARIZONA/CULTURAL ASPECTS/BENEFICIARIES/ PACIFIC NORTHWEST/SALT RIVER PROJECT

0161

SMITH, C.L./PADFIELD, H.I.

1969

LAND, WATER AND SOCIAL INSTITUTIONS. IN W.G. MCGINNIES AND B.J. GOLDMAN, EDS., ARID LANDS IN PERSPECTIVE, P. 327-336.

UNIVERSITY OF ARIZONA PRESS, TUCSON. 437 P.

PAPER ADDRESS THE QUESTION 'WHY DO NOT ALL WELL-DESIGNED WATER RESOURCE PROJECTS PROMOTE ECONOMIC DEVELOPMENT?' THE ANSWER LIES IN UNDERSTANDING THE RELATIONSHIP BETWEEN LAND, WATER AND SOCIAL INSTITUTIONS. SEVERAL LAND-WATER-INSTITUTION COMPLEXES ARE DISCUSSED (THE SALT RIVER PROJECT AND THE TENNESSEE VALLEY AUTHORITY, FOR EXAMPLE) IN TERMS OF THE CONCEPT OF 'WATERSPACE' WHICH DENOTES THE INTERPLAY OF WATER, LAND AND SOCIAL INSTITUTIONS HAVING IDENTICAL TIME AND SPACE BOUNDARIES.

WATER RESOURCES DEVELOPMENT/INSTITUTIONS/SOCIAL ORGANIZATION/WATER MANAGEMENT(APPLIED)/ECONOMIC DEVELOPMENT/SALT RIVER PROJECT/TENNESSEE VALLEY AUTHORITY/METROPOLITAN WATER DISTRICT/LOWER MEKONG RIVER SCHEME/CULTURAL ASPECTS

0162

SNYDER, J.H.

1954

ON THE ECONOMICS OF GROUND-WATER MINING: A CASE STUDY IN AN ARID AREA.

JOURNAL OF FARM ECONOMICS 36(4):600-610.

ANTELOPE VALLEY IN SOUTHERN CALIFORNIA IS MAINLY DEPENDENT ON GROUNDWATER. THE VALLEY IS SUBJECT TO SERIOUS OVERDRAFT OF GROUNDWATER DUE TO ITS EXTENSIVE USE IN IRRIGATED AGRICULTURE. CONCERN HAS BEEN EXPRESSED OVER THE IMPACT OF THE DECLINING WATER TABLE. STUDY SHOWS THAT TECHNOLOGICAL INNOVATION HAS SO FAR KEPT PACE WITH THE INCREASING COSTS NORMALLY ASSOCIATED WITH A FALLING WATER LEVEL. POSSIBLE FUTURE DEVELOPMENTS DUE TO DECLINE IN WATER LEVEL ARE PROJECTED. ECONOMIC FORCES ASSOCIATED WITH COST-PRICE CONDITIONS AND TECHNOLOGICAL ADVANCEMENT HAVE STIMULATED GROUNDWATER OVERDRAFT AS OPPOSED TO ITS USE ON A SAFER YIELD BASIS. ASSUMING ALL ACREAGE IN ALFALFA, THE ESTIMATED EARNINGS FOR THE PERIOD OF 1927-1950 WITH GROUNDWATER USED ON A SAFE YIELD RATE (DRAFT = RECHARGE) ARE LESS THAN 5,000,000 DOLLARS. FOR ONLY THE PERIOD OF 1947-1950, ACTUAL EARNINGS TOTALLED 4,500,000 DOLLARS.

GROUNDWATER/MINING/WITHDRAWAL/CALIFORNIA/IRRIGATION WELLS/AGRICULTURE/ECONOMIC IMPACT/OVERDRAFT/ARID LANDS/MOJAVE DESERT/COSTS

0163

STEELHAMMER, R.H./GARLAND, J.G.

1970

SUBSIDENCE RESULTING FROM THE REMOVAL OF GROUNDWATERS.

SOUTH TEXAS LAW JOURNAL 12:201-213.

SEE: SWRA W71-07209.

GROUNDWATER/TEXAS/SUBSIDENCE/OIL/WITHDRAWAL/LEGAL ASPECTS/PERCOLATION/ WATER RIGHTS

0164

STOW, D.A.V./SKIDMORE, J./BERGER, A.R.

1976

PRELIMINARY BIBLIOGRAPHY ON GROUNDWATER IN DEVELOPING COUNTRIES, 1970-1976.

ASSOCIATION OF GEOSCIENTISTS FOR INTERNATIONAL DEVELOPMENT, ST. JOHN'S NEWFOUNDLAND A1C 5S7, CANADA, THE GEOSCIENCES IN INTERNATIONAL DEVELOPMENT, REPORT 4. 305 P.

BIBLIOGRAPHY ON LITERATURE PUBLISHED SINCE 1970 DEALING WITH GROUNDWATER IN DEVELOPING COUNTRIES. INDEXED BY COUNTRY AND BY SUBJECT.

BIBLIOGRAPHIES/GROUNDWATER/DEVELOPING COUNTRIES

0165

STRAAYER, J.A.

1970

PUBLIC PROBLEMS AND NON-DECISION MAKING, A STUDY OF THE TUCSON WATER SYSTEM.

NATURAL RESOURCES JOURNAL 10:545-556.

THIS AUTHOR ARGUES THAT POLITICAL SYSTEMS IN METROPOLITAN AREAS HAVE FAILED TO PRODUCE COMPREHENSIVE AND SUSTAINED PROGRAMS TO DEAL WITH METROPOLITAN ENVIRONMENTAL PROBLEMS BECAUSE 1) THE RELATIONSHIP BETWEEN PATTERN OF GOVERNMENTAL ORGANIZATION AND PROBLEM BOUNDARIES IN METROPOLITAN AREAS, 2) VARIATIONS IN THE NUMBER OF FUNCTIONS PERFORMED BY METROPOLITAN AREA GOVERNMENTS, 3)VARIATIONS IN THE RESOURCES POSSESSED BY, AND DEMANDS PLACED UPON, METROPOLITAN GOVERNMENTS, AND 4) A RESULTANT VARIATION IN 'THE PROPENSITY OF METROPOLITAN AREA DECISION-MAKERS TO TREAT A GIVEN SET OF ENVIRONMENTAL CONDITIONS AS A PUBLIC PROBLEM, AND THEN TO INCUR THE DECISION-COSTS NECESSSARY TO DEAL WITH THAT PROBLEM.' TUCSON'S GROUNDWATER PROBLEM ILLUSTRATES THESE POINTS AS A RAPIDLY GROWING CITY IN AN ARID REGION DEPENDENT ON A DECLINING GROUNDWATER RESOURCE FOR ITS TOTAL WATER SUPPLY. BECAUSE AT LEAST 7 DIFFERENT AGENCIES WITH DIFFERENT CONSTITUENCIES HAVE SOME HAND IN DEALING WITH THE WATER PROBLEM, THIS PROBLEM WILL CONTINUE UNTIL: 1) POTENTIAL BOUNDARIES ARE ALTERED TO MATCH PROBLEM BOUNDARIES; 2) THE PROBLEM BECOMES A CRISIS; 3) RESOURCES-MONEY ARE INCREASED; 4) STATE LAW IS CHANGED; AND/OR 5) INCREASED DEMANDS, INCREASED RESOURCES, CHANGES IN THE LAW OR INCREASED EDUCATION ACT TO ALTER PERCEPTIONS OF THE DECISION MAKER.

GROUNDWATER/ARIZONA/TUCSON/LEGAL ASPECTS/POLITICAL ASPECTS/WATER SUPPLY/GROUNDWATER MINING

0166

STULTS, H.M.

1968

PREDICTING FARMER RESPONSE TO A FALLING WATER TABLE: AN ARIZONA CASE STUDY.

UNIVERSITY OF ARIZONA (PH.D. DISSERTATION). 109 P.

GROUNDWATER LEVELS IN PINAL COUNTY HAVE BEEN DROPPING STEADILY SINCE LARGE SCALE EXPANSION OF IRRIGATED AGRICULTURE BEGAN IN THE 1940'S. SINCE 95 PERCENT OF THE WATER IN PINAL COUNTY IS USED BY FARMERS, THE INITIAL IMPACT OF INCREASING PUMPING COSTS FALLS ALMOST ENTIRELY ON FARMERS, RESULTING IN CONTINUOUS ADJUSTMENTS IN RESOURCE USE, CROPPING PATTERNS OUTPUT AND INCOME. FARMER ADJUSTMENTS TO INCREASING PUMPING COSTS ARE ANALYZED IN TWO STEPS: 1) AN ECONOMIC MODEL OF TYPICAL PINAL COUNTY FARMS IS DEVELOPED FOR 4 SIZE GROUPS AND 3 PUMPING LIFTS WITHIN EACH SIZE CLASS. 2) DATA PROVIDED BY ANALYSIS OF TYPICAL PINAL COUNTY FARMS IS INCORPORATED IN A LINEAR PROGRAMMING MODEL. RESULTS FROM THIS MODEL SUGGEST THAT PINAL COUNTY FARMERS DO NOT FACE AN IMMEDIATE WATER CRISIS. A DECLINING WATER TABLE WILL REQUIRE LARGE ADJUSTMENTS OVER TIME BUT WILL NOT SUBSTANTIALLY AFFECT NET FARM INCOME. (AFTER AUTHOR)

GROUNDWATER/IRRIGATION/AGRICULTURE/PINAL COUNTY/ARIZONA/ECONOMIC IMPACT/ CROP PRODUCTION/ARID LANDS/MODELS/LINEAR PROGRAMMING/IRRIGATION PRACTICES/ PUMPING/COSTS

0167

TALBOT, L.M.

1972

ECOLOGICAL CONSEQUENCES OF RANGELAND DEVELOPMENT IN MASAILAND, EAST AFRICA. IN M.T. FARVAR AND J.P. MILTON, EDS., THE CARELESS TECHNOLOGY: ECOLOGY AND INTERNATIONAL DEVELOPMENT, P. 694-711.

NATURAL HISTORY PRESS, GARDEN CITY, NEW YORK. 1030 P.

THE MASAI'S CULTURE AND SURVIVAL ARE BASED ON SEMINOMADIC PASTORALISM. MUCH EFFORT HAS BEEN SPENT IN DEVELOPING THEIR RANGE RESOURCES WHICH HAS CONTRIBUTED TO THEIR DETERIORATION RESULTING IN FAMINE FOR THE MASAI AND THEIR LIVESTOCK. TWO CASE HISTORIES ARE DISCUSSED WHICH ILLUSTRATE THAT WHEN THE CONSTRAINTS OF AN ENVIRONMENT, PARTICULARLY THE WATER RESOURCE CONSTRAINTS, ARE REMOVED AND NOT REPLACED WITH CULTURAL CONSTRAINTS, ENVIRONMENTAL DETERIORATION RESULTS.

EAST AFRICA/ARID LANDS/ENVIRONMENTAL IMPACT/WATER RESOURCES DEVELOPMENT/ WELLS/RANGE MANAGEMENT/OVERGRAZING/WATER SUPPLY

0168

TALBOT, L.M.

1971

ECOLOGICAL ASPECTS OF AID PROGRAMS IN EAST AFRICA, WITH PARTICULAR REFERENCE TO RANGELANDS. IN B. LUNDHOLM, ED., ECOLOGY AND THE LESS DEVELOPED COUNTRIES, APRIL 1971, STOCKHOLM. PROCEEDINGS, P. 21-51.

SWEDISH ECOLOGICAL RESEARCH COMMITTEE. BULLETIN 13.

DESCRIBES IN DETAIL ECOLOGICAL CONSEQUENCES OF ATTEMPTS TO ASSIST THE MASAI PEOPLE OF EAST AFRICA THROUGH IMPROVEMENT OF GRAZING AND DEVELOPMENT OF THEIR RANGELAND RESOURCES. THE BASIC PROBLEM IS THAT IMPROVEMENTS OF WATER SUPPLIES AND OTHER FORMS OF DEVELOPMENT HAVE BEEN CARRIED OUT SEPARATELY, NOT AS A PART OF A COMPREHENSIVE RESOURCE MANAGEMENT PROGRAM THAT TAKES INTO ACCOUNT THE ECOLOGY OF THE WHOLE AREA. THE MASAI PEOPLE S CURRENT AND PAST HISTORY, THE LAND, THE CLIMATE, WILDLIFE AND RESOURCE-DEGRADING DEVELOPMENT ACTIVITIES STILL GOING ON TODAY ARE DESCRIBED. SUGGESTIONS ARE GIVEN FOR ECOLOGICAL DEVELOPMENT AND CONSEQUENCES OF FAILURE TO ADOPT AN ECOLOGICAL PROGRAM ARE DISCUSSED.

OALS/KWIC AF 4/AID/EAST AFRICA/RANGES/RANGE MANAGEMENT/ENVIRONMENTAL EFFECTS/ECOLOGY/LAND RESOURCES/WATER RESOURCES/WATER RESOURCES DEVELOPMENT/ WATER MANAGEMENT/NATURAL RESOURCES/ECONOMICS/WILDLIFE/LAND USE/PLANNING/ TOPOGRAPHY/CLIMATE/HUMANS/VEGETATION/LIVESTOCK/BIBLIOGRAPHIES

0169

THEIS, C.V.

1935

THE RELATION BETWEEN THE LOWERING OF THE PIEZOMETRIC SURFACE AND THE RATE AND DURATION OF DISCHARGE OF A WELL USING GROUNDWATER STORAGE.

AMERICAN GEOPHYSICAL UNION, TRANSACTIONS 16:519-524.

WHEN A WELL IS PUMPED WATER LEVELS IN THE AREA ARE LOWERED. UNLESS THIS LOWERING OCCURS INSTANTANEOUSLY IT REPRESENTS A LOSS OF STORAGE. THE MATHEMATICAL THEORY OF GROUNDWATER HYDRAULICS HAS BEEN BASED ON THE ASSUMPTION THAT EQUILIBRIUM HAS BEEN ATTAINED AND THAT WATER LEVELS ARE NO LONGER FALLING. PAPER INVESTIGATES A MATHEMATICAL THEORY THAT CONSIDERS THE ACTION OF GROUNDWATER BEFORE EQUILIBRIUM IS REACHED, AND THUS INVOLVES TIME AS A VARIABLE. THE PRINCIPLE VALUE OF THE EQUATION DEVELOPED IS THAT IT PROVIDES PART OF THE THEORETICAL BACKGROUND FOR PREDICTING FUTURE EFFECTS OF A GIVEN PUMPING REGIMEN UPON THE WATER LEVELS IN THE AREA.

GROUNDWATER/PUMPING/WITHDRAWAL/WATER TABLE/TRANSMISSIVITY/WATER STORAGE/ WELLS/AQUIFERS/WATER LEVELS/MATHEMATICAL MODELS/STORAGE COEFFICIENT

0170

THEIS, C.V.

1938

THE SIGNIFICANCE AND NATURE OF THE CONE OF DEPRESSION IN GROUNDWATER BODIES.

ECONOMIC GEOLOGY 33(8):889-902.

IN NATURE THE HYDRAULIC SYSTEM IN AN AQUIFER IS IN BALANCE: THE DISCHARGE IS EQUAL TO THE RECHARGE AND THE WATER TABLE OR OTHER PIEZOMETRIC SURFACE IS MORE OR LESS FIXED IN POSITION. DISCHARGE BY WELLS IS A NEW DISCHARGE SUPERIMPOSED ON THE PREVIOUS SYSTEM. A NEW EQUILIBRIUM IS ESTABLISHED WHEN WATER LEVELS FALL ENOUGH TO REDUCE NATURAL DISCHARGE OR INCREASE NATURAL RECHARGE BY AN AMOUNT EQUAL TO THE AMOUNT DISCHARGED BY THE WELL. THE CHARACTERISTICS OF THE CORE OF DEPRESSION ARE CONSIDERED MATHEMATICALLY WITH TIME AN ESSENTIAL VARIABLE. THE RATE OF LATERAL GROWTH OF THE CORE IS INDEPENDENT OF THE RATE OF DISCHARGE BY THE WELL AND DEPENDS ON THE PHYSICAL CHARACTERISTICS OF THE AQUIFER.

GROUNDWATER/PUMPING/DISCHARGE(WATER)/WITHDRAWAL/RECHARGE/WATER TABLE/AQUIFERS/ WATER STORAGE/TRANSMISSIVITY/ARTESIAN WELLS/STORAGE COEFFICIENT

0171

THEIS, C.V.

1940 A

THE SOURCE OF WATER DERIVED FROM WELLS: ESSENTIAL FACTORS CONTROLLING THE RESPONSE OF AN AQUIFER TO DEVELOPMENT.

CIVIL ENGINEERING 10(5):277-280.

A KNOWLEDGE OF THE FACTORS THAT CONTROL RESPONSE OF AN AQUIFER TO DEVELOPMENT IS NECESSARY TO INTERPRET EXISTING RECORDS, AND CAN YIELD THE ONLY METHOD OF PREDICTING THE EFFECT OF GROUNDWATER DEVELOPMENT IN AREAS WHERE RECORDS OF THE PAST ARE LACKING. THESE FACTORS ARE 1) DISTANCE TO, AND CHARACTER OF THE RECHARGE; 2) DISTANCE TO LOCALITY OF NATURAL RECHARGE; 3) THE CHARACTER OF THE CONE OF DEPRESSION. HYDROLOGIC EFFECTS OF DEVELOPMENT IN ARTESIAN AND UNCONFINED AQUIFERS ARE DISCUSSED. RECOMMENDATIONS ARE MADE FOR THE IDEAL DEVELOPMENT OF ANY AQUIFER TO INSURE MAXIMUM UTILIZATION OF THE SUPPLY.

GROUNDWATER/WELLS/DISCHARGE(WATER)/GROUNDWATER MINING/GROUNDWATER RECHARGE/ WATER TABLE/ARTESIAN WELLS/WATER MANAGEMENT(APPLIED)/GROUNDWATER MANAGEMENT/ WATER POLICY

0172

THEIS, C.V.

1940 B

THE EFFECT OF A WELL ON THE FLOW OF A NEARBY STREAM.

AMERICAN GEOPHYSICAL UNION, TRANSACTIONS 22(3):734-738.

USING CERTAIN HYDRAULIC IDEALIZATIONS, THE AUTHOR DEVELOPS AN EQUATION TO DETERMINE THE EFFECT OF PUMPING A WELL ON THE FLOW OF A NEARBY STREAM. EQUATION ALLOWS ONE TO PREDICT THAT IN AN AQUIFER WITH A SPECIFIC YIELD OF 20 PERCENT AND A TRANSMISSIVITY OF 50,000 A WELL ONE MILE FROM A STREAM WILL TAKE ABOUT 30 PERCENT OF ITS WATER FROM STREAMFLOW AFTER 1 YEAR OF PUMPING AND ABOUT 90 PERCENT AFTER 20 YEARS OF PUMPING. A WELL 5 MILES FROM THE STREAM WILL TAKE ABOUT 2 PERCENT OF ITS WATER FROM THE STREAM AFTER 5 YEARS OF PUMPING AND ABOUT 20 PERCENT AFTER 20 YEARS. IN AN AQUIFER WITH A TRANSMISSIVITY OF 400,000 A WELL ONE MILE FROM THE RIVER WILL TAKE ABOUT 90 PERCENT OF ITS WATER FROM THE STREAM IN 3 YEARS AND A WELL 5 MILES FROM THE STREAM WILL TAKE ABOUT 5 PERCENT AFTER ONE YEAR AND ABOUT 75 PERCENT AFTER 20 YEARS OF PUMPING.

SURFACE-GROUNDWATER RELATIONSHIPS/STREAMFLOW/INFILTRATION/GROUNDWATER/ PUMPING/WELLS/TRANSMISSIVITY/STORAGE COEFFICIENT/MATHEMATICAL MODELS

0173

THOMAS, H./BUTCHER, L.

1961

GROUND-WATER DILEMMA AT TEBOULBA, TUNISIA. IN GROUNDWATER IN ARID ZONES, SYMPOSIUM OF ATHENS, 1961.

INTERNATIONAL ASSOCIATION OF SCIENTIFIC HYDROLOGY, PUBLICATION 57(2):597-604.

TEBOULBA'S DILEMMA IS THAT THE CURRENT RATE OF PUMPING FROM WELLS IS DEPLETTNG THE GROUNDWATER RESERVOIRS, BUT THE WATER THUS BEING WITHDRAWN FROM STORAGE IS OF BETTER QUALITY THAN SOME OF THE WATER THAT REPLENISHES THE RESERVOIR, SO THAT EVEN IF THE RATE OF WITHDRAWAL IS REDUCED, THE QUALITY OF WATER IN SOME WELLS MAY DETERIORATE. IN THE VICINITY OF TEBOULBA THERE IS A SHALLOW BODY OF USABLE GROUNDWATER BOUNDED ON FOUR SIDES BY SALINE WATER. WITHDRAWALS HAVE CREATED SALINE WATER ENCROACHMENT FROM TWO SIDES. WATER BENEATH THE USABLE GROUNDWATER IS SALINE AS IS MUCH OF THE RECHARGE FROM PRECIPITATION. OPTIMUM UTILIZATION OF THIS GROUNDWATER CANNOT BE ACHIEVED BY ADHERENCE TO THE PRINCIPLE OF PERENNIAL YIELD. (AFTER AUTHORS)

GROUNDWATER/SALINE WATER INTRUSION/SALINE WATER/TUNISIA/WELLS/PUMPING/ GROUNDWATER MINING/AQUIFERS/RECHARGE

0174

THOMAS, J.W.

1975

THE CHOICE OF TECHNOLOGY FOR IRRIGATION TUBEWELLS IN EAST PAKISTAN: AN ANALYSIS OF A DEVELOPMENT POLICY DECISION.

HARVARD UNIVERSITY, CAMBRIDGE, MASSACHUSETTS, STUDIES IN INTERNATIONAL AFFAIRS 32:31-67.

THIS ARTICLE EXAMINES TECHNOLOGICAL ALTERNATIVES AVAILABLE TO THE GOVERNMENT, EVALUATES THE CHOICE OF TECHNOLOGY IN TERMS OF NATIONAL DEVELOPMENT PRIORITIES AND FEASIBILITY OF IMPLEMENTATION, AND ANALYZES THE FACTORS WHICH DETERMINED THE FINAL CHOICE. THREE DIFFERENT TUBEWELL TECHNOLOGY PACKAGES WERE EVALUATED BY THE GOVERNMENT AND INTERNATIONAL DONOR AGENCIES IN CONSIDERATION OF THE DEVELOPMENT OF GROUNDWATER-IRRIGATION SCHEMES: HIGH-COST, CAPITAL-INTENSIVE WELLS UTILIZING IMPORTED TECHNOLOGIES AND FOREIGN CONTRACTORS; MEDIUM-COST, COMPLEX TUBEWELLS UTILIZING CAPITAL INTESNIVE, IMPORTED TECHNOLOGIES WITH INSTALLATION BY FOREIGN OR DOMESTIC CONTRACTORS; AND LOW-COST WELLS USING LABOR-INTENSIVE METHODS, ADAPTED TECHNOLOGIES AND SUPPLIES GENERALLY MANUFACTURED OR ASSEMBLED WITHIN THE COUNTRY AND INSTALLED BY DOMESTIC CONTRACTORS. THE AUTHOR EVALUATES THESE ALTERNATIVES AND CHOOSES THE LOW-COST AS BEST, ALTHOUGH THE MEDIUM-COST WAS CHOSEN BY THE GOVERNMENT BASED ON ECONOMIC FACTORS, ALTERNATIVE PERCEPTIONS, AND ORGANIZATIONAL OBJECTIVES.

GROUNDWATER/IRRIGATED AGRICULTURE/ECONOMIC IMPACT/POLITICAL ASPECTS/ INSTITUTIONAL EFFECTS/LINKAGES/BANGLADESH/AGRICULTURE/IRRIGATION WELLS/ DONOR AGENCIES/FOREIGN AID/ECONOMIC DEVELOPMENT/WORLD BANK/PERCEPTIONS

0175

THORNTON, D.W.

1968

THE DEVELOPMENT OF WATER RESOURCES IN LOW INCOME COUNTRIES.

MEDITERRANEA 26:622-233.

A REVIEW OF WATER RESOURCES DEVELOPMENT IN AFGHANISTAN, BOTSWANA, INDIA, PAKISTAN, AND SUDAN IN WHICH METHODS OF EXPLOITATION AND THE ECONOMIC CRITERIA FOR INITIAL INVESTMENT AND FOR OPTIMIZATION OF WATER IN EXISTING SCHMES ARE DISCUSSED. SHORT CASE HISTORIES ARE DEVELOPED ON GOVERNMENT BOREHOLES FOR CATTLE DRINKING IN BOTSWANA, PRIVATE PUMP SCHEMES IN SUDAN AND TUBEWELLS IN PAKISTAN, AND LARGE-SCALE IRRIGATION PROJECTS IN SUDAN. CONCLUDES BY ASKING TO WHAT EXTENT EMPHASIS SHOULD BE PLACED ON WATER DEVELOPMENT. TO ANSWER THIS IT IS USEFUL TO DISTINGUISH BETWEEN 3 SITUATIONS: THOSE AREAS WHERE INCREASED WATER SUPPLIES SEEM TO BE NECESSARY FOR SURVIVAL OF A GROWING POPULATION; THOSE, WHERE IF LIVING STANDARDS ARE TO BE INCREASED, WATER DEVELOPMENT MUST TAKE PRIORITY; AND THOSE WHERE THE DEVELOPMENT OF OTHER RESOURCES MAY BE EQUALLY, OR MORE, EFFECTIVE IN RAISING LIVING STANDARDS. BUT IN ALL THESE COUNTRIES THERE IS AN URGENT NEED FOR MORE CAREFUL PLANNING OF INDIVIDUAL PROJECTS, AND, ASSOCIATED WITH THIS PLANNING, WISE PROGRAMS OF RESOURCE SURVEY AND FIELD EXPERIMENTATION.

WATER RESOURCES DEVELOPMENT/ECONOMIC DEVELOPMENT/IRRIGATION/AGRICULTURE/ GROUNDWATER/STREAMFLOW/PUMPS/WELLS/CANALS/ARID LANDS/LIVESTOCK/BOTSWANA/ AFGHANISTAN/PAKISTAN/INDIA/SUDAN/COST-BENEFIT ANALYSIS/WATER MANAGEMENT(APPLIED)/WATER SHORTAGE

0176

TODD, D.K./MCNULTY, D.O.

1976

POLLUTED GROUNDWATER: A REVIEW OF THE SIGNIFICANT LITERATURE.

WATER INFORMATION CENTER, INC., PORT WASHINGTON, NEW YORK. 179 P.

A REVIEW OF THE LITERATURE ON POLLUTED GROUNDWATER. TOPICS INCLUDE URBAN POLLUTION, INDUSTRIAL POLLUTION, AGRICULTURAL POLLUTION, POLLUTION FROM WELLS, SALT WATER AND SURFACE WATER, POLLUTANTS AND EFFECTS, AND EVALUATING POLLUTION.

GROUNDWATER/WATER POLLUTION/WATER QUALITY/WATER POLLUTION SOURCES/SALINE WATER/ SALINE WATER INTRUSION/NITRATES/DDT/ORGANIC WASTES/FARM WASTES/ WELLS/INJECTION WELLS/RECHARGE WELLS/BACTERIA/HEALTH/MONITORING/RADIOISOTOPES

0177

U.S. ARMY ENGINEER DISTRICT, SAN FRANCISCO, CALIFORNIA

1972

FLOOD PLAIN INFORMATION: GUADALUPE RIVER, SANTA CLARA COUNTY, CALIFORNIA. PREPARED FOR

SANTA CLARA COUNTY FLOOD CONTROL AND WATER DISTRICT. 22 P.

SEE: SWRA W76-08815.

FLOODS/FLOODING/FLOOD FORECASTING/FLOOD PROFILES/FLOODWAYS/FLOOD PLAINS/ SUBSIDENCE/ECONOMIC IMPACT/FLOOD DAMAGE/CALIFORNIA

0178

UNITED NATIONS WATER RESOURCES DEVELOPMENT CENTRE, NEW YORK

1960

LARGE-SCALE GROUND-WATER DEVELOPMENT.

SAME AS AUTHOR, PUBLICATION 60.11.B.3, E/3424-ST/ECA/65. 94 P.

SEE: SWRA W73-07349.

GROUNDWATER/WELLS/WATER WELLS/ARID LANDS/GROUNDWATER AVAILABILITY/ECONOMIC FEASIBILITY/SOCIAL ASPECTS/LEGAL ASPECTS/WATER MANAGEMENT(APPLIED)/DRILLING/ IRRIGATION WELLS

0179

VALERY, N.

1972

WATER MINING TO MAKE THE DESERTS BLOOM.

NEW SCIENTIST 56(819):322-324.

SEE: SWRA W73-04584.

GROUNDWATER/GROUNDWATER MINING/OVERDRAFT/AGRICULTURE/LAND RECLAMATION/ARID LANDS/SALINITY/SOIL-WATER-PLANT RELATIONSHIPS/WATER CONSERVATION/CROP PRODUCTION/WATER RESOURCES DEVELOPMENT/WATER MANAGEMENT(APPLIED)/GROUNDWATER RECHARGE/AGE/SALINE WATER/IRRIGATION WATER/DRAINAGE/RECYCLING/SEWAGE DISPOSAL/ DESALINATION/SEA WATER/WATER TABLE/SEWAGE TREATMENT/DUNES/CLAYS/ADSORPTION

0180

VAN AMELSVOORT, V.

1971

RURAL WATER-SUPPLY DEVELOPMENT AND THE RECENT APPEARANCE OF ENDEMIC GOITER.

TROPICAL AND GEOGRAPHICAL MEDICINE 23:304-305.

ESTIMATIONS OF THE IODINE CONTENT OF THE UNDERGROUND AND SURFACE WATER IN A NIGERIAN VILLAGE SUPPORT THE HYPOTHESIS THAT A CHANGE FROM THE USE OF SURFACE WATER FROM THE RIVER TO THE USE OF UNDERGROUND WELL WATER HAS CAUSED THE RECENT APPEARANCE OF ENDEMIC GOITER. AUTHOR RECOMMENDS THAT WHEN A RURAL WATER DEVELOPMENT SCHEME IS PROPOSED, AN ESTIMATION OF THE IODINE CONTENT OF THE NEW SOURCES SHOULD BE MADE, ESPECIALLY IN REGIONS NEAR THOSE IN WHICH ENDEMIC GOITER HAS BEEN FOUND. (AUTHOR)

GROUNDWATER/WELLS/SURFACE WATERS/NIGERIA/WATER QUALITY/HEALTH/GOITER/IODINE

0181

VAN DER LEEDEN, F. COMP., ED.

1975

WATER RESOURCES OF THE WORLD, SELECTED STATISTICS.

WATER INFORMATION CENTER, INC., PORT WASHINGTON, NEW YORK. 568 P.

A COMPREHENSIVE, STATISTICAL BOOK OF WATER RESOURCES INFORMATION FOR 138 COUNTRIES. DATA ON STREAMFLOW, RUNOFF, GROUNDWATER, WATER USE, IRRIGATION, INDUSTRIAL AND PUBLIC WATER REQUIREMENTS AND WATER USE PROJECTIONS ARE PRESENTED ON A COUNTRY-BY-COUNTRY BASIS. ADDITIONAL DATA IS PRESENTED ON CLIMATES, THE OCEANS, MAJOR RIVERS, LAKES, RESERVOIRS AND DAMS, AVAILABILITY OF HYDROLOGIC INFORMATION, THE WATER SUPPLY SITUATION IN DEVELOPING COUNTRIES, DESALINATION, AND FINANCING OF WATER PROJECTS BY INTERNATIONAL ORGANIZATIONS.

WATER RESOURCES/WATER RESOURCES DEVELOPMENT/GROUNDWATER/STREAMFLOW/ HYDROLOGIC DATA/DESALINATION

0182

WALTON, W.C.

1970

GROUNDWATER RESOURCE EVALUATION.

MCGRAW-HILL BOOK COMPANY, NEW YORK. 664 P.

THIS BOOK, IN ADDITION TO SERVING AS A TEXT FOR GROUNDWATER COURSES, SHOULD AID IN THE SYSTEMATIC APPRAISAL OF GROUNDWATER RESOURCE PROBLEMS BY PRACTICING ENGINEERS AND GEOLOGISTS. INCLUDED ARE BASIC PRINCIPLES OF GROUNDWATER RESOURCE EVALUATION AND THE PRATICAL APPLICATION OF TECHNIQUES TO WELL AND AQUIFER PROBLEMS. ILLUSTRATIVE CASE HISTORIES OF ANALYSES BASED ON ACTUAL FIELD DATA ARE PRESENTED. A COMPILATION OF LITERATURE DEALING WITH GROUNDWATER RESOURCE EVALUATION IS ALSO PROVIDED.

GROUNDWATER RESOURCES/HYDROLOGY/EVALUATION/BIBLIOGRAPHIES

0183

WARREN, J.P. ET AL

1974

COSTS OF LAND SUBSIDENCE DUE TO GROUNDWATER WITHDRAWAL.

TEXAS A AND M UNIVERSITY, COLLEGE STATION, TEXAS WATER RESOURCES INSTITUTE. 79 P.

LAND SURFACE SUBSIDENCE DUE TO GROUNDWATER WITHDRAWAL AFFECTS OVER 3000 SQUARE MILES OF HARRIS CO., TEXAS. AN ANALYSIS OF THE COSTS OF LAND SUBSIDENCE WAS DONE ON 300 SQUARE MILES WITHIN THE AFFECTED AREA. SUBSIDENCE CAUSES FEW DIRECT DAMAGES TO STRUCTURES. ALL DAMAGES AND PROPERTY LOSSES WERE RELATED TO EITHER TIDAL OR FRESHWATER FLOODING. SUBSIDENCE RESULTED IN ESTIMATED PRIVATE DAMAGES OF 60.67 MILLION DOLLARS IN THE STUDY AREA BETWEEN 1943 AND 1973 AND PRIVATE PROPERTY LOSSES OF 48.96 MILLION DOLLARS. TOTAL PUBLIC COSTS WERE CONSERVATIVELY ESTIMATED

AT OVER 4 MILLION DOLLARS. A METHOD IS DEVELLOPED TO PROJECT COSTS RELATED TO SUBSIDENCE INTO THE FUTURE. AN ALTERNATIVE SOURCE OF WATER, SURFACE WATER, IS AVAILABLE TO THE AREA BUT ITS DIRECT COSTS ARE HIGHER THAN THE DIRECT COSTS OF PUMPING GROUNDWATER. THE APPRECIATION OF BREAK-EVEN ANALYSIS, BASED ON CURRENT DIRECT COSTS FOR GROUNDWATER AND SURFACE WATER AND ESTIMATED ANNUAL INDIRECT SUBSIDENCE-RELATED COSTS IMPLIES THAT THE PURCHASE OF ALL OF THE AREA'S RECENT WATER NEEDS FROM THE SURFACE WATER SOURCE WOULD HAVE BEEN ECONOMICALLY JUSTIFIED, EVEN WITH LARGE DIFFERENCES IN DIRECT COSTS.

SUBSIDENCE/ECONOMIC IMPACT/WATER TRANSFER/GROUNDWATER/WELLS/TEXAS

0184

WIDMAN, G.L.

1968

GROUNDWATER - HYDROLOGY AND THE PROBLEM OF COMPETING WELL OWNERS.

ROCKY MOUNTAIN MINERAL LAW INSTITUTE, 14TH, 1968, PAPERS, P. 523-544.

A REVIEW OF HYDROLOGICAL PRINCIPLES IS PROVIDED AS A BASIS FOR THE TITLE PROBLEM, WHICH IS THAT OF PROTECTION OF MEANS OF DIVERSION OF GROUNDWATER (MAINTENANCE OF PUMPING WATER LEVEL). A FURTHER REVIEW OF STATE STATUTORY AND CASE POSITIONS ON SUCH PROTECTION IS GIVEN. FOCUS IS ON UTAH'S PROPERTY VIEW, COLORADO'S ECONOMIC REACH TEST AND THE CONDITIONAL DECREE SOLUTION OF DELAWARE.

GROUNDWATER/HYDROLOGY/WATER LAW/LEGAL ASPECTS/JUDICIAL DECISIONS/WATER RIGHTS/ WATER LEVEL FLUCTUATIONS/UTAH/COLORADO/DELAWARE/WATER ALLOCATION(POLICY)/ DIVERSION/PUMPING/HYDROSTATIC PRESSURE

0185

WILLIAMS, D.E.

1977

THE DASHTE-NAZ GROUND-WATER BARRIER AND RECHARGE PROJECT.

GROUND WATER 15(1):23-31.

SEE: SWRA W77-05365.

SALINE WATER INTRUSION/SALINE WATER/GROUNDWATER/WELLS/PUMPING/IRAN/GROUNDWATER RECHARGE/INJECTION WELLS/GROUNDWATER MINING/ARTIFICIAL RECHARGE/SEDIMENTARY ROCKS

0186

WILLIFORD, G.H./BEATTIE, B.R./LACEWELL, R.D.

1976

THE IMPACT OF THE DECLINING GROUNDWATER SUPPLY IN THE NORTHERN HIGH PLAINS OF TEXAS AND OKLAHOMA ON EXPENDITURES FOR COMMUNITY SERVICES.

TEXAS WATER RESOURCES INSTITUTE, TECHNICAL REPORT 71. 36 P.

REDUCED AVAILABILITY OF GROUNDWATER IN THE NORTHERN HIGH PLAINS OF TEXAS AND OKLAHOMA IS EXPECTED TO HAVE REPERCUSSIONS THROUGHOUT THE REGIONAL ECONOMY DUE TO REDUCTION IN AGRICULTURAL INCOME. THE DECLINE IN ECONOMIC BASE IS EXPECTED TO LEAD TO AN OUT-MIGRATION OF POPULATION. A DECREASE IN POPULATION AND AVAILABLE INCOME WILL RESULT IN REDUCED EXPENDITURES FOR COMMUNITY SERVICES. STUDY ESTABLISHES CONCEPTS FOR THE EMPIRICAL ANALYSIS AND MEASUREMENT OF SERVICE EXPENDITURES. LINEAR MODEL FORMS ARE APPLIED USING A CROSS-SECTIONAL DATA SET TO DEVELOP SERVICE EXPENDITURE FUNCTIONS. PROJECTIONS OF FUTURE EXPENDITURE LEVELS ARE MADE FOR SELECTED COMMUNITY SIZES. TOTAL AND PERCAPITA EXPENDITURES ARE PROJECTED TO INCREASE MORE IN SMALLER COMMUNITIES RELATIVE TO LARGER COMMUNITIES WHICH SUGGEST THE EFFECTS OF A DECLINING GROUNDWATER SUPPLY WILL HAVE A MORE ADVERSE IMPACT ON SMALLER COMMUNITIES.

GROUNDWATER/TEXAS/OKLAHOMA/OGALLALA AQUIFER/AGRICULTURE/IRRIGATION/ECONOMIC IMPACT/MODELS/LINEAR PROGRAMMING/FORECASTING/MIGRATION

0187

YOUNG, R.A.

1970

THE ARIZONA WATER CONTROVERSY: AN ECONOMIST'S VIEW.

ARIZONA ACADEMY OF SCIENCE, JOURNAL 6(1):3-10.

SEE: SWRA W70-08532

ARIZONA/WATER RESOURCES/WATER UTILIZATION/ECONOMICS/WATER POLICY/IMPORTED WATER/WATER SUPPLY/ALTERNATIVE PLANNING/ECONOMIC IMPACT

0188

YOUNG, R.A./MARTIN, W.E.

1967

THE ECONOMICS OF ARIZONA S WATER PROBLEM.

ARIZONA REVIEW 16(3):9-18. SWRA W70-01200.

THE AUTHORS HOLD THAT IN ARIZONA, WHERE PER CAPITA WATER CONSUMPTION RANKS AMONG THE HIGHEST IN THE NATION, THE PRICE SYSTEM SHOULD BE PROPORTIONATE TO ALLOCATION OF THE WATER. AT PRESENT THE ANNUAL WATER DEFICIT WHICH IS MET BY OVERDRAFT OF GROUNDWATER, IS 3.5 MILLION ACRE FEET, AN AMOUNT EQUAL TO THAT CONSUMED BY LOW VALUE EXTENSIVE CROPS. THESE CROPS RANK LOWEST AMONG ECONOMIC ACTIVITIES OF THE STATE IN TERMS OF DOLLARS OF PERSONAL INCOME RETURNED PER ACRE FOOT OF WATER USED. ARIZONA S WATER PROBLEM IS NOT ONE OF PHYSICAL SHORTAGE BUT OF ALLOCATION OF AVAILABLE WATER THOSE ECONOMIC SECTORS THAT WILL MAINTAIN A HIGH RATE OF ECONOMIC GROWTH. THEIR ESTIMATES BASED ON PRESENT PLANS FOR ALLOCATING COLORADO RIVER WATER DIVERTED THROUGH THE PROPOSED CENTRAL ARIZONA PROJECT CAST DOUBT AS TO WHETHER THE PROJECT CAN GENERATE ECONOMIC BENEFITS IN EXCESS OF COSTS OF CONSTRUCTION AND OPERATION. THE FACT THAT SUFFICIENT RESOURCES ARE AVAILABLE TO FINANCE THE PROJECT IS NO MEASURE OF ITS ECONOMIC DESIRABILITY. (OALS)

ECONOMIC DEVELOPMENT/ARIZONA/WATER RESOURCES DEVELOPMENT/OALS

AUTHOR INDEX

ACHI, K. 0001
ACKERMAN, E. 0002
AERO SERVICE CORP., PHILADELPHIA, DIVISION OF LITTON INDUSTRIES 0003
AHMAD, N. 0004
AMIRAN, D.H.K. 0005
ANDERSON, D.V. 0049
ANONYMOUS 0006
ARCHER, T. 0106
ARIZONA TOWN HALL, 10TH, CASTLE HOT SPRINGS, 1967 0007

BAGLEY, E.S. 0008
BAGLEY, J.M. 0009
BAIRD, F.L. 0010
BALMER, G.G. 0060
BARICA, J. 0011
BARKLEY, P.W. 0012
BAUER, R.W. 0013
BEATTIE, B.R. 0186
BEAUMONT, P. 0014
BECKER, R.J. 0015
BEKURE, S. 0016
BENNETT, G.D. 0065
BENNETT, J.W. 0017
BERGER, A.R. 0164
BERINGER, C. 0121
BITTINGER, M.W. 0018
BOKHARI, S.M.H. 0019
BOOKMAN, M. 0020
BOROVSKIY, V.M. 0021
BOWDEN, C. 0022
BOWDEN, L.W. 0023
BRUINGTON, A.E. 0024
BRUNE, G. 0025
BRYAN, K. 0026
BULL, W.B. 0027 0028 0029
BURDAK, T.G. 0030 0107
BURDON, D.J. 0031
BUSCH, C.D. 0110
BUTCHER, L. 0173

CALIFORNIA, DEPARTMENT OF WATER RESOURCES 0032 0033
CASE, C.M. 0049
CASTANY, G. 0034
CASTLEBERRY, J.N., JR. 0035
CHALMERS, J.R. 0036
CHILD, F.C. 0037
CLYMA, W. 0038
COMPTON, R.L. 0039
CONOVER, C.S. 0040

DARLING, F.F. 0041
DAVIS, G.H. 0144 0145
DAVIS, I.F., JR. 0042
DAVIS, P.N. 0043
DAVIS, S.N. 0044 0077
DEE, N. 0045
DEVRIES, R.N. 0046
DITWILER, C.D. 0047
DOBYNS, H.F. 0048
DOMENICO, P. 0112
DOMENICO, P.A. 0049 0050
DOMMEN, A.J. 0051
DORFMAN, R. 0052
DRACUP, J.A. 0067
DUCKSTEIN, L. 0053 0054
DUPNICK, E. 0054

EATON, F.M. 0055
ERICKSON, G.H. 0105

FARVAR, M.A. 0041
FINKEL, H. 0056
FOGEL, M.M. 0110
FREEMAN, V.M. 0057
FRIEDMAN, A.E. 0058

GARLAND, J.G. 0163
GHAFFAR, M. 0091
GINDLER, B.J. 0059
GLOVER, R.E. 0060
GOTSCH, C.H. 0061
GRACY, D.B. 0062
GREEN, D.E. 0063
GREEN, J.H. 0064 0146
GREENMAN, D.W. 0065
GRUBB, H.W. 0066
GUM, R. 0114

HALL, W.A. 0067
HARGREAVES, G.H. 0068
HARMAN, W.L. 0081
HARRISON CHURCH, R.J. 0069
HARSHBARGER, J.W. 0070
HARTMAN, L.M. 0071
HEADY, H.F. 0072

HEINDL, L. 0073
HELWEG, O.J. 0074
HENNIGHAUSEN, F.H. 0075
HOCK, K.J. 0076
HOGG, T.C. 0160
HOLBURT, M.B. 0059
HOLLOWAY, M. 0131
HOLZER, T.L. 0077
HOOD, J.W. 0078
HOSKIN, G.K. 0079
HOWE, C.W. 0080
HUGHES, W.F. 0081 0082

ISKANDAR, W. 0083

JENKINS, C.T. 0084
JENTSCH, C. 0085
JONES, L.L. 0086 0087 0095
JUDD, B.I. ET AL. 0088

KAHANA, Y. 0089
KAM, W. 0090
KANEDA, H. 0037 0091
KASHEF, A.-A.I. 0092
KELSO, M.M. 0093
KISIEL, C.C. 0053
KLAUSING, R.L. 0099
KLEPPER, R. 0152
KOMIE, E.E. 0094

LACEWELL, R.D. 0095 0186
LAL, D. 0096
LARSON, J. 0086
LOEF, G. 0002
LOF, G. 0097
LOFGREN, B.E. 0098 0099

MACK, L.E. 0093 0100
MAGEE, A.C. 0082
MAHONEY, F. 0101
MALMBERG, G.T. 0102
MANDEL, S. 0103 0104
MARGAT, J. 0034
MARTIN, W.A. 0105
MARTIN, W.E. 0093 0106 0107
0108 0188

MATLOCK, W.G. 0109 0110
MAXEY, G.B. 0050 0111 0112
MCCAULEY, C.A. 0113 0114
MCNULTY, D.O. 0176
MECKELEIN, W. 0115
MERO, F. 0104
MEYER, W.R. 0116
MILLER, R.E. 0028
MILNE, C. 0117
MOHAMMAD, G. 0118 0119 0120
0121
MOORE, C.V. 0122 0123
MOORE, J.E. 0124
MOORTI, T.V. 0125
MOSES, R.J. 0126
MUNDORFF, M.J. 0127

NACE, R.L. 0128
NULTY, L. 0129

ORTIZ, I.S. 0130
OSBORN, J.E. 0095 0131
OSTERHOUDT, F.H. 0132
OTTAWAY, D.B. 0133

PADFIELD, H.I. 0161
PASHLEY, E.F., JR. 0134
PETERSON, D.F. 0135 0136
PICARD, L. 0137
PIFER, J. 0138
POLAND, J.F. 0139 0140 0141
0142 0143 0144 0145 0146 0156
POLAND, T.F. 0029

QUINN, F. 0147

RAHN, P.H. 0148
REVELLE, R. 0052 0149
ROHDY, D.D. ET AL 0150
ROLL, J.R. 0151

SANGHI, A.K. 0152
SCHAMP, H. 0153
SCHMORAK, S. 0154
SCHRAMM, G. 0155
SCHUMANN, H.H. 0156
SHEAHAN, N.T. 0157
SIMPSON, E. 0158
SKIBITZKE, H.E. 0159
SKIDMORE, J. 0164
SMITH, C.L. 0160 0161
SMITH, R.E. 0010
SNYDER, J.H. 0122 0162
STEELHAMMER, R.H. 0163
STEPHENSON, D.A. 0050
STOW, D.A.V. 0164
STRAAYER, J.A. 0165
STULTS, H.M. 0166
SWARZENSKI, W.V. 0065
SYNDER, J.H. 0123

TALBOT, L.M. 0167 0168
THEIS, C.V. 0169 0170 0171 0172
THOMAS, H. 0052 0173
THOMAS, J.W. 0174
THORNTON, D.W. 0175
TODD, D.K. 0176

U.S. ARMY ENGINEER DISTRICT, SAN FRANCISCO, CALIFORNIA 0177
UNITED NATIONS WATER RESOURCES DEVELOPMENT CENTRE, NEW YORK 0178

VALERY, N. 0179
VAN AMELSVOORT, V. 0180
VAN DER LEEDEN, F. 0181

WALKER, M. 0131
WALTON, W.C. 0182
WARREN, J. 0087
WARREN, J.P. 0183
WIDMAN, G.L. 0184
WILLIAMS, D.E. 0185
WILLIFORD, G.H. 0186
WOOD, L.A. 0124

YOUNG, R.A. 0038 0107 0108 0187 0188

KEYWORD INDEX

ADAPTATION 0041
ADJUDICATION 0020
ADMINISTRATION 0002 0121 0149
ADMINISTRATIVE AGENCIES 0020
ADMINISTRATIVE DECISIONS 0056
ADSORPTION 0179
AFGHANISTAN 0175
AGE 0179
AGRICULTURAL CREDIT 0149
AGRICULTURAL RESEARCH 0149
AGRICULTURAL USE OF WATER 0007 0042
AGRICULTURE 0023 0030 0051 0052 0061 0069 0076 0091 0093 0095 0100 0108 0118 0119 0120 0129 0135 0138 0162 0166 0174 0175 0179 0186
AID 0003 0069 0168
AIR POLLUTION 0015
ALFALFA 0138
ALGERIA 0001
ALLOCATION 0016
ALTERNATIVE PLANNING 0045 0187
ANALOG MODELS 0107 0124 0158
ANALOG SIMULATION 0076
ANALYTICAL TECHNIQUES 0061 0084 0091
APPROPRIATE TECHNOLOGY 0051
AQUICLUDES 0117
AQUIFER CHARACTERISTICS 0046
AQUIFER MANAGEMENT 0103
AQUIFERS 0020 0024 0027 0028 0029 0031 0034 0046 0050 0053 0069 0089 0103 0104 0110 0117 0121 0124 0130 0139 0140 0143 0145 0149 0150 0154 0157 0158 0169 0170 0173
ARABIAN DESERT 0041 0072
ARABLE LAND 0102 0127
ARCHEOLOGY 0017
ARID LANDS 0005 0011 0012 0021 0022 0023 0027 0028 0029 0030 0031 0040 0044 0048 0050 0059 0062 0067 0073 0085 0089 0094 0098 0101 0103 0107 0108 0112 0113 0114 0122 0123 0134 0135 0136 0138 0143 0145 0146 0151 0154 0158 0162 0166 0167 0175 0178 0179
ARIZONA 0013 0015 0019 0026 0030 0036 0038 0048 0054 0076 0088 0093 0100 0106 0108 0113 0114 0134 0138 0142 0156 0159 0160 0165 0166 0187 0188
ARTESIAN AQUIFERS 0025
ARTESIAN WELLS 0001 0025 0027 0028 0029 0064 0075 0078 0098 0099 0105 0130 0139 0140 0143 0144 0145 0146 0170 0171
ARTIFICIAL RECHARGE 0042 0057 0059 0089 0092 0141 0185
ARTIFICIAL RECHARGE MANAGEMENT 0158
ASSESSMENTS 0020
ATACAMA 0070
ATMOSPHERE 0097

BACTERIA 0176
BANGLADESH 0118 0174
BASINS 0111
BEHAVIOR 0010 0017
BENEFICIARIES 0160
BENEFITS 0160
BIBLIOGRAPHIES 0022 0032 0036 0053 0164 0168 0182
BIOLOGICAL CONTROLS 0005
BOTSWANA 0175
BRACKISH WATER 0127
BRAZIL, NORTHEASTERN 0068
BULLOCKS 0119

CALCIUM 0055
CALIFORNIA 0027 0028 0029 0032 0033 0036 0039 0047 0057 0098 0099 0117 0122 0123 0140 0142 0143 0145 0146 0151 0162 0177
CANALS 0004 0052 0118 0120 0121 0149 0175
CAPILLARY ACTION 0021
CARRYING CAPACITY 0041
CATCHMENTS 0003 0057
CATTLE 0013
CENTRAL ARIZONA PROJECT 0108 0113
CENTRIFUGAL PUMPS 0004
CHLORIDE 0078 0104
CITRUS FRUITS 0138
CLAYS 0179
CLIMATE 0038 0168
CLIMATIC CHANGE 0026
CLIMATIC DATA 0088
COALS 0022
COASTAL PLAINS 0110 0117
COASTS 0033
COLORADO 0012 0023 0036 0084 0124 0150 0184
COLORADO RIVER BASIN 0022
COMMON-POOL PROBLEM 0058
COMPACTION 0099 0142
COMPENSATION 0079
COMPETING USES 0036 0054 0076 0094

COMPETITION 0009
COMPUTER PROGRAMS 0046
COMPUTERS 0089 0157
CONJUNCTIVE USE 0007 0036
CONNECTICUT 0148
CONSERVATION 0015
CONSTRUCTION COSTS 0024
CORN 0152
COST-BENEFIT ANALYSIS 0003 0020 0059 0068 0071 0121 0160 0175
COSTS 0003 0015 0042 0062 0087 0106 0112 0118 0119 0121 0149 0162 0166
COTTON 0119 0138
CREDIT 0118
CROP PRODUCTION 0005 0007 0016 0030 0052 0076 0082 0091 0095 0096 0100 0118 0119 0121 0125 0129 0131 0135 0138 0149 0150 0166 0179
CROP RESPONSE 0152
CROP YIELDS 0052 0091 0121 0149
CROPPING PATTERNS 0051 0091 0119
CROPS 0004 0061 0091 0119 0159
CULTIVATED LANDS 0062 0082
CULTIVATION 0091
CULTURAL ASPECTS 0160 0161

DAKHLA OASIS 0115
DAMS 0057
DARCY'S LAW 0044 0110
DATA COLLECTIONS 0158
DATES 0001
DDT 0176
DEATH 0088
DELAWARE 0184
DESALINATION 0014 0019 0057 0103 0179 0181
DESERTIFICATION 0109 0115 0133
DESERTS 0021 0070 0111 0112 0136 0153 0158
DEVELOPING COUNTRIES 0003 0019 0125 0164
DEVELOPMENT POLICY 0061
DIGITAL COMPUTERS 0116
DISCHARGE(WATER) 0025 0154 0170 0171
DIVERSION 0007 0079 0184
DONOR AGENCIES 0174
DRAINAGE 0001 0004 0019 0021 0052 0055 0065 0068 0102 0120 0121 0127 0149 0159 0179
DRAINAGE PATTERNS 0090 0111
DRAINAGE PRACTICES 0031
DRAINAGE WELLS 0135
DRAINS 0119
DRAWDOWN 0060 0107 0117 0124 0149
DRILLING 0003 0126 0178

DROUGHTS 0069 0072 0073 0088 0133
DRY FARMING 0063 0096 0131 0150
DUNES 0179
DYNAMIC PROGRAMMING 0053

EAST AFRICA 0167 0168
ECOLOGY 0015 0017 0053 0136 0168
ECONOMIC ASPECTS 0019 0160
ECONOMIC DEVELOPMENT 0001 0003 0013 0019 0023 0037 0041 0052 0061 0072 0080 0091 0101 0118 0121 0129 0135 0149 0153 0155 0161 0174 0175 0188
ECONOMIC FEASIBILITY 0138 0178
ECONOMIC IMPACT 0016 0018 0023 0030 0039 0041 0047 0052 0058 0061 0063 0066 0067 0071 0076 0081 0082 0086 0087 0091 0095 0096 0100 0103 0107 0108 0113 0114 0121 0122 0123 0125 0129 0131 0132 0135 0149 0150 0151 0152 0162 0166 0174 0177 0183 0186 0187
ECONOMIC JUSTIFICATION 0053
ECONOMICS 0007 0012 0015 0020 0040 0049 0053 0059 0066 0068 0076 0093 0100 0112 0168 0187
ECOSYSTEMS 0136
EDUCATION 0121
EGYPT 0070 0115 0153
ELECTRIC WELL LOGGING 0154
ELECTRICITY 0118
ENERGY 0022
ENERGY CONVERSION 0022
ENVIRONMENT 0076
ENVIRONMENTAL EFFECTS 0005 0011 0022 0038 0041 0045 0072 0073 0136 0168
ENVIRONMENTAL IMPACT 0015 0069 0167
EVALUATION 0042 0093 0158 0182
EVAPORATION 0005 0023 0074 0097 0102
EVAPOTRANSPIRATION 0031 0074
EXHAUSTIBLE RESOURCES 0058
EXPLOITATION 0031
EXTERNALITIES 0058

FARM WASTES 0176
FAULTS(GEOLOGY) 0117 0137
FEDERAL GOVERNMENT 0006
FEDERAL JURISDICTION 0126
FERTILIZERS 0052 0091 0096 0118 0119 0121 0125 0129 0149

FLOOD CONTROL 0002 0020
FLOOD DAMAGE 0177
FLOOD FORECASTING 0177
FLOOD PLAINS 0177
FLOOD PROFILES 0177
FLOODING 0177
FLOODS 0015 0136 0177
FLOODWAYS 0177
FLOW 0111
FLOW RATES 0042
FORAGES 0130
FORECASTING 0132 0186
FOREIGN AID 0174

GEOHYDROLOGY 0158
GEOLOGIC MAPS 0003
GEOLOGIC STRUCTURES 0137
GEOLOGY 0025
GEOTHERMAL STUDIES 0022
GOITER 0180
GOSSYPIUM 0005 0076
GOVERNMENT 0013 0056
GRAZING 0041 0072 0136
GREAT BASIN 0111
GREAT PLAINS 0022
GREEN REVOLUTION 0037 0091
0129
GROUNDWATER 0001 0002 0004
0005 0006 0007 0008 0010 0011
0012 0016 0018 0019 0021 0023
0025 0026 0027 0028 0029 0030
0031 0032 0033 0034 0035 0036
0038 0039 0040 0042 0043 0044
0046 0047 0048 0050 0051 0053
0055 0057 0058 0059 0060 0062
0063 0064 0065 0066 0067 0068
0070 0071 0073 0074 0075 0076
0077 0078 0079 0081 0082 0083
0084 0085 0086 0087 0089 0091
0094 0095 0096 0097 0098 0099
0100 0102 0104 0105 0107 0109
0110 0112 0113 0114 0116 0118
0119 0120 0121 0122 0123 0124
0125 0126 0127 0128 0129 0130
0131 0132 0133 0135 0136 0137
0138 0139 0140 0141 0142 0143
0145 0146 0148 0149 0151 0152
0154 0156 0157 0158 0159 0162
0163 0164 0165 0166 0169 0170
0171 0172 0173 0174 0175 0176
0178 0179 0180 0181 0183 0184
0185 0186
GROUNDWATER AVAILABILITY 0178
GROUNDWATER BARRIERS 0020 0024
0117
GROUNDWATER BASINS 0049 0068
0111 0116 0126 0138 0150 0153
GROUNDWATER LAW 0035
GROUNDWATER MANAGEMENT 0008
0010 0018 0020 0034 0067 0071
0089 0171

GROUNDWATER MINING 0004 0008
0010 0036 0038 0040 0043 0049
0053 0054 0058 0067 0068 0075
0077 0079 0081 0082 0083 0094
0103 0106 0107 0110 0112 0116
0124 0135 0138 0152 0156 0157
0165 0171 0173 0179 0185
GROUNDWATER MOVEMENT 0025 0043
0044 0046 0110 0111 0154
GROUNDWATER PUMPING 0092
GROUNDWATER QUALITY 0067
GROUNDWATER RECHARGE 0004 0011
0024 0034 0053 0105 0110 0112
0122 0123 0132 0136 0138 0158
0171 0179 0185
GROUNDWATER RESOURCES 0073
0182
GROUNDWATER TECHNOLOGY 0137
GROUNDWATER-SURFACE WATER
RELATIONSHIPS 0060
GULLY EROSION 0090
GYPSUM 0055 0120

HEALTH 0176 0180
HISTORY 0025 0026 0062 0121
0128 0137 0159
HUMAN DISEASES 0041
HUMAN RESOURCES 0017
HUMANS 0168
HYDROELECTRIC POWER 0136
HYDROGEOLOGY 0003 0025 0034
0040 0044 0070 0073 0099 0111
0112 0117 0158
HYDROLOGIC BUDGET 0102 0110
0158
HYDROLOGIC CYCLE 0056
HYDROLOGIC DATA 0073 0084 0107
0181
HYDROLOGIC PROPERTIES 0021
HYDROLOGY 0043 0124 0149 0158
0182 0184
HYDROSTATIC PRESSURE 0079 0184

IMPORTED WATER 0187
INCRUSTATION 0004
INDIA 0051 0096 0125 0175
INDIANS OF NORTH AMERICA 0013
INDUS BASIN 0052 0055 0065
0070 0102 0119 0120 0121 0127
0149
INDUSTRIAL USE 0097
INDUSTRY 0037
INFILTRATION 0148 0172
INJECTION 0117
INJECTION WELLS 0006 0024 0057
0144 0157 0176 0185
INPUT-OUTPUT ANALYSIS 0053

INSTITUTIONAL ASPECTS 0048
0067 0129 0155
INSTITUTIONAL CONSTRAINTS 0008
0042 0071
INSTITUTIONAL EFFECTS 0034
0174
INSTITUTIONS 0161
INTER-BASIN TRANSFERS 0107
0122 0123 0147
INTERSTATE 0126
IODINE 0180
IRAN 0041 0185
IRRIGATED AGRICULTURE 0066
0082 0083 0100 0131 0152 0174
IRRIGATED LAND 0021
IRRIGATION 0002 0004 0009 0011
0023 0030 0038 0052 0061 0063
0080 0093 0095 0096 0098 0099
0108 0110 0113 0118 0120 0121
0125 0131 0132 0134 0135 0136
0139 0140 0143 0145 0146 0159
0166 0175 0186
IRRIGATION CANALS 0019 0065
0069 0102 0105 0127
IRRIGATION DISTRICTS 0138
IRRIGATION EFFECTS 0001 0008
0021 0038 0044 0063 0065 0074
0082 0119 0125 0127 0129 0149
0150 0152
IRRIGATION PRACTICES 0001 0004
0005 0021 0031 0042 0062 0069
0074 0091 0096 0107 0119 0120
0121 0125 0129 0131 0135 0138
0149 0150 0166
IRRIGATION PROGRAMS 0003 0069
0150 0153
IRRIGATION SYSTEMS 0085
IRRIGATION WATER 0036 0038
0042 0055 0065 0068 0102 0106
0125 0179
IRRIGATION WELLS 0010 0028
0051 0063 0082 0091 0110 0119
0120 0124 0128 0138 0141 0162
0174 0178
ISRAEL 0104 0135 0137 0154

JUDICIAL DECISIONS 0079 0184

KALAHARI 0160
KHARGA OASIS 0115 0153

LAND APPRAISALS 0042
LAND MANAGEMENT 0005 0100
LAND RECLAMATION 0055 0065
0102 0115 0120 0127 0153 0179
LAND RESOURCES 0015 0168
LAND USE 0003 0005 0015 0052
0076 0091 0096 0100 0119 0120
0121 0129 0149 0168

LEACHING 0120
LEGAL ASPECTS 0008 0018 0023
0036 0039 0042 0043 0046 0047
0056 0058 0059 0067 0105 0112
0123 0126 0138 0163 0165 0178
0184
LEGISLATION 0008 0056
LINEAR PROGRAMMING 0016 0166
0186
LINKAGES 0120 0174
LIVESTOCK 0003 0007 0013 0041
0069 0072 0149 0168 0175
LOUISIANA 0142
LOWER MEKONG RIVER SCHEME 0161

MAIZE 0119
MALI 0069
MANAGEMENT 0007 0042 0046
MAPS 0003
MARICOPA COUNTY 0076
MATHEMATICAL ANALYSIS 0053
MATHEMATICAL MODELS 0049 0053
0054 0060 0061 0076 0084 0091
0150 0169 0172
MEIGS SA13 0076
METROPOLITAN WATER DISTRICT
0161
MEXICO 0110 0116 0130 0155
MIDDLE ASIA 0041
MIDDLE EAST 0014
MIGRATION 0186
MINING 0162
MISSOURI RIVER 0022
MODEL STUDIES 0042 0046
MODELS 0016 0018 0023 0030
0032 0050 0067 0074 0087 0100
0112 0116 0149 0150 0157 0166
0186
MOJAVE DESERT 0162
MONITORING 0154 0176
MORTALITY 0088

NATURAL RECHARGE 0024 0040
0117 0124
NATURAL RESOURCES 0015 0058
0168
NAVIGATION 0080 0136
NEVADA 0036 0050 0111 0142
NEW MEXICO 0036 0075 0078 0116
0132
NIGER 0003 0069 0133
NIGERIA 0180
NITRATES 0176
NOMADS 0003 0041 0069 0072
0101 0133
NUCLEAR ENERGY 0022
NUCLEAR WASTES 0022
NUMERICAL ANALYSIS 0053

OASES 0153
OBSERVATION WELLS 0154
OGALLALA AQUIFER 0012 0016
0063 0066 0095 0131 0186
OIL 0039 0163
OIL FIELDS 0072
OIL SHALES 0022
OKLAHOMA 0046 0095 0186
OPERATING COSTS 0024
OPERATIONS RESEARCH 0053
OPPORTUNITY COST 0058
OPTIMIZATION 0058
OPTIMUM DEVELOPMENT PLANS 0049
0053
ORGANIC WASTES 0176
ORYZA 0005
OVERDRAFT 0007 0020 0042 0047
0094 0103 0110 0126 0162 0179
OVERGRAZING 0026 0133 0167
OVERLYING PROPRIETOR 0008 0020

PACIFIC NORTHWEST 0160
PAKISTAN 0004 0019 0037 0052
0055 0061 0065 0070 0091 0102
0118 0119 0120 0121 0127 0129
0135 0149 0175
PALMS 0001
PAPAGO INDIAN RESERVATION 0013
0048
PAPAGOS 0048
PASTURES 0069
PERCEPTIONS 0174
PERCOLATION 0163
PERTURBATION 0015
PERU 0005
PERUVIAN DESERT 0005 0070
PESTICIDES 0005
PESTS(INSECTS) 0005
PHORADENDRON 0088
PHREATOPHYTES 0026 0105
PIEZOMETRIC LEVEL 0024
PINAL COUNTY 0088 0113 0114
0134 0156 0166
PIT RECHARGE 0024 0117
PLANNING 0045 0076 0168
PLANT COMMUNITIES 0026
PLANT COVER 0026
PLANT POPULATIONS 0088
POLICY 0012
POLITICAL ASPECTS 0002 0010
0041 0047 0071 0129 0149 0155
0165 0174
POLLUTANT IDENTIFICATION 0006
POLLUTION 0015
POPULATIONS 0014
POTABLE WATER 0085
POTATOES 0138
PRECIPITATION(ATMOSPHERIC)
0124
PRIOR APPROPRIATION 0036
PRODUCTION FUNCTION 0091 0152
PRODUCTIVITY 0149

PROPERTY RIGHTS 0058
PROPERTY VALUES 0059
PROSOPIS JULIFLORA 0088
PUBLIC RIGHTS 0008 0071
PUMPING 0004 0028 0030 0033
0036 0042 0044 0055 0059 0068
0081 0098 0099 0104 0106 0107
0112 0118 0119 0121 0124 0126
0130 0138 0140 0148 0149 0150
0152 0159 0166 0169 0170 0172
0173 0184 0185
PUMPS 0175
PUNJAB 0061 0065 0102 0118
0119 0121 0149

RADIOISOTOPES 0176
RAINFALL 0057
RANGE MANAGEMENT 0101 0167
0168
RANGES 0168
REASONABLE USE 0036 0043 0094
RECHARGE 0042 0092 0154 0170
0173
RECHARGE WELLS 0092 0122 0123
0176
RECLAMATION 0057
RECYCLING 0179
REGIONAL ANALYSIS 0005 0061
REGIONAL GEOGRAPHY 0072
REGRESSION ANALYSIS 0091
REGULATION 0071
RESEARCH AND DEVELOPMENT 0158
RESERVOIRS 0005 0057
RESOURCES 0005
REVELLE REPORT 0004 0120 0121
REVIEWS 0006 0053
RICE 0119
RIPARIAN RIGHTS 0062
RIPARIAN VEGETATION 0026
RIVER BASINS 0136
ROCKY MOUNTAIN REGION 0022
RUNOFF 0002 0149

SAFE YIELD 0049 0103 0104
SAHARA 0001 0041 0070 0083
0153
SAHELIAN ZONE 0002 0069 0133
SALINAS VALLEY 0123
SALINE SOILS 0021 0031 0055
0065 0074 0102 0115 0127 0149
SALINE WATER 0004 0005 0021
0052 0055 0059 0065 0074 0092
0102 0104 0110 0118 0120 0127
0157 0173 0176 0179 0185
SALINE WATER INTRUSION 0011
0020 0024 0032 0033 0047 0055
0059 0065 0067 0075 0078 0092
0110 0117 0120 0122 0123 0128
0135 0154 0157 0173 0176 0185

SALINE WATER-FRESHWATER INTERFACES
0011 0032 0092 0154
SALINE WATERS 0031
SALINITY 0001 0004 0005 0011
0019 0021 0031 0032 0038 0052
0055 0059 0065 0072 0074 0085
0102 0104 0121 0127 0136 0149
0179
SALINITY CONTROL AND RECLAMATION
PROJECT 1 0019
SALT BALANCE 0021
SALT RIVER PROJECT 0160 0161
SALT RIVER VALLEY 0038 0159
SALTS 0011 0021 0074
SAN PEDRO VALLEY 0026
SAND DUNES 0115
SANTA CRUZ RIVER BASIN 0026
SAUDI ARABIA 0072
SCARP 1 0052
SEA WATER 0002 0097 0179
SECHURA DESERT 0005
SEDIMENT YIELD 0109
SEDIMENTARY ROCKS 0185
SEMIARID CLIMATE 0031 0040
0073
SENEGAL 0069
SETTLEMENTS 0041 0072
SEWAGE DISPOSAL 0179
SEWAGE EFFLUENT 0105
SEWAGE TREATMENT 0179
SHALLOW WELLS 0003
SOCIAL ASPECTS 0001 0010 0015
0017 0022 0023 0038 0041 0046
0048 0059 0063 0072 0073 0085
0096 0103 0136 0153 0178
SOCIAL ORGANIZATION 0013 0017
0161
SOCIOECONOMIC RESEARCH 0149
SODIUM 0052 0120
SOIL CHEMICAL PROPERTIES 0021
SOIL PHYSICAL PROPERTIES 0021
SOIL-WATER-PLANT RELATIONSHIPS
0096 0179
SOILS 0021 0149
SOMALIA 0101
SONORA 0026 0110
SONORAN DESERT 0013 0048 0106
SORGHUM 0096
SOUTHWEST U.S. 0008 0022 0026
0036 0147
SPRING WATERS 0025
SPRINGS 0025 0044 0104
SPRINKLER IRRIGATION 0068
STATE JURISDICTION 0126
STOCK WATER 0031
STORAGE 0040 0089
STORAGE COEFFICIENT 0064 0169
0170 0172
STREAMFLOW 0018 0026 0035 0043
0057 0060 0084 0105 0124 0148
0172 0175 0181
STREAMS 0043 0060
STRIP MINE WASTES 0022
STRIP MINES 0022
SUBSIDENCE 0027 0028 0029 0039
0050 0064 0067 0077 0086 0087
0090 0094 0098 0099 0103 0113
0114 0130 0134 0139 0140 0141
0142 0143 0144 0145 0146 0151
0156 0163 0177 0183
SUBSURFACE MAPPING 0158
SUBSURFACE WATERS 0008 0042
0071 0079 0124
SUDAN 0083 0175
SUGAR CANE 0096 0119
SURFACE IMPORTATION 0057
SURFACE WATER IMPORTATION 0108
SURFACE WATERS 0004 0019 0038
0052 0057 0060 0068 0084 0087
0105 0109 0120 0124 0126 0148
0159 0180
SURFACE-GROUNDWATER RELATIONSHIPS
0006 0018 0035 0036 0040 0043
0084 0103 0105 0124 0148 0159
0172
SURVEYS 0085
SYSTEMS ANALYSIS 0053 0089

TECHNOLOGY 0002 0037 0097 0136
TENNESSEE VALLEY AUTHORITY
0161
TEST WELLS 0043
TEXAS 0010 0025 0035 0036 0062
0063 0066 0081 0082 0086 0087
0095 0116 0131 0142 0163 0183
0186
THEORETICAL ANALYSIS 0042
TIMING 0152
TOPOGRAPHY 0085 0168
TRANSMISSIVITY 0110 0169 0170
0172
TRANSPORTATION 0002
TREES 0088
TUBEWELLS 0004 0051 0052 0061
0091 0102 0118 0119 0120 0121
0125 0127 0129 0149
TUCSON 0165
TUNISIA 0173
TURBINE PUMPS 0004

UNDERGROUND STORAGE 0094
UNIT COST 0024
UPPER VOLTA 0069
URBAN AREAS 0014
URBAN PLANNING 0076
URBANIZATION 0007
USSR 0021
UTAH 0036 0184

VEGETATION 0026 0038 0044 0109
0168
VEGETATION CHANGE 0026

WASTE WATER DISPOSAL 0135
WATER ALLOCATION(POLICY) 0007
0014 0022 0043 0056 0069 0149
0184
WATER BALANCE 0102 0104 0127
WATER BUDGET 0149
WATER CHEMISTRY 0032 0111
WATER CONSERVATION 0005 0007
0015 0094 0105 0179
WATER CONSUMPTION 0009 0034
WATER CONTROL 0085
WATER COSTS 0007 0054 0076
0125 0138 0152
WATER DELIVERY 0085
WATER DEMAND 0002 0007 0022
0089 0097 0107
WATER DISTRIBUTION 0009 0085
WATER LAW 0008 0018 0036 0043
0046 0056 0058 0059 0105 0126
0184
WATER LEVEL DECLINES 0116
WATER LEVEL FLUCTUATIONS 0008
0010 0033 0079 0110 0184
WATER LEVELS 0088 0110 0140
0154 0169
WATER MANAGEMENT 0005 0036
0070 0093 0111 0150 0168
WATER MANAGEMENT(APPLIED) 0006
0012 0017 0019 0035 0040 0042
0045 0047 0049 0053 0056 0073
0080 0092 0103 0104 0107 0112
0117 0135 0149 0155 0160 0161
0171 0175 0178 0179
WATER MEASUREMENT 0043
WATER POLICY 0056 0135 0158
0171 0187
WATER POLLUTION 0011 0015 0128
0148 0176
WATER POLLUTION SOURCES 0006
0176
WATER QUALITY 0002 0004 0011
0022 0024 0031 0032 0038 0044
0065 0073 0074 0075 0076 0078
0083 0094 0102 0123 0127 0135
0148 0157 0176 0180
WATER QUALITY CONTROL 0006
WATER REQUIREMENTS 0119 0149
0152
WATER RESOURCES 0015 0038 0089
0093 0168 0181 0187
WATER RESOURCES DEVELOPMENT
0001 0002 0003 0005 0006 0014
0017 0019 0031 0036 0038 0045
0056 0057 0062 0068 0069 0070
0072 0073 0080 0101 0108 0109
0118 0128 0135 0136 0147 0149
0150 0153 0155 0160 0161 0167
0168 0175 0179 0181 0188
WATER RESOURCES PLANNING 0094
0158

WATER REUSE 0024 0057 0097
0105 0157
WATER RIGHTS 0008 0036 0043
0054 0056 0058 0059 0071 0079
0105 0112 0163 0184
WATER SHORTAGE 0022 0063 0073
0093 0108 0126 0175
WATER SOURCES 0003 0005 0025
0069 0128
WATER SPREADING 0072
WATER STORAGE 0069 0101 0158
0169 0170
WATER SUPPLY 0002 0007 0014
0016 0025 0038 0042 0054 0057
0062 0066 0073 0076 0081 0093
0097 0100 0116 0129 0147 0165
0167 0187
WATER TABLE 0001 0004 0007
0008 0016 0026 0042 0052 0055
0065 0076 0077 0078 0088 0102
0118 0121 0127 0132 0138 0141
0149 0158 0169 0170 0171 0179
WATER TRANSFER 0019 0029 0038
0086 0098 0113 0143 0147 0151
0183
WATER USERS 0094 0136
WATER UTILIZATION 0002 0016
0038 0054 0069 0071 0076 0079
0128 0187
WATER WELLS 0062 0141 0178
WATER YIELD 0007 0049 0093
0112
WATERLOGGING 0004 0019 0052
0055 0121 0149 0159
WATERSHED MANAGEMENT 0089 0101
0105
WELL CASINGS 0024
WELL SCREENS 0024
WELLS 0003 0004 0023 0028 0032
0035 0040 0042 0043 0044 0048
0050 0057 0060 0061 0068 0069
0072 0084 0091 0092 0096 0101
0102 0104 0105 0107 0114 0115
0118 0120 0124 0125 0127 0133
0135 0138 0148 0151 0153 0156
0157 0167 0169 0171 0172 0173
0175 0176 0178 0180 0183 0185
WELLTON-MOHAWK IRRIGATION DISTRICT
0019
WEST AFRICA 0069
WEST U.S. 0070
WESTERN DESERT 0153
WHEAT 0119
WILDLIFE 0072 0168
WITHDRAWAL 0008 0016 0027 0028
0029 0034 0035 0039 0049 0050
0052 0079 0082 0086 0087 0098
0099 0103 0113 0114 0130 0138
0139 0140 0141 0142 0144 0145
0151 0157 0162 0163 0169 0170
WORLD BANK 0174

ZONING 0076