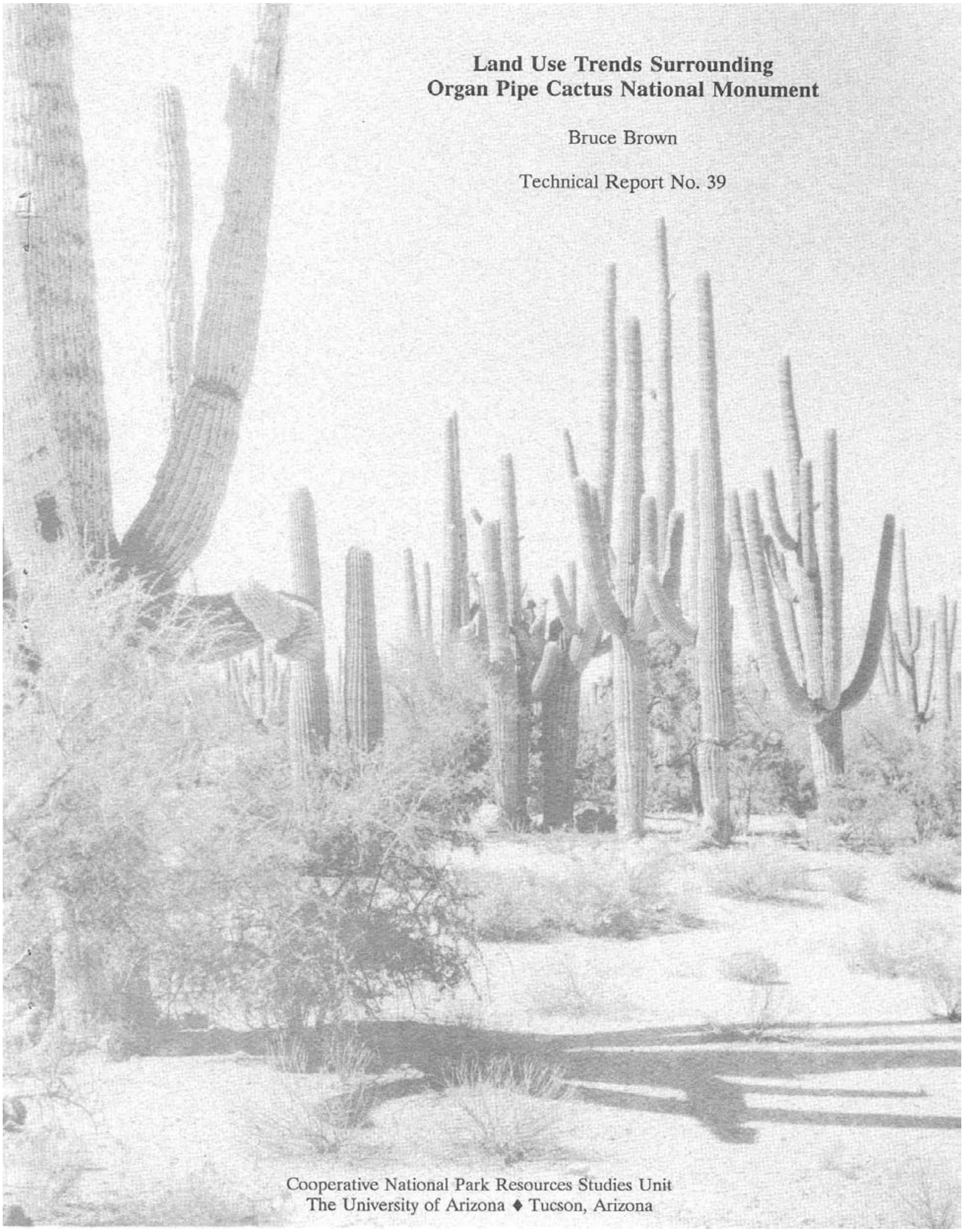

Land Use Trends Surrounding Organ Pipe Cactus National Monument

Bruce Brown

Technical Report No. 39

Cooperative National Park Resources Studies Unit
The University of Arizona ♦ Tucson, Arizona

COOPERATIVE NATIONAL PARK RESOURCES STUDIES UNIT

The University of Arizona, Tucson

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Land Use Trends Surrounding Organ Pipe Cactus National Monument

Bruce Brown

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EXECUTIVE SUMMARY

Organ Pipe Cactus National Monument (ORPI) is situated in southern Arizona, near the geographical center of the Sonoran Desert. The northern boundary of ORPI begins approximately 20 mi south of the town of Ajo and extends south to the border with Mexico, a distance of about 25 mi. The monument encompasses a total area of 333,779 a.

Although ORPI is adequately protected by law, there is continued concern about protecting and preserving the fragile desert biota. The monument is actively collecting information and data through several research programs and projects, with one of the largest being the Sensitive Ecosystems Program (SEP).

The present study, entitled "Land Use Trends Surrounding Organ Pipe Cactus National Monument," is one of nineteen (19) research efforts within SEP and is concerned with agricultural development in the Sonoyta Valley and its impact on the monument. The Sonoyta Valley aquifer is a common water resource shared by the United States and Mexico. The southern portion of ORPI forms part of the Rio Sonoyta watershed as well as the northern portion of the groundwater aquifer.

The Mexican portion of the Sonoyta Valley is a prime site for agricultural development. Over 30,000 a had been developed for irrigated agriculture in the valley by the end of 1987. A considerable number of wells have been drilled to provide irrigation water for these lands. The Mexican Government has invested in transportation and electrical infrastructure as well as in the administration of credit, production, and marketing programs to provide critical assistance for local farmers.

A large proportion of the irrigated lands is adjacent to the southern boundary of ORPI, which has raised concerns about possible effects on the flora and fauna of the monument. A primary concern is that continued or increased pumping in Mexico may lower the groundwater table and also reduce hydrostatic pressure at certain locations within ORPI, such as Quitobaquito, Burro and Williams springs. Another concern is the intrusion of agricultural chemicals into the monument through air drift and transportation by insects.

These concerns have made it evident that the use of resources outside of ORPI influence the methods of managing the resources within the monument. The present research is a first step in this process and has the following overall objective:

> Assess and quantify land use changes occurring in the Sonoyta Valley.

Irrigated agriculture, on a large scale, is relatively new to the Sonoyta Valley and consisted primarily of cattle ranching and subsistence farming as late as the early 1960s.
In 1966, the Mexican Government began a limited-scale program to encourage and subsidize development of land and water resources throughout northern Sonora including the Sonoyta Valley. This program is administered by the Secretaría de Agricultura y Recursos Hidráulicos (SARH) located in Sonoyta.

By 1968, a total of 45 wells were reported, of which 12 were irrigation wells equipped with pumps. This number increased to a total of 112 wells, with 41 equipped for irrigation by 1973. In 1977, a total of 10,441 a had been developed and were being irrigated from 71 irrigation wells. A 1982 census of water and land resources reported 155 active agricultural wells serving 19,975 a. Total cropped acreage increased steadily up to 1981 when approximately 20,000 a were in production. Farmed acreage and the number of wells have remained relatively constant since 1982.

Cotton, wheat, and alfalfa have traditionally occupied 80 to 90% of the total cropped acreage. In recent years, pasture and fruits have almost doubled in area, from 10 to 20% of the total, and are becoming more important crops in the valley.

The most widely grown crop in 1987-88 was wheat, which occupied 44% of the 22,455 irrigated acres in production. Percentages of the total area for other major crop acreages in 1987-88 were cotton, 16%; ryegrass, 9%; sesame, 8%; alfalfa, 7%; and fruit trees, 6%. The other 20% consists of vegetables, barley, sorghum, and assorted tree crops.

Land ownership in the Sonoyta Valley is divided between cooperative farms having a formally organized structure, called ejidos, and private ownership. Ownership of the agricultural lands in the Sonoyta Valley is about 50% private and 50% ejidos.

Production inputs such as seeds, fertilizers, and pesticides are programmed and purchased through the SARH organization. Permits to drill and operate irrigation wells are also obtained through SARH. A staff of agronomists and agricultural engineers from SARH and the Bancorural provide technical advice and support for all farms, as well as crop monitoring. Information gathered by the technical staff includes: crop growth stage; yield; insect, disease, and weed infestations along with recommended control measures; irrigation schedules and application amounts; potential for improvement of irrigation systems; and financial data for budgeting purposes.

Groundwater withdrawals were approximately equal to recharge in 1978 and began to exceed groundwater recharge in 1979. Although net depletion of the aquifer has steadily increased since 1979 to a maximum level of 55,025 acre-feet (a-ft) in 1987, the cropped area has remained relatively constant since 1981. The Mexican Government is fully aware of the overdraft situation of the aquifer and has placed a moratorium on the drilling of new wells.

At the beginning of 1988, SARH listed a total of 212 wells in the Sonoyta Valley, with 165 being used for irrigation. A moratorium is presently in effect which prohibits the development of new wells for irrigation.

Total pumping capacity and 1987-88 water withdrawals were also estimated by SARH to be 217,166 gallons per minute (gpm) and 83,152 a-ft, respectively. Total annual pumping capacity in the Sonoyta Valley is estimated to be 191,000 a-ft based on an average annual use of 200 days/year by all pumps. This is more than twice the rate of groundwater withdrawals for 1987-88.

A moratorium is also currently in effect to limit the land developed for irrigated agriculture to the present 32,000 a. Approximately 20,000 a are currently being farmed, which is 60 to 70% of the total developed area. Lands developed for irrigation are also in excess of the area currently being used for irrigated agriculture.

Although moratoriums are currently in effect, a considerable increase in groundwater withdrawals could occur without the development of new water and land resources due to the existing excess capacity in pumping and developed agricultural lands. Nevertheless, under existing conditions, annual groundwater withdrawals will still be approximately 2.5 times the annual rate of recharge and the depth to water will continue to increase in the near future. Development of new agricultural lands and further development of water resources is highly dependent upon governmental funding of expansion programs.

Four different methods are recommended to monitor agricultural development in the Sonoyta Valley. The first method is based on establishing photo points that cover the agricultural area by comparing photographs from different periods in time to detect changes.

The second method is to take photographs of the agricultural area from the air. Again, the procedure is to compare photographs taken at different points in time and identify changing trends.

The third method is to rely on the annual data collected by SARH which reports crops, acreages and water volumes withdrawn for agriculture.

The fourth method is to compute the amount of water withdrawn for agricultural purposes based upon electrical consumption, pumping lifts, and pump system efficiencies.

An indirect effect of agricultural development activities in the Sonoyta Valley is the increasing amount of light pollution impacting the viewscape from ORPI. Light pollution impacts on ORPI consist of urban sky glow and light trespass. Most of the urban sky glow is emitted from the Town of Sonoyta, while lesser amounts originate from Lukeville and rural areas on both the east and west sides of the Sonoyta Valley.

Sources of most light trespass are inconsequential and cause only minor annoyance to nighttime viewing in ORPI. Light trespass is very minor at present but could increase, especially if the border crossing goes to a 24-hour schedule.

It is recommended that ORPI personnel maintain a working relationship with the SARH office in Sonoyta. Through this relationship it will be possible to:

1. obtain annual data on land and water use.
2. obtain annual electrical and water depth information.
3. estimate water withdrawals from SARH estimates and calculations using the energy consumption method.

It is also recommended that ORPI personnel continue with the monitoring protocol developed in the Monitoring Handbook for the agricultural and light pollution photo points. The agricultural photo points will provide visual information to support quantity estimates of land and water use. The light pollution photo points will document impacts and provide support to resulting calculations of impacts.

Efforts expended in completing the results presented in this report have involved two areas outside of the scope of work that could be highly productive and are recommended for future research activities. The first area involves improvements in monitoring the groundwater aquifer and the second area centers on enhancing the precision of measuring agricultural lands.

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ACKNOWLEDGEMENTS

The Great Western Research study team consisted of F. Bruce Brown, Principal Investigator, and Harold L. Payne, Agronomist. These individuals wish to express their appreciation to the staff at Organ Pipe Cactus National Monument for their timely assistance in conducting this study.

Much of the content for this study is based on information supplied by the Secretaría de Agricultura y Recursos Hidráulicos located in Sonoyta, Mexico. We wish to thank the professionals in that organization for their willingness and patience in preparing our numerous requests for data.

ABSTRACT

This study is concerned with agricultural development in the Sonoyta Valley and its impact on the Organ Pipe Cactus National Monument (ORPI). The Sonoyta Valley is a common water resource shared by the U.S. and Mexico, and parallels the southern boundary of ORPI.

At the beginning of 1988, there was a total of 212 wells in the Sonoyta Valley with 165 wells being used to irrigate 22,455 a. Total annual pumping capacity in the Sonoyta Valley is estimated to be 191,000 a-ft and total developed lands approximate 33,000 a. Annual groundwater recharge is estimated to be 28,135 a-ft/year and 1987-88 water withdrawals approximated 83,160 a-ft. Net depletion of the aquifer has steadily increased since 1979, reaching the largest difference of 55,025 a-ft in 1987, while the cropped area has remained relatively constant since 1981, around 22,000 a.

Moratoriums are currently in effect that prohibit additional development of land and water resources in the valley. However, a considerable increase in groundwater withdrawals could occur without the development of new water and land resources due to the existing excess capacity in installed pumping plants and developed agricultural lands.

An indirect effect of agricultural development activities in the Sonoyta Valley is the increasing amount of light pollution impacting the viewscape from ORPI. Sources of most light trespass are inconsequential and cause only minor annoyance to nighttime viewing at the present time.

STUDY OVERVIEW

INTRODUCTION

Organ Pipe Cactus National Monument (ORPI) is situated in southern Arizona, near the geographical center of the Sonoran Desert. The northern boundary of ORPI begins approximately 20 mi south of the town of Ajo and extends south to the border with Mexico, a distance of about 25 mi. The monument encompasses a total area of 333,779 a.

In 1976, ORPI was proclaimed a Biosphere Reserve as an outstanding representative of the Sonoran Desert ecosystem under the United Nations Educational, Scientific, and Cultural Organization (UNESCO) Man and the Biosphere Program. Increased protection was provided for the ecological communities in ORPI in 1978 when 312,000 a were granted wilderness status.

Although ORPI is adequately protected by law, there is continued concern about protecting and preserving the fragile desert biota. The monument is actively collecting information and data through several research programs and projects, with one of the largest being the Sensitive Ecosystems Program (SEP), of which this study was a part.

The SEP is designed to: (1) inventory elements of ORPI resources where data are insufficient; (2) complete studies in progress; and (3) initiate new research. A principal objective of SEP is to develop methodologies, tools, and step-by-step instructions for long-term monitoring of resources and key ecological parameters. Final monitoring protocols are to be suitable for future use by resource managers in identifying problems before serious or irreversible deterioration occurs as well as providing information to develop plans of mitigation. The present land use study presented in this report is one of nineteen (19) research efforts within SEP.

STUDY OBJECTIVES

The Rio Sonoyta aquifer is a common water resource shared by the U.S. and Mexico. The southern portion of ORPI forms part of the Rio Sonoyta watershed as well as the northern portion of the groundwater aquifer.

The Mexican portion of the Sonoyta Valley is a prime site for agricultural development. Approximately 30,000 a had been developed for irrigated agriculture in the valley by the end of 1987. A considerable number of wells have been drilled to provide irrigation water for these lands. The Mexican government has invested in transportation and electrical infrastructure as well as in the administration of credit, production, and marketing programs to provide critical assistance for local farmers.

Development of the agricultural resources has stimulated economic growth in the town of Sonoyta and throughout the Sonoyta Valley. This agricultural-based growth has been a positive force in the economy of northern Sonora.

A large proportion of the irrigated lands in the Sonoyta Valley is adjacent to the southern boundary of ORPI, which has raised concerns about the possible effects on the flora and fauna of the monument. A primary concern is that continued or increased pumping in Mexico may lower the groundwater table and also reduce hydrostatic pressure at certain locations within ORPI such as Quitobaquito, Burro and Williams springs. Another concern is the intrusion of agricultural chemicals into the monument through air drift and transportation by insects.

These concerns have made it evident that the use of resources outside of ORPI influences the methods of managing the resources within the monument. The present research has the overall objective of assessing and quantifying land use changes occurring in the Sonoyta Valley. Information and procedures developed through this project will be useful in monitoring and protecting the natural resources of the monument. The overall objective of this project is accomplished through achieving the following eight specific objectives.

1. Determine total acreage currently under production in the Rio Sonoyta Valley within a 10-mi radius of the monument's southern boundary (See "Past and Present Agricultural Development").

2. Estimate the current cropping pattern and acreage of each crop within the study area (See "Past and Present Agricultural Development").

3. Estimate the annual volume of water being withdrawn for irrigation (See "Past and Present Agricultural Water Use").

4. Determine the past and present land usage in the valley, and project future trends (See "Past and Present Agricultural Development" and "Projected Future Agricultural Development").

5. Document major factors that have stimulated agricultural development in the valley (See 'Projected Future Agricultural Development").

6. Identify factors that appear to support continued development in the valley (See "Projected Future Agricultural Development").

7. Document the impact of light pollution on the nighttime viewscape from the monument (See "Light Pollution").

8. Establish photo points to monitor land use changes along the southern boundary of the monument (See "Monitoring Future Agricultural Development" and "Light Pollution").

This report consists of seven major sections as outlined in the Table of Contents. "Study Overview" provides an introduction to the scope of work, sections on "Past and Present Agricultural Development" through "Light Pollution" present technical data, analyses and procedures, and "Conclusions and Recommendations" contains the results of the study.

In addition, a bibliography is included at the end of the report followed by Appendices 1 and 2. Appendix 1 is a list of contacts made during the course of completing this project and

Appendix 2 contains data pertaining to the amounts and types of agricultural chemicals applied in the Sonoyta Valley for recent cropping seasons. The final report is available in both English and Spanish.

PAST AND PRESENT AGRICULTURAL DEVELOPMENT

STUDY AREA

At the outset of this research effort, the study area was to include all lands located in Mexico within a 10-mi radius of the southern ORPI boundary, approximately 400 mi^2 (256,000 a). This area includes the majority of agricultural lands in the Sonoyta Valley with the exception of approximately 50 mi^2 located adjacent to the extreme eastern portion of the study area.

It became apparent, early in the research effort, that available agricultural data pertained to the entire Sonoyta Valley and could not be easily disaggregated to coincide with the 400 mi^2 study area. Therefore, the study area was expanded to include the additional lands in the eastern portion of the valley. As a result, the gross study area approximates 450 mi^2 (288,000 a) and is shown on Figure 1.

At the end of 1987, just over 30,000 a had been developed for irrigated agriculture in the valley. This is slightly more than 10% of the gross study area. The progress of agricultural development within the Sonoyta Valley is described in the following paragraphs.

HISTORICAL AGRICULTURAL DEVELOPMENT IN THE SONOYTA VALLEY

The Sonoyta Valley is located in the northern part of the State of Sonora. The valley parallels the U.S.-Mexican border and extends along the entire southern boundary of ORPI with additional extensions on both sides of the monument. The total length of the valley is approximately 45 mi and varies from 4 to 10 mi in width. The principal commercial center is the town of Sonoyta, located along the Sonoyta River opposite the U.S. border town of Lukeville, Arizona. The Sonoyta River flows intermittently throughout the valley and discharges into the Sea of Cortez near Puerto Peñasco, approximately 60 mi southwest of Sonoyta.

The community of Sonoyta is located near the center of the valley with an estimated population of 15,000 people in January 1988. The town is served by a major highway, Mexico Federal Highway 2, which connects Sonoyta with Caborca from the south and with San Luis, Río Colorado, on the west. Paved roads also extend from Sonoyta to Puerto Peñasco towards the southwest, and to the agricultural areas in the eastern portion of the valley.

A municipal airport with a paved runway facilitates air service to the community. Electric power, telephone service, a hospital, television, and other modern conveniences are available in the area. Schools, churches, businesses and social groups have been organized to meet the needs of the community.

Valley topography varies from nearly level to moderately steep. Soil textures are predominantly medium- to fine-textured and are suitable for nearly all crops. Water quality varies from excellent in the eastern part of the valley to moderately saline and highly saline and unsuitable in

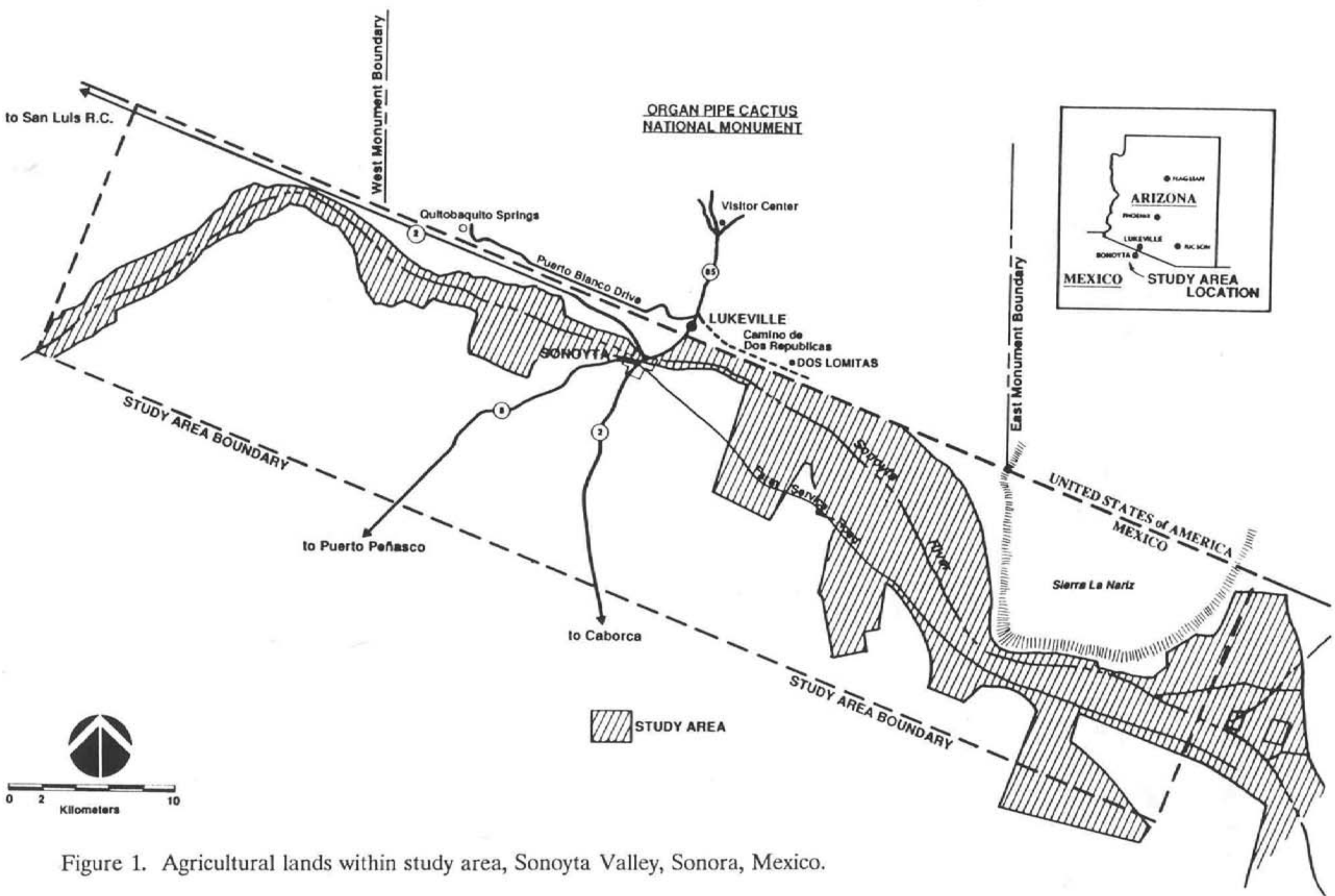

Figure 1. Agricultural lands within study area, Sonoyta Valley, Sonora, Mexico.

the western part. Accumulations of harmful salts occur in some areas, especially where fine-textured soils are irrigated with moderate and/or highly saline water sources.

Rapid and severe erosion is occurring along much of the river banks throughout the Sonoyta Valley. Apparently, a large portion of this erosion has occurred within the lifetime of the older residents of the area. Information indicates that the level of the riverbed was almost at the same elevation as the town-site and flooding was a common occurrence. At the highway bridge in downtown Sonoyta, the riverbed now lies about 15 ft below the surrounding land surface.

The climate is ideally suited to a wide variety of crops that could be produced under year-round cropping rotations. Winter temperatures are mild and favorable for most cool-season crops. Summers are typical of the Sonoran Desert, with midday temperatures exceeding 38°C (100°F) and nighttime temperatures around 25°C (in the upper 70s). The average annual temperature is 21°C (70°F). Rainfall is low, 201 mm (7.9 in.) per year with the majority occurring in the months of August and January. The evaporation rate measured at Quitovac is 2,953 mm (116 in.) per year (Técnicas Modernas de Ingeniería, S.A. 1982).

Irrigated agriculture, on a large scale, is relatively new to the Sonoyta Valley. Agricultural activities in the Sonoyta Valley consisted primarily of cattle ranching and subsistence farming as late as the early 1960s. The only lands actively farmed were located adjacent to the stream banks and irrigated from sporadic flows in the Sonoyta River. Lack of water storage facilities and distribution systems limited the irrigated area to about 250 a. Crop production was primarily for subsistence of local residents who also maintained small areas of pasture lands for livestock.

The first deep wells were installed in 1952 east of the town of Sonoyta. Development of groundwater resources progressed slowly throughout the 1950s and early 1960s as local landowners had to rely upon their own resources to install irrigation and livestock wells (Técnicas Modernas de Ingeniería, S.A. 1982).

In 1966, the Mexican government began a limited-scale program to encourage and subsidize development of land and water resources throughout northern Sonora including the Sonoyta Valley. By 1968, a total of 45 wells was reported, of which 12 were irrigation wells equipped with pumps (Técnicas Modernas de Ingeniería, S.A. 1982).

Government support of agricultural development greatly increased in the early 1970s. Well-drilling activities intensified with a new infrastructure of supporting services for agriculture including technical advice and assistance, financial credit, crop insurance, and direct subsidies for well drilling and development of irrigation systems. By 1973, a total of 112 wells had been drilled and 41 were equipped with irrigation pumps (Técnicas Modernas de Ingeniería, S.A. 1982).

In 1977, a total of 10,411 a had been developed and were being irrigated from 71 irrigation wells in the Sonoyta Valley. An additional 32 wells were under construction at that time and an estimated 1,826 families were direct beneficiaries of the irrigation infrastructure and related government support programs implemented in the valley to promote agricultural development (Técnicas Modernas de Ingeniería, S.A. 1982).

A 1982 census of water and land resources reported 125 active agricultural wells serving 25,700 a (Técnicas Modernas de Ingeniería, S.A. 1982). However, expansion of irrigated acreage decreased to almost a standstill during this same year primarily due to the devaluation of the peso. Many agricultural loans came into default and agricultural development ceased, in contrast to its rapid expansion during the proceeding 10 years.

Another disincentive to expansion during this same period related to cotton, one of the leading crops. The area planted to cotton had grown from 3,650 a in 1977 to 12,800 a in 1983. During 1983, the crop suffered a severe infestation of Southwest Cotton Rust disease, along with the introduction of several new types of insects which continue to persist. Cotton acreage rapidly declined to 1,062 a by 1985. Wheat, pasture and other crops have taken the place of cotton and total farmed acreage has remained about the same up to the present time.

Annual reports showing acreage planted to each crop are kept by the Secretaría de Agricultura y Recursos Hidráulicos (SARH) in Sonoyta. An 11-year record (1977 to 1988) of the types of crops and associated acreages in the Sonoyta Valley is shown in Table 1. Total cropped acreage increased steadily until 1981 when approximately 20,000 a were in production. Farmed acreage and the numbers of wells have remained relatively constant since 1982.

HISTORICAL CROPPING PATTERN

The cropped acreage of the Sonoyta Valley has been historically dominated by three major crops: cotton, wheat and alfalfa. The percentage of total cropped acreage occupied by these crops is shown in Figure 2 along with pasture and fruit. Cotton, wheat, and alfalfa have traditionally occupied 80 to 90% of the total cropped acreage. However, in recent years, pasture and fruits have almost doubled in area, from 10 to 20% of the total, and are becoming more important crops in the valley.

Approximately two-thirds of the entire acreage was devoted to cotton prior to 1984. There were several reasons for the predominance of this single crop. One important factor was the favorable climate. Cotton requires a long growing season with a high number of heat units for maximum production. The frost-free period in the Sonoyta Valley is about 250 days in length and is conducive to full-season production and high yields.

Second is the relatively low labor requirements and adaptability of the crop to mechanization. This permits large acreages to be farmed with moderate levels of capitalization and labor as compared to vegetable and fruit crops.

Third, cotton enjoyed a period of favorable market prices in the late 1970s and early 1980s which made it an economically attractive crop, particularly in the irrigated areas having inexpensive water sources such as Sonoyta.

Table 1. Cropping pattern in total acres, Sonoyta Valley, 1977-78 to 1987-88.

CROPS	1977-78	1978-79	1979-80	1980-81	1981-82	1982-83	1983-84	1984-85	1985-86	1986-87	1987-88
Wheat	603	1,250	860	2,505	5,483	5,256	526	5,550	10,302	10,619	10,176
Sesame	608	210	37	126	855	788	289	430	1,356	1,729	-
Cotton	3,651	4,824	8,321	10,463	8,707	8,598	12,814	7,207	1,062	2,067	3,483
Cartano	395	173	-	-	-	-	-	-	-	-	-
Beans	-	15	141	127	291	42	62	467	2,265	96	124
Corn	-	111	301	79	645	40	170	193	262	450	445
Alfalfa	662	692	1,502	1,993	2,806	2,453	2,598	1,739	1,363	1,694	1,531
Vegetables	-	-	67	158	262	170	62	447	217	200	153
Vineyard	5	128	225	-	-	-	-	-	-	57	12
Fruit	40	44	44	888	1,578	2,556	2,939	2,369	1,783	1,598	1,529
Forrage	-	-	-	72	37	5	40	64	-	430	-
Sorghum	-	-	-	-	-	-	-	82	-	336	309
Pasture	-	-	-	-	-	-	-	-	874	953	2,964
TOTAL	5,356	7,845	11,671	16,322	19,935	19,975	19,999	18,407	18,558	19,856	22,455

Source: Secretaría de Agricultura y Recursos Hidráulicos.

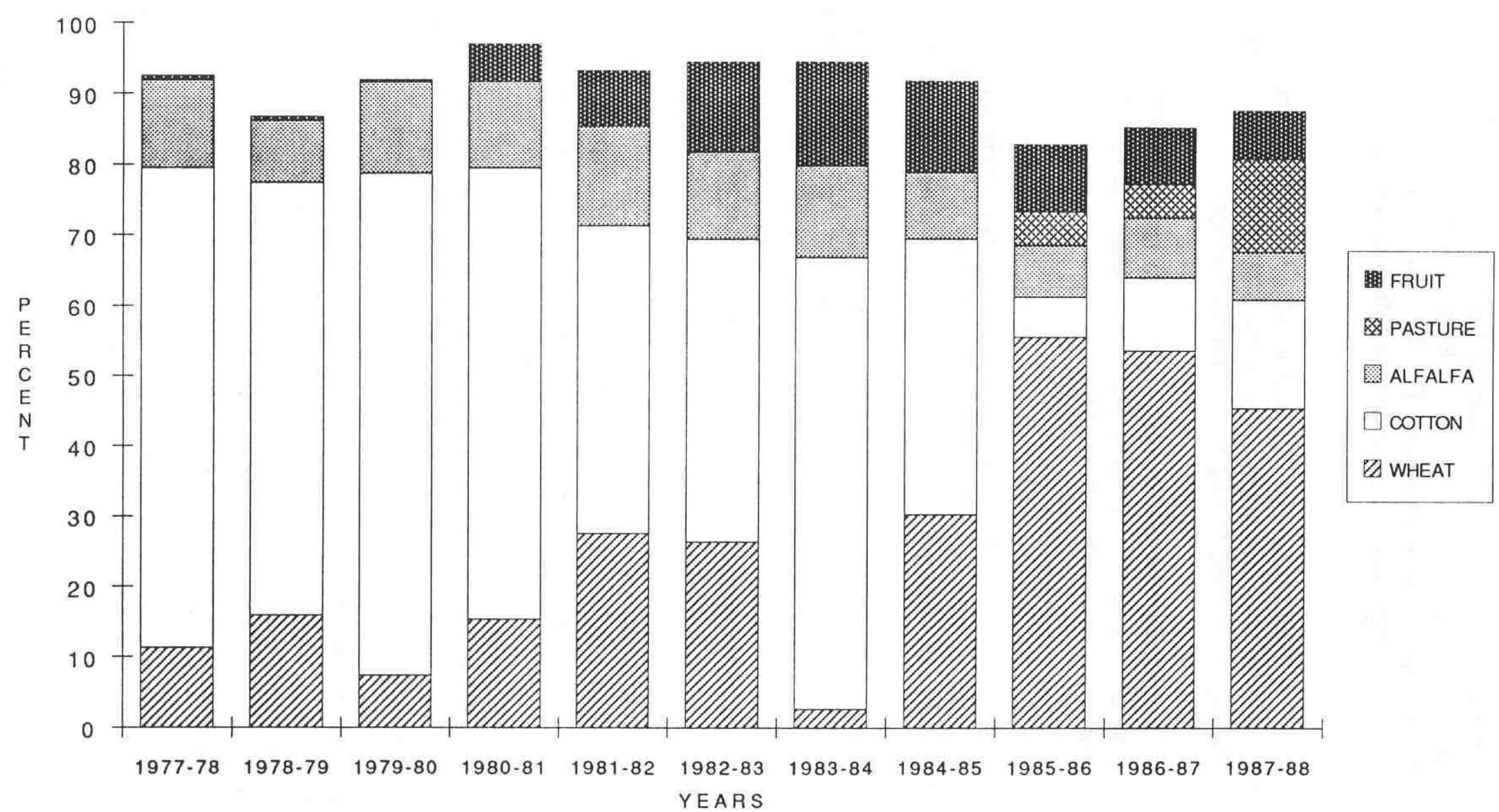

Figure 2. Land use of selected crops, Sonoyta Valley, Mexico.

Fourth, cotton is a nonperishable crop and allows much more flexibility in production, storage and marketing. Combined, these factors presented a favorable set of economic and physical circumstances in creating a favorable environment for the production of cotton throughout northern Sonora prior to the cotton rust infestation of 1983.

Similar factors have encouraged the production of wheat and alfalfa in the Sonoyta Valley. Favorable climate, inexpensive water sources, good agricultural soils, low labor requirements, nonperishability, and the need to establish a crop rotation to enhance cotton production have all been determining factors in the number of acres devoted to these two crops. As cotton acreage dramatically decreased after 1983, wheat and pasture have been most commonly planted as replacement crops on these acreages.

The 10 to 15% of total cropped acreage not devoted to cotton, wheat, and alfalfa has been planted to a wide variety of other crops (See Table 1). The most important of these crops are fruit trees. Peaches and apples dominate the orchard plantings and currently occupy 1,352 a (90%) of a total 1,517 a. These orchards are mostly young and just coming into production. Many were planted between 1980 and 1984 and are not yet bearing to their full potential. There are also 116 a of olive trees and 12 a of grapes that have been grouped into the orchard category. All together, this category comprises about 10% of the total agricultural acreage.

Sesame has been grown for some time in the Sonoyta Valley and occupied 1,729 a in 1987, approximately 8% of the total acres in production. Sesame is an oilseed crop and the product is shipped to an oil press for processing and extraction of a high-quality cooking oil. Strong demand and high prices for unsaturated oils in the world market have attributed to expansion of sesame acreage in recent years.

The traditional crops of beans and corn have historically occupied only about 4% of the total cropped acreage. These two crops have occupied about the same number of acres over the 11-year history under consideration and account for only a small portion of the total irrigated area, with the exception of 1985-86. In this year, over 2,000 a were planted into beans, which accounted for 12% of the total acreage in agricultural production that season.

Vegetables have increased in acreage from 44 a to approximately 200 a since 1983. Although this area is not a large percentage of the total acreage, it is significant in that vegetable crops represent a use of water for higher-valued crops requiring larger inputs of capital, labor, and management. This could indicate the beginning of a natural change of cropping patterns toward the higher-valued and more labor intensive crops as water becomes more scarce and increasingly expensive.

PRESENT CROPPING PATTERN

The cropping pattern for the 1987-88 season is presented in Table 2 along with the five-and ten-year averages. The most widely grown crop in 1987-88 was wheat, which occupied 44% of the total 22,455 irrigated acres in the valley. Percentages of the total area for other major crop

Table 2. Comparison of historical and present cropping trends, in acres, Sonoyta Valley, Mexico.

CROPS	10-YEAR AVERAGE	PERCENT	5-YEAR AVERAGE	PERCENT	1987-88	PERCENT
Wheat	5,253	30.0	7,435	37.4	10,176	45.3
Sesame	643	3.7	918	4.6	1,729	7.7
Cotton	6,755	38.6	5,327	26.8	3,483	15.5
Safflower	17	0.1	-	-	-	-
Beans	363	2.1	603	3.0	124	0.6
Corn	270	1.5	304	1.5	445	2.0
Alfalfa	1,837	10.5	1,785	9.0	1,531	6.8
Vegetables	174	1.0	216	1.1	153	0.7
Vineyard	42	0.2	14	0.1	12	0.1
Fruit	1,533	8.8	2,044	10.3	1,529	6.8
Forage	65	0.4	107	0.5	-	-
Sorghum	73	0.4	145	0.7	309	1.4
Pasture	479	2.7	958	4.8	2,964	13.2
TOTAL	17,502	100.0	19,855	100.0	22,455	100.0

Source: Secretaría de Agricultura y Recursos Hidráulicos, Sonoyta, Sonora.

acreages in 1987-88 were cotton, 16%; ryegrass, 9%; sesame, 8%; alfalfa, 7%; and fruit trees, 6%. The other 10% consisted of vegetables, barley, sorghum, and assorted tree crops.

The shift in recent years from cotton to wheat and pasture can readily be seen in Figure 3, where the five- and ten-year averages are compared to the 1987-88 distribution. The most noticeable trend is the steady decrease in cotton acreage paralleling the steady increase in wheat acreage.

Substantial attention has been given to the potential for increasing apple and peach production. A packing shed for processing and shipping fruit was built in 1984. Another shed is scheduled to be built in the near future and a significant acreage of young peach and apple trees, which are not yet in full production, is being cultivated.

Interest in vegetable production has increased in recent years. Soil, climate, and water quality are all favorable for vegetable production in the Sonoyta Valley. However, developing a marketing structure and transporting perishable crops to distant markets have been major obstacles overshadowing the expansion of vegetable acreage. Some interest has been shown by vegetable producers in Arizona, as a few have been actively working with local growers to provide technical assistance and marketing development. The area has a geographical advantage over the rest of Sonora for export of produce to the United States due to its proximity to the border. Although several obstacles must be overcome, an excellent potential does exist for a sizeable vegetable industry in the Sonoyta Valley.

PAST AND PRESENT AGRICULTURAL WATER USE

HISTORICAL AGRICULTURAL WATER USE

Prior to the use of deep well turbine pumps, agricultural water use was limited to direct diversion from the Rio Sonoyta into canals serving adjacent lands. Irrigated areas were small and production was consumed in the local area.

Due to the ephemeral nature of the Rio Sonoyta, surface irrigation was quite limited and shallow wells were used to tap the groundwater resources. However, the primary use of wells during the period prior to the 1960s was to satisfy domestic and livestock needs.

Technology and equipment capable of pumping large volumes of water were developed in the 1940s and began to be used to tap the large groundwater resources beneath the Sonoyta Valley sometime in the 1960s. Development of the existing well field correlates closely with governmental programs facilitating expansion of irrigation in the area. Such a close correlation is, as expected, due to the immediate capital requirements and the time-lagged accrual of benefits characteristic of irrigation developments. Drilling deep wells and equipping them with pumps and motors requires a large investment of capital during the construction phase, while benefits typically do not begin until several years into the production of irrigated crops. Once government funding became readily available, landowners and cooperative farms (ejidos) were able to begin drilling wells and developing irrigation systems for large tracts of land.

Figure 3. Cropping trend comparisons, Sonoyta Valley, Mexico.

The land area developed for irrigation, number of wells, pumping capacity, and annual volume of groundwater withdrawn at several points in time over the past 20 years is shown in Table 3. The rapid development of the well field and agricultural lands in the late 1970s can readily be seen.

It has been estimated that the average annual surface flow of the Rio Sonoyta passing the gaging station at the Sonoyta Bridge is 11,340 a-ft/year (Técnicas Modernas de Ingeniería, S.A. 1982). An additional 28,135 a-ft/year are estimated to be recharging the groundwater aquifer from the river. These estimates are based upon an average 7.9 in. annual rainfall over the 5,000 mi[1] of the Rio Sonoyta watershed minus evaporation losses and consumptive use by vegetation.

It was noted by SARH that water levels in many wells measured during their annual well inventories of 1982 and 1983 had risen significantly. This was attributed to unseasonably high levels of winter rainfall and higher than normal river flows during these two years. Based on these and other observations, it appears that the amount of effective groundwater recharge in the Sonoyta Valley is closely correlated to rainfall quantities and recharge occurs rather quickly.

Table 3. Historically irrigated acreage, pumping capacity number of wells and groundwater pumpage, for selected years, Sonoyta Valley, Mexico.

YEAR	IRRIGATED AREA (acres)	NUMBER OF WELLS (Total/ Irrigation)	PUMPING CAPACITY (gallons per minute)	ACTUAL PUMPAGE (acre-feet)
1973	NA	112/71	14,465	7,938
1977	10,411	201/41	NA	NA
1978	7,845	209/NA	71,200	59,940
1981	19,935	260/155	189,745	104,733
1982	19,975	290/155	213,203	81,000
1983	19,999	290/155	213,203	81,000

Source: Técnicas Modernas de Ingeniería, S.A. (1982); Secretaría de Agricultura y Recursos Hidráulicos (1978, 1986).

The irrigated acreage and water withdrawals estimated by SARH for the past 10 years is shown in Table 4. Based on the calculations in the table, groundwater withdrawals were approximately equal to recharge in 1978 and began to exceed groundwater recharge in 1979. Although net depletion of the aquifer has steadily increased since 1979 to a maximum level of 55,025 a-ft in 1987, the cropped area has remained relatively constant since 1981. This can be explained by the shift of large acreages from cotton to crops using moderately lower amounts of water, such as wheat and pasture.

Table 4. Summary of crop acreage and water withdrawals, Sonoyta Valley, Mexico 1977-1987.

YEAR	CROPPED AREA (acres)	REPORTED WATER WITHDRAWAL (A-Ft)	ESTIMATED AQUIFER DEPLETION* (A-Ft)
1977	5,356	14,828	-
1978	7,845	21,269	-
1979	11,671	33,561	5,426
1980	16,322	48,837	20,702
1981	19,935	49,045	20,910
1982	19,975	55,037	26,902
1983	19,999	46,895	18,760
1984	18,407	44,640	16,505
1985	18,558	46,895	18,760
1986	19,856	49,064	20,929
1987	22,455	83,160	55,025
11-year Average	16,398	44,839	-

*Based on average annual recharge of 28,135 a-ft.

Source: Secretaría de Agricultura y Recursos Hydráulicos, Sonoyta, Mexico.

Two detailed geohydrologic studies have been conducted in the Sonoyta Valley during the past 10 years. The first was done by SARH in 1978. It included an inventory of wells and pumps, developed and irrigated cropland, pump tests, geologic surveys, climatological and hydrographic summaries, water quality tests and recommendations for management of the groundwater aquifer.

The second study covered the entire municipality of Puerto Peñasco (Técnicas Modernas de Ingeniería, S.A. 1982). This study was broader in scope and included analyses of the economic base, population, business development, utilities, services and labor force, as well as the agricultural and hydrological activities in the area.

In 1986, the SARH office in Sonoyta prepared a complementary study to the 1978 work (Secretaría de Agricultura y Recursos Hidráulicos 1986). This study describes the present level of agricultural and water resources development along with recommendations for improved management and utilization.

PRESENT WATER USE

Present water use in the Sonoyta Valley is monitored by SARH. The valley has been divided into 8 zones for management purposes. A description of these zones is shown in Table 5. Zones 1, 3 and 4 are located outside of the study area.

Table 5. Description of agricultural zones in Sonoyta Valley as designated by the Secretaría de Agricultura y Recursos Hidráulicos, Sonoyta, Mexico.

ZONE	LOCATION
2	Along Sonoyta River, west of Sonoyta
3	North of Rocky Point
4	Quitovac
5	East of Sonoyta, west of Sierra La Naríz, south of Sonoyta River
6	East of Sonoyta, west of Sierra La Naríz, north of Sonoyta River
7	East of Sierra La Naríz, south of Sonoyta River
8	East of Sierra La Naríz, north of Sonoyta River

A summary of developed acreage, wells and irrigation facilities by type of system and management zone is given in Table 6. As shown in the table, the irrigated area was 79% percent of the developed area in 1986. The cropped area (from Table 4) was only 59% of the total developed area. Forty-five percent of the developed area is served by earthen ditches, 37% by concrete-lined ditches and 18% by closed pipeline.

Table 6. Summary of farmland and irrigation facilities in Sonoyta Valley, Mexico, December 31, 1986.

ITEM	UNIT	<---ZONES---> 2	3	4	5	6	7	8	TOTAL	PERCENT
Developed area	acres	6,439	2,915	445	6,948	4,907	5,659	6,160	33,473	100
Irrigated area	acres	4,751	1,621	247	5,856	3,904	4,719	5,236	26,334	79
Number of wells	units	31	16	1	31	21	25	30	155	-
Pumping capacity	gpm*	39,546	12,997	2,060	45,887	34,316	36,942	45,411	217,159	-
Earthen ditches	miles	19	-	-	27	17	13	25	101	45
Concrete ditches	miles	41	5	1	19	6	9	5	86	37
Pipeline	miles	3	3	-	8	8	12	6	40	18
Sprinkler irrigation	acres	395	-	-	173	-	-	-	568	2
Levelled area	acres	2,656	1,149	-	2,360	1,779	1,626	2,286	11,856	31

*gallons per minute

Source: 1986 unnamed internal report by Secretaría de Agricultura y Recursos Hidráulicos on agricultural activities, problems, and solutions in the Municipality of Puerto Peñasco.

Surface irrigation is practiced on 98% of the area while only 31% of these lands have been precision levelled. Sprinkler irrigation systems serve only 2% of the irrigated area and are relatively new to the valley.

At the beginning of 1988, SARH listed a total of 212 wells in the Sonoyta Valley with 165 being used for irrigation. Total pumping capacity was also estimated by SARH to be 217,166 gallons per minute (gpm). Using the general "rule-of-thumb" of 10 gpm/a (which assumes a typical summer cropping pattern for desert climates and an irrigation efficiency of 70%), this would be sufficient water to adequately meet a peak water demand during July and August for 22,000 a under the situation where all wells are in full operation. The summer cropping pattern for the 1987-88 season occupied approximately 9,000 a or 40% of the total reported cropped area.

Total cropped acreage for 1987 was estimated by SARH to be 22,455 a with 83,152 a-ft of water withdrawn for irrigation (See Table 4). Estimates of groundwater withdrawals by SARH are calculated values based upon cropped area multiplied by crop consumptive use and divided by an estimated average irrigation efficiency of 70% (on-farm water losses of 30%). Field observations of irrigation systems and methods of water distribution indicate that an estimated 30% on-farm water loss is quite conservative and that 45 or 50% on-farm losses are closer to present field conditions.

Approximately 31% of the irrigated farmlands have been levelled to improve irrigation efficiency and appear to be in the range of achieving a 30% on-farm loss. The balance of the lands is not levelled to precision and remain in various states of development. Consequently, irrigation efficiency is low on these fields and on-farm water losses are in the range of 40 to 60%. Based upon these observations, the weighted average irrigation efficiency in the Sonoyta Valley is estimated to be 60% for purposes of this study. This is an average 40% on-farm water loss.

In order to put these efficiency estimates into proper perspective, it should be noted that typical irrigation efficiencies on Central Arizona farmlands consist of 35% on-farm losses where 10% of the field ditches are earthen and 90% of the land is precision levelled for irrigation. A state-mandated water conservation plan for Central Arizona requires all farms to reduce on-farm losses to 25% by 1990 and to 15% by 2025 (Arizona Department of Water Resources 1985).

The consumptive use of water by crops grown in the Sonoyta Valley is shown in Table 7. The crop coefficient for consumptive use is the amount of water, in a-ft/acre, required by plants to achieve full production. Alfalfa is an exception in this case because the consumptive use shown in the table is less than the amount required to maintain the crop at full production. This is due to the fact that alfalfa is a crop that can tolerate under-irrigation and then quickly recover once full irrigation resumes.

The general practice in the Sonoyta Valley is to under-irrigate alfalfa during the high water demand months of July and August and supply full irrigation quantities throughout the rest of the year. This results in a lower crop coefficient than is required to maintain alfalfa at full production throughout the entire year.

Table 7. Estimated crop consumptive use values for Sonoyta Valley, Mexico.

CROP	ANNUAL CONSUMPTIVE USE (a-ft/a)
Alfalfa	3.9
Cotton	2.9
Wheat	2.1
Rye Grass	3.9
Corn	1.6
Sorghum	2.6
Milo	2.6
Barley	2.5
Sesame	1.5
Cabbage	1.9
Watermelon	2.1
Cantaloupe	2.0
Onion	0.7
Carrot	2.5
Grape	3.8
Beans	1.5
Peach	3.6
Apple	3.2
Sudan	2.6

Source: Secretaría de Agricultura y Recursos Hidráulicos, Sonoyta, Sonora.

The estimated crop consumptive use, in a-ft/a during the period 1977 to 1988 is shown in Table 8. The annual weighted average varies between 2.5 and 3.0 a-ft/acre. Estimates of the total groundwater pumpage can be calculated using crop consumptive use coefficients, irrigation efficiency percentages and acreage served. The crop consumptive use coefficient for each crop is divided by the estimated irrigation efficiency and then multiplied by the number of acres.

For example, applying an irrigation efficiency of 70% to the 1987-88 cropping pattern and using the total area served of 22,455 a results in an estimated water withdrawal of 84,502 a-ft. The assumed level of efficiency is a critical factor in estimating the volume of groundwater withdrawals. If an irrigation efficiency of 60% is assumed, the estimated groundwater withdrawal would be 98,586 a-ft. A 50% efficiency level results in a total volume estimate of 118,293 a-ft.

The other factor having a certain degree of uncertainty is the "field value" of the consumptive use coefficient. The values in Table 7 assume that all crops are irrigated to satisfy water demands to achieve full production. However, in the Sonoyta Valley, there are occasions throughout the year when crop water demand is not completely met for many crops due to reasons such as irrigation system capacity limitations, pump breakdowns, excessive on-farm water losses, uneven fields and the planting of acreages too large for a given water supply.

Under-irrigation overstates the apparent overall irrigation efficiency, resulting in lower estimates of water withdrawal. At the same time, the crop consumptive use coefficients used in the calculation are larger than the field values and this results in higher estimates of water withdrawal. It is apparent that a certain degree of subjectivity is associated with estimating water withdrawals using the procedure described above. Although the error factor in establishing appropriate irrigation efficiencies does tend to offset the uncertainty inherent in the crop coefficients, data collection is too demanding to ascertain the degree to which these variables compensate each other. It is evident that one weakness in estimating total water use for an area based on calculating crop demand is that making precise estimates of overall irrigation efficiency and an assumption of a full water supply to all crops are necessary or, inversely, an assumption of the degree of under-irrigation is relied upon. Using the weighted crop consumptive use of 2.6 a-ft/acre (See Table 8) for 1987-88 and an irrigation efficiency of 60% resulted in an estimated 98,586 a-ft of total pumpage. This results in an estimated 70,500 a-ft net depletion of the groundwater aquifer.

The water withdrawal estimated by SARH for the same period is 83,152 a-ft, which is approximately 20% lower than our estimated 98,586 a-ft using a 60% efficiency. The SARH withdrawal estimate is essentially in agreement with our estimates when a 70% efficiency is used. It is obvious that the level of assumed irrigation efficiency has a considerable influence on the resulting estimate of water withdrawal.

In order to cross-check the above estimates, another method of estimating groundwater withdrawals was used. This method utilizes records of electricity delivered to wells and estimates the water pumped from the energy consumed. Parameters for three variables are needed for this calculation: depth of lift; total energy consumed; and overall pumping efficiency.

Table 8. Estimated consumptive use (a-ft), by crop and total pumpage for 60 and 70% efficiency, Sonoyta Valley, Mexico, 1977-1988.

CROPS	1977-78	1978-79	1979-80	1980-81	1981-82	1982-83	1983-84	1984-85	1985-86	1986-87	1987-88
Wheat	1,266	2,625	1,806	5,261	11,514	11,038	1,105	11,655	21,634	22,300	21,370
Sesame	-	912	315	56	189	1,283	1,182	434	645	2,034	2,594
Cotton	10,588	13,990	24,131	30,343	25,250	24,934	37,161	20,900	3,080	5,994	10,101
Safflower	790	346	-	-	-	-	-	-	-	-	-
Beans	-	23	212	191	437	63	93	701	3,398	144	186
Corn	-	178	482	126	1,032	64	272	309	419	720	712
Alfalfa	2,582	2,699	5,858	7,773	10,943	9,567	10,132	6,782	5,316	6,607	5,971
Vegetables	-	-	134	316	524	340	124	894	434	400	306
Vineyard	19	486	855	-	-	-	-	-	-	217	46
Fruit	144	158	158	3,197	5,681	9,202	10,580	8,528	6,419	5,753	5,504
Forrage	-	-	-	187	96	13	104	166	-	1,118	-
Sorghum	-	-	-	-	-	-	-	213	-	874	803
Pasture	-	-	-	-	-	-	-	-	3,409	3,717	11,560
TOTAL	15,389	21,416	33,950	47,448	55,667	56,503	60,753	50,582	44,753	49,877	59,152
Average in a-ft/a	2.873	2.730	2.909	2.907	2.792	2.829	3.038	2.748	2.412	2.512	2.634
60% Efficiency	25,648	35,694	56,584	79,081	92,778	94,171	101,255	84,304	74,588	83,128	98,586
70% Efficiency	21,984	30,595	48,500	67,783	79,524	80,718	86,790	72,260	63,933	71,252	84,502

Source: Calculated from Table 1 and Table 7.

Average depth to water for each irrigation well throughout the Sonoyta Valley as measured by SARH technicians for the years 1983 to 1987 is given in Tables 9 and 10. These depths are static water levels taken after all pumps have been shut down for several days. A substantial difference in depths to water between the eastern and western portions of the valley is evident. If Sierra La Naríz is used as a division line, the average depth to water on the eastern side is 287 ft, while it is 81 ft on the western side.

The water level in the immediate vicinity of a well being pumped declines as soon as the pump is started. This drop is referred to as "drawdown". Since drawdown depths have not been measured, our estimates were made based upon known drawdown levels in other areas having similar aquifers to arrive at an average pumping depth for the east and west sides of the valley. The average drawdown has been estimated to be 32 ft for wells east of Sierra La Naríz and 15 ft for wells west of Sierra La Naríz. This figure is added to the average depth to water from Tables 9 and 10 to estimate total pumping depth.

The energy required to lift one a-ft of water one ft in elevation at 100% efficiency is 1.024 kilowatt-hours (kwh). It has been estimated that the pumping units in the Sonoyta Valley have an overall efficiency of 54%, which is comparable to wells in Central Arizona under similar conditions. Electrical consumption data pertaining to the eastern and western portions of the valley, were obtained from the Comisi6n Federal de Electricidad in Puerto Peñasco (1987).

Estimated water withdrawals in 1987 using the energy method of estimation are shown in Table 11. Total water withdrawals are estimated to be 63,922 a-ft for 1987. This is approximately 23% lower than the SARH estimate of 83,152 a-ft. The energy consumption estimate does not account for internal combustion pump motors, which are 10 to 15% of the total, and the estimate is somewhat understated. Based on available data, the estimated water withdrawal for 1987-88 is in the range of 80,000 a-ft. The overdraft of the groundwater aquifer is about 50,000 a-ft.

Total pumping capacity of all pumps throughout the valley is estimated by SARH at 217,166 gal./min. or 955 a-ft/day. If all wells were operated continuously for 365 days a year, allowing 10% for down time, total annual pumping capacity would be 314,000 a-ft. The 80,000 a-ft estimated to be pumped in 1987 is only 25% of the total potential pumping capacity were all wells to be pumped continuously. However, irrigation pumps are typically operated 180 to 225 days per year on most irrigated farms having similar climates to the Sonoyta Valley. Using an average annual use of 200 days per year by all pumps, total annual groundwater withdrawals in the Sonoyta Valley would be 191,000 a-ft, more than twice the current withdrawal rates.

A government-subsidized program of pump electrification has been underway since 1984. Conversion of diesel and gas pump engines to electric motors is nearly complete. In past years, high costs for diesel fuel plus high maintenance costs and high mechanical failure rates of pump engines have limited pumping capacity. The reduced cost of pumping water with electricity, in addition to more reliable electric motors, has substantially increased the overall pumping capability in the valley without drilling additional wells.

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Table 9. Depth (in ft) to water west of Sierra la Naríz Sonoyta Valley, Mexico, 1983 to 1987.

WELL	EJIDO	1983	CHANGE	1984	CHANGE	1985	CHANGE	1986	CHANGE	1987
3.01	Ej. Co. Colorado	16.86	-0.36	17.22	-1.48	18.70	1.02	17.68	-0.92	18.60
4.11	Ej. Co. Colorado	16.08	-0.52	16.60	0.85	15.75	-1.12	16.86	0.13	16.73
4.12	Ej. Morelia	18.77	-0.03	18.80	-0.46	19.26	-0.62	19.88		19.88
4.14	Ej. Santo Domingo	-	-	-	-	9.25	-1.44	10.70	-0.33	11.02
5.01	Ej. Morelia	-	-	-	-	46.03	-1.15	47.18	-2.36	49.54
5.02	Ej. Morelia	-	-	-	-	35.60	-0.62	36.22	-0.85	37.07
5.03	Ej. Morelia	-	-	-	-	51.18	-3.67	54.86	0.23	54.63
5.05	Ej. Santo Domingo	34.25	3.08	31.17	-0.10	31.27	-1.05	32.32	-2.69	35.01
5.08	Ej. Santo Domingo	22.90	-1.61	24.51	-0.85	25.36	-1.84	27.20	-2.17	29.36
5.20	Ej. Jaime Jerez	19.06	-2.56	21.62	-1.71	23.33	-15.03	38.35	10.07	28.28
5.21	Ej. Jaime Jerez	21.16	-0.33	21.49	1.02	20.47	-0.13	20.60	-1.48	22.08
5.23	Ej. Jaime Jerez	-	-	-	-	34.28	-17.72	52.00	11.29	40.72
5.24	Ej. Josefa	39.44	0.89	38.55	-3.87	42.42	-1.97	44.39	-0.30	44.68
5.26	Ej. Josefa	84.71	1.21	83.50	-0.66	84.15	-1.84	85.99	-0.20	86.19
5.30	Ej. Jaime Jerez	10.70	-2.59	13.29	-1.44	14.73	-16.44	31.17	9.94	21.23
5.31	Ej. Morelia	39.76	-2.66	42.42	-1.51	43.93	-16.37	60.30	8.63	51.67
5.33	Ej. Josefa	24.93	-2.62	27.56	-0.16	27.72	-1.25	28.97	-	-
6.02	Ej. Papago	86.42	-4.04	90.45	-0.30	90.75	-0.66	91.40	-1.90	93.31
6.04	Ej. Morelia	30.15	1.18	28.97	1.05	27.92	-1.54	29.46	-2.59	32.05
6.09	Ej. Morelia	48.82	-	-	-	-	-	-	-	50.62
6.15	Ej. Papago	69.36	-0.52	69.88	-2.72	72.60	-0.07	72.67	-2.85	75.52
6.28	Hombres Blancos	-	-	-	-	39.24	-1.12	40.35	-0.98	41.34
6.33	Hombres Blancos	-	-	-	-	26.38	3.71	22.67	-	-
6.36	Hombres Blancos	48.29	0.95	47.34	-0.03	47.38	6.50	40.88	-8.17	49.05
6.41	Ej. Jaime Jerez	104.99	-2.72	107.71	-6.17	113.88	1.18	112.70	-1.64	114.34
6.49	Ej. Morelia	-	-	-	-	85.30	-	-	-	89.04
6.50	Zona Urbana Sonoyta	-	-	-	-	45.54	0.59	44.95	-0.33	45.28
6.51	Ej. Papago	-	-	-	-	69.32	-0.43	69.75	-2.30	72.05
6.55	Ej. Morelia	-	-	-	-	-	-	74.97	2.79	72.18
6.56	Lopez Mateos	-	-	-	-	-	-	127.95	2.53	125.43
7.01	San Martin	65.75	0.26	65.49	-1.18	66.67	-2.23	68.90	0.00	68.90
7.03	Emiliano Zapata	63.22	0.07	63.16	-0.03	63.19	-2.23	65.42	-2.82	68.24
7.04	Emiliano Zapata	-	-	-	-	53.18	-2.36	55.54	3.81	51.74
7.05	Emiliano Zapata	79.17	0.10	79.07	-0.62	79.69	-15.45	95.14	10.73	84.42
7.06	Emiliano Zapata	-	-	-	-	78.61	-1.87	80.48	-2.82	83.30
7.08	Lopez Mateos	50.20	-	-	-	-	-	50.36	-	-
7.11	Emiliano Zapata	61.55	-0.33	61.88	-0.13	62.01	0.33	61.68	-2.30	63.98
7.13	Emiliano Zapata	60.04	0.07	59.97	-1.21	61.19	-2.17	63.35	-20.31	83.66
7.22	Emiliano Zapata	77.20	-0.59	77.79	-1.44	79.23	-1.71	80.94	-	-
7.23	Ej. Desierto de Sonora	-	-	-	-	112.07	-2.49	114.57	48.16	66.40
7.25	Ej. Desierto de Sonora	100.62	-4.30	104.92	2.17	102.76	-4.69	107.45	-3.84	111.29
7.26	Ej. Desierto de Sonora	-	-	-	-	143.37	-1.61	144.98	-2.43	147.41
7.27	Lopez Mateos	48.88	0.59	48.29	-1.90	50.20	-1.41	51.61	0.00	51.61
7.28	Emiliano Zapata	97.24	-1.44	98.69	-0.79	99.47	-1.97	101.44	-2.82	104.26
7.30	Hombres Blancos	-	-	56.17	-	-	-	54.79	0.00	54.79
7.31	Emiliano Zapata	-	-	-	-	66.60	-8.01	74.61	4.95	69.65
8.01	San Marcelo	75.23	-0.82	76.05	4.33	71.72	-6.73	78.44	-4.40	82.84
8.02	San Marcelo	86.84	-	-	-	72.93	-17.03	89.96	-	-
8.03	San Marcelo	120.54	-0.52	121.06	2.49	118.57	-5.05	123.62	-4.00	127.62
8.04	San Marcelo	107.25	-0.23	107.48	-1.97	109.45	-1.21	110.66	-	-
8.06	Feo I. Madero	95.18	-0.43	95.60	-6.40	102.00	3.58	98.43	-4.69	103.12
8.23	Feo I. Madero	84.05	-1.12	85.17	-1.57	86.75	-2.17	88.91	-3.18	92.09
8.24	Feo I. Madero	85.99	-0.07	86.06	-1.21	87.27	-1.31	88.58	-4.07	92.65

Table 9 (Continued).

WELL	EJIDO	1983	CHANGE	1984	CHANGE	1985	CHANGE	1986	CHANGE	1987
8.27	Col. Sonoyta	-	-	-	-	146.46	-1.18	147.64	-4.10	151.74
8.29	Col. Sonoyta	130.22	-0.92	131.13	-5.35	136.48	-2.26	138.75	-	-
8.30	Col. Sonoyta	146.85	-0.52	147.38	-1.87	149.25	-3.90	153.15	-5.09	158.23
8.31	Col. Sonoyta	119.59	-0.62	120.21	-1.18	121.39	-3.35	124.74	-3.38	128.12
8.32	Col. Sonoyta	128.81	-0.62	129.43	-1.71	131.13	-0.36	131.50	-	-
8.33	Feo I. Madero	120.37	0.43	119.95	-0.62	120.57	-2.89	123.46	-4.72	128.18
8.37	Col. Sonoyta	121.59	-1.77	123.36	1.02	122.34	1.02	121.33	-3.67	125.00
8.39	Feo I. Madero	114.21	-1.18	115.39	-0.30	115.68	-	-	-	121.62
9.04	Ej. Desierto de Sonora	-	-	-	-	200.56	-3.71	204.26	-4.13	208.40
15.02	Ej. Co. Colorado	10.47	-19.06	29.53	3.44	26.08	-0.16	26.25	-	-
15.03	Ej. Co. Colorado	20.34	-	-	-	185.37	3.15	182.22	0.13	182.09
20.01	Col. Sonoyta	-	-	-	-	148.46	-1.12	149.57	-0.36	149.93
20.05	Col. Sonoyta	154.72	-	-	-	-	168.01	24.84	143.18	-
20.10	Col. Sonoyta	-	-	-	-	162.40	-5.61	168.01	-2.13	170.14
AVERAGE		70.28	-1.16	70.84	-0.86	76.96	-2.90	80.33	0.41	81.06

Source: Secretaría de Agricultura y Recursos Hidráulicos, Sonoyta, Sonora.

Table 10. Depth (in ft) to water east of Sierra la Naríz, Sonoyta Valley, Mexico, 1983 to 1987.

WELL	EJIDO	1983	CHANGE	1984	CHANGE	1985	CHANGE	1986	CHANGE	1987
9.01	Col. Benito Juarez	184.19	0.33	183.86	-4.49	188.35	-3.71	192.06	-2.59	194.65
9.02	Col. Benito Juarez	210.04	-1.21	211.25	-2.99	214.24	-3.12	217.36	-3.61	220.96
9.03	Col. Benito Juarez	208.79	-2.10	210.89	-2.30	213.19	-2.92	216.11	-3.54	219.65
11.05	Col. Cuanh Temoc	173.46	-0.82	174.28	-0.62	174.90	-0.07	174.97	-2.66	177.62
11.06	Col. Cuanh Temoc	179.76	-4.53	184.28	-2.13	186.42	1.41	185.01	-3.02	188.02
11.09	Col. Cuanh Temoc	171.52	-4.86	176.38	-7.84	184.22	9.55	174.67	-	-
11.10	Col. Cuanh Temoc	-	-	161.48	-9.12	170.60	-13.12	183.73	-	-
11.11	Col. Cuanh Temoc	182.12	-0.82	182.94	0.26	182.68	-0.59	183.27	-5.71	188.98
12.01	Col. A. Obregon	-	-	273.42	-8.07	281.50	-4.20	285.69	8.96	276.74
12.02	Col. A. Obregon	297.87	-1.31	299.18	-8.56	307.74	-2.89	310.63	7.55	303.08
12.03	Col. A. Obregon	261.32	-1.84	263.16	-8.04	271.19	-3.77	274.97	9.48	265.49
20.06	Feo I. Madero	-	-	-	-	-	-	271.03	-2.43	273.46
20.12	Col. CNCI Fracso	-	-	-	-	-	-	220.11	-8.73	228.84
21.03	Col. CNCI Fracso	-	-	254.76	2.76	252.00	-	-	-	253.15
21.04	Col. CNCI Fracso	-	-	-	-	202.59	-1.87	204.46	-	-
21.05	Col. America	-	-	277.13	-1.51	278.64	-4.99	283.63	-0.59	284.22
21.06	Col. CNCI Fracso	189.47	-	-	-	-	-	178.38	0.69	177.69
21.09	Col. America	309.02	3.25	305.77	-8.53	314.30	-6.96	321.26	-2.26	323.52
21.10	Col. America	268.63	-4.33	272.97	-1.31	274.28	-4.43	278.71	-5.22	283.92
21.11	Col. America	321.36	4.40	316.96	-8.43	325.39	-2.10	327.49	-	-
21.13	Col. CNCI Fracso	213.68	-1.28	214.96	-8.43	223.39	1.67	221.72	-4.72	226.44
21.14	Col. CNCI Fracso	192.42	-2.26	194.68	-4.76	199.44	-7.81	207.25	-	-
21.15	Col. CNCI Fracso	200.79	-2.36	203.15	-6.30	209.45	-4.30	213.75	-5.09	218.83
21.18	Col. CNCI Fracso	210.37	-2.40	212.76	-4.36	217.13	-6.50	223.62	-1.38	225.00
21.19	Col. America	264.04	-4.13	268.18	-0.43	268.60	-7.91	276.51	-3.81	280.31
21.20	Col. CNCI Fracso	226.71	-2.46	229.17	-4.04	233.20	-7.61	240.81	-1.80	242.62
21.22	Col. CNCI Fracso	-	-	-	-	217.39	-5.45	222.83	-5.02	227.85
21.23	Col. E. Obsegonista	-	-	-	-	-	-	215.78	-4.04	219.82
22.03	Col. Grupo Valdez	196.92	-2.82	199.74	-1.90	201.64	-1.64	203.28	-4.56	207.84
22.04	Col. Grupo Valdez	214.34	3.44	210.89	-8.92	219.82	2.30	217.52	-11.02	228.54
22.06	Col. E. Obsegonista	-	-	-	-	195.21	-2.03	197.24	-3.38	200.62
22.10	Col. 21 de Marzo II Frac	318.04	4.30	313.75	-7.94	321.69	-5.12	326.80	-	-
22.11	Col. 21 de Marzo II Frac	305.61	5.18	300.43	-8.14	308.56	-6.27	314.83	-3.84	318.67
22.12	Col. 21 de Marzo I Frac	297.34	-6.00	303.35	-0.52	303.87	4.10	299.77	-10.70	310.47
22.14	Ejido La Naríz	-	-	-	-	-	-	244.36	-	-
23.06	Col. Direccion Del Norte	-	-	-	-	277.00	6.00	271.00	-9.78	280.77
23.07	Col. 21 de Marzo	274.15	-4.99	279.13	-1.21	280.35	5.77	274.57	-8.73	283.30
23.11	Col. Direccion Del Norte	284.84	-6.89	291.73	-9.74	301.48	8.10	293.37	-	-
23.12	Col. Direccion Del Norte	-	-	250.59	-0.75	251.34	-	-	-	-
23.13	Col. Cuanh Temoc	236.35	3.87	232.48	-34.51	266.99	27.72	239.27	-3.02	242.29
23.14	Col. Direccion Del Norte	234.45	-7.51	241.96	-0.82	242.78	-2.40	245.18	-1.77	246.95
23.15	Col. Direccion Del Norte	-	-	-	-	205.71	-1.38	207.09	-1.02	208.10
24.01	Col. Jalisco	352.85	-1.31	354.17	-7.51	361.68	-	-	-	357.77
24.02	Col. Jalisco	-	-	-	-	384.19	1.80	382.38	-2.92	385.30
24.03	Col. 21 de Marzo III Frac	340.48	-	-	-	344.49	-0.16	344.65	-1.15	345.80
24.05	Col. 21 de Marzo III Frac	397.47	0.52	396.95	-1.77	398.72	0.92	397.80	-0.82	398.62
24.06	Ej. El Ejemplo	387.99	6.76	381.23	-3.15	384.38	-1.02	385.40	-1.74	387.14
24.07	R. San Francisquito	-	-	280.35	-	-	-	-	-	-
24.08	Col. 21 de Marzo III Frac	306.69	-1.67	308.37	-1.35	309.71	-3.48	313.19	-2.23	315.42
24.09	Col. 21 de Marzo III Frac	-	-	321.78	-0.33	322.11	-	-	-	-
24.12	Col. 21 de Marzo III Frac	-	-	-	-	398.16	0.85	397.31	0.98	396.32
24.15	Col. Jalisco	320.27	-0.85	321.13	0.00	321.13	0.85	320.27	-	-
24.20	Col. 21 de Marzo III Frac	398.42	-1.44	399.87	-2.03	401.90	-0.26	402.16	-	-

Table 10 (Continued).

WELL	EJIDO	1983	CHANGE	1984	CHANGE	1985	CHANGE	1986	CHANGE	1987
24.21	Col. Direccion Del Norte	272.67	-0.39	273.06	-1.87	274.93	-7.68	282.61	0.16	282.45
24.22	Col. 21 de Marzo III Frac	-	-	349.97	-9.71	359.68	-0.66	360.33	-5.12	365.45
34.01	Col. 21 de Marzo II Frac	-	-	378.84	7.94	370.90	-9.74	380.64	8.56	372.08
34.02	Col. America	420.60	-0.98	421.59	-1.48	423.06	-10.24	433.30	7.84	425.46
36.02	Ej. El Ejemplo	423.92	-0.16	424.08	-0.66	424.74	-0.69	425.43	0.62	424.80
36.06	Ej. El Ejemplo	479.95	-0.36	480.31	-2.17	482.48	-1.71	484.19	3.22	480.97
36.07	Ej. El Ejemplo	-	-	482.61	-1.54	484.15	-1.41	485.56	0.33	485.24
	AVERAGE	275.10	-1.08	282.34	-4.43	285.13	-1.60	280.64	-1.99	287.02

Source: Secretaría de Agricultura y Recursos Hidráulicos, Sonoyta, Sonora.

Table 11. Estimated groundwater withdrawals for 1987 calculated from energy consumption, Sonoyta Valley, Mexico.

ITEM	UNIT	EAST VALLEY	WEST VALLEY
Average Depth to Water	ft	287	81
Average Drawdown	ft	32	15
Total Water Lift	ft	319	96
1987 Energy	kwh	13,861,519	7,463,895
Pumping Efficiency	%	54.0	54.0
Energy Required to Lift 1 a-ft	kwh	605	182
TOTAL PUMPAGE	a-ft	22,912	41,010

Source: Secretaría de Agricultura y Recursos Hidráulicos Sonoyta, Sonora; Comisión Federal de Electricidad, Puerto Peñasco, Sonora.

It can be observed from the above rationale that the present pumping capacity is 2.5 times the estimated withdrawal rate in 1987 and that groundwater withdrawals could easily double without drilling new wells if existing pumps were operated more days throughout the year. Lands developed for irrigation are also in excess of the area currently being used for irrigated agriculture. Although a moratorium is currently in effect for the Sonoyta Valley, a considerable increase in groundwater withdrawals could occur without the development of new wells or irrigated areas due to the existing excess capacity in both land and water resources.

PROJECTED FUTURE AGRICULTURAL DEVELOPMENT

PRESENT GOVERNMENT POLICIES AND PROGRAMS

Land ownership in the Sonoyta Valley is divided between cooperative farms having a formally organized structure, called ejidos, and private ownership. Ownership of the agricultural lands in the Sonoyta Valley are about 50% privately owned and 50% ejidos. Most of the irrigated lands have been developed by ejidos. The ejidos within the study area are shown in Figure 4.

Ejidos were established as part of the agrarian land reforms which began in 1917 when the government initiated land redistribution programs to reduce large land holdings by individuals and to provide access to landownership for a larger number of people.

Ejidos are similar in ownership to Indian trust lands in the United States. Lands are assigned to individuals and can be utilized, developed, and even passed on to family members but cannot be sold. The majority of ejidos in Mexico are small in size, in the range of 2 hectares (ha). Ejidos in the Sonoyta Valley are somewhat larger, ranging from about 10 to 500 ha in size.

The ejido is a miniature community with a group of people having adjacent land assignments living in a central area sharing equipment and facilities. A formal organization exists for each ejido with elected officers to represent interests of the ejido in business, government programs, and political affairs.

A centralized governmental structure exists to provide close control of crop production on all lands. This function is handled by the local office of SARH. Annual cropping programs are formulated in coordination with SARH, the local bank (Bancorural), the state organization of Agrarian Reform, and ejido representatives. Meetings are held among these officials to specify the type and acreage of each crop. Decisions regarding processing and marketing of agricultural products are also coordinated in these planning meetings.

Production inputs such as seed, fertilizer, and pesticides are programmed and purchased through the SARH organization. Permits to drill and operate irrigation wells are also obtained through SARH. A staff of agronomists and agricultural engineers from SARH and the Bancorural provide technical advice and support as well as crop monitoring for all farms. Information gathered by the technical staff includes: crop growth stage; yield; insect, disease, and weed infestations along with recommended control measures; irrigation schedules and application amounts; potential for improvement of irrigation systems; and financial data for budgeting purposes.

Government agencies regulating farm activities have placed a moratorium on the drilling of new wells for irrigation in the Sonoyta Valley. New wells can only be drilled to replace wells taken out of service. In addition, a limit of 32,000 a has been set as the maximum acreage to be developed in the valley.

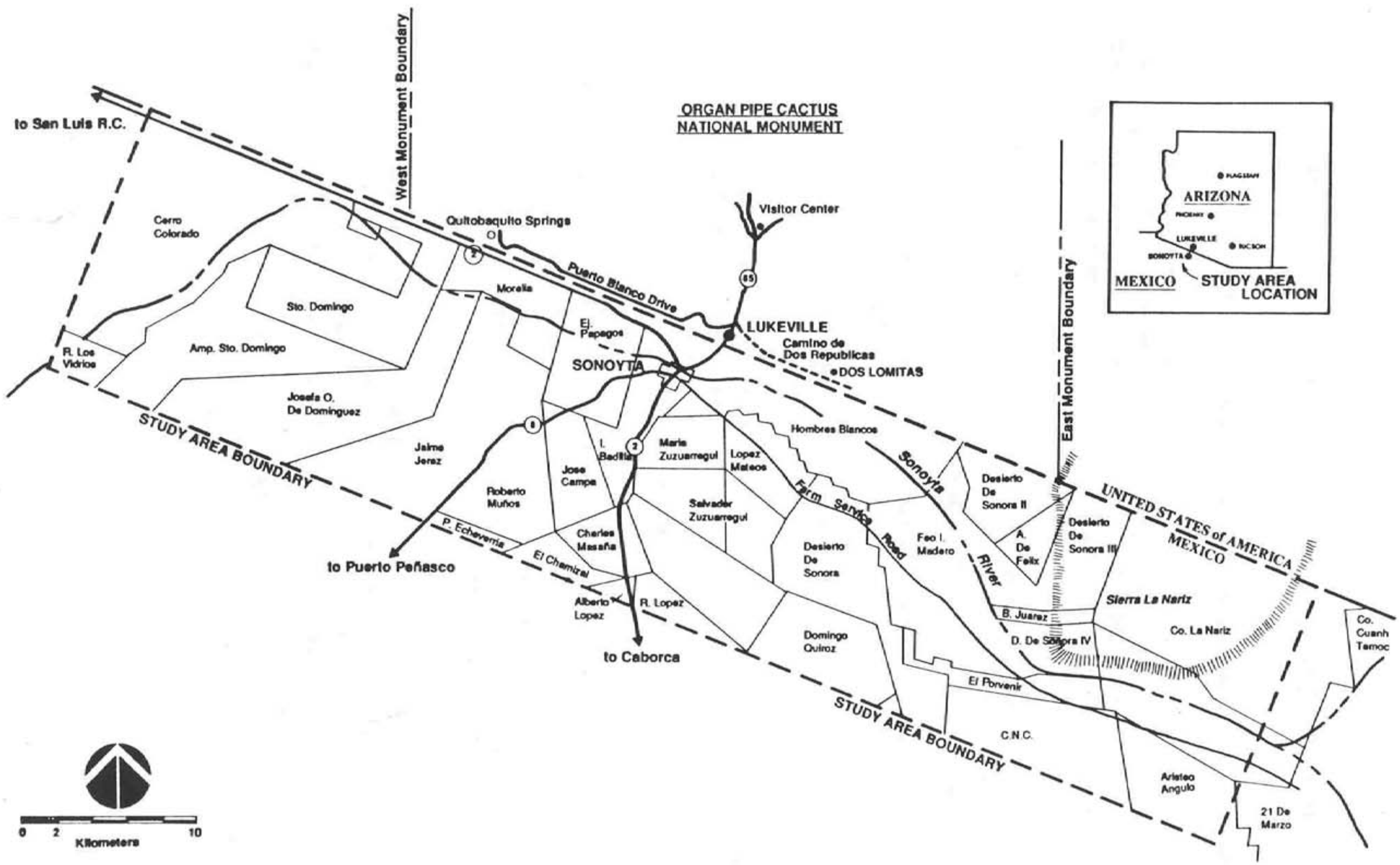

Figure 4. Ejidos within study area, Sonoyta Valley, Sonora, Mexico.

Cropped acreage steadily increased from 1977 to 1981. It has remained around 20,000 a from 1981 to the present. Thirty to forty percent of the developed lands are idle. There are sufficient lands not presently in production to satisfy near-term expansion of cropped acreage. Development of new lands is not likely to occur within the next 10 years, and perhaps longer, depending upon economic conditions in the agricultural sector.

Total pumping capacity has increased rapidly in the past 5 years as diesel pump motors have been replaced with more reliable and more efficient electric motors. The total number of wells has not changed significantly, but the overall capability to pump water has increased by using the more dependable electric motors and thereby expanding the number of acres that can be irrigated. Most of the wells have now been converted from diesel to electric power, and quantum increases in pumping capacity similar to that occurring within the past 5 years are not anticipated in the near future.

Continued development of additional agricultural lands in the Sonoyta Valley does not appear likely in the near future since water withdrawals to serve existing farmlands are nearly three times the renewable water supply. In addition, development of new agricultural lands and further development of water resources are highly dependent upon governmental funding of expansion programs.

FUTURE CROPPING PATTERN

Future changes in the cropping pattern are likely to follow the trend of areas in the Southwestern United States, which also utilize groundwater aquifers under conditions of overdraft. As water tables decline and electricity costs increase, pumping costs gradually increase until traditional field crops such as cotton, alfalfa, wheat, and pasture, which have low revenues per unit of water applied, eventually become uneconomical to produce. High-value crops, which produce more income per unit of water, begin to take their place. These are typically vegetable, fruit, and nut crops, which require less water per dollar of revenue generated but need more capital inputs, a higher level of management and more sophisticated marketing techniques. These crops, however, do require smaller acreages to produce the equivalent farm income generated by traditional field crops. Market consumption in terms of acres required to reach saturation is less for vegetable and fruit, so total farmed acreage generally declines. Total water use also declines and the overdraft of the groundwater reserves is gradually reduced.

A shift from high water use to low water use crops is beginning in the Sonoyta Valley. Cotton and alfalfa acreage has declined from a high of 77% of the total acreage in 1983 to 22% in 1987. Wheat and pasture have increased from 3% of the total acreage in 1983 to 57% in 1987. Beans, sesame, vegetables, and fruit currently occupy 24% of the 1987 crop acreage. These three crops accounted for only 19% of the total acreage in 1983.

Wheat and pasture require less water than cotton and alfalfa but produce relatively low revenues per unit of water consumed. There is a current effort on the part of government agencies to increase the acreage devoted to fruits and vegetables, and decrease field crop acreages. Peach acreage has increased rapidly in recent years and a packing shed is currently in operation. Plans are underway to build another packing shed to accommodate increased production as young orchards begin to mature and reach full production.

Vegetable production has excellent potential in the Sonoyta Valley. Water is of good quality in most areas, the climate is favorable for both winter and summer crops, and soils on most farms are well suited for vegetable production. The area has an economic advantage for vegetable exportation to the United States due to its favorable location and low cost of labor. With development of marketing and processing facilities, the vegetable industry could quickly flourish and constitute a substantial portion of the agricultural industry in the valley.

FUTURE WATER WITHDRAWALS

Future use of groundwater for agriculture will correspond directly to types and acreages of crops grown. Market prices and governmental agency decisions are major factors influencing cropping patterns and the number of productive acreages in the Sonoyta Valley as well as the availability and cost of water. Water will continue to increase in cost and decrease in availability as groundwater levels decline. Crop planners will have to take this into account and design crop plans to generate additional revenues to pay the higher costs of pumping. Three likely alternative scenarios for future crop acreage and corresponding water withdrawals are given in Table 12. Alternative I represents present cropping trends dominated by field crops and an irrigated area of 22,500 a. Alternative II assumes that fruits and vegetables will increase to 50% of the cropped acreage which decreases to 15,000 a. Alternative III portrays a situation where the fruit and vegetable industry flourishes in the valley and occupies 80% of the total agricultural area; however, the number of irrigated acres decreases to 10,000.

Under Alternative I, annual estimated water withdrawals approach 100,000 a-ft. Alternative II water withdrawals are estimated to decrease to 61,000 a-ft and to 37,000 a-ft under Alternative III.

Existing conditions are setting the course for a transition in the valley cropping pattern. This transition will involve a gradual shift from field crops to vegetable/fruit crops and a decrease in irrigated acres. It should be emphasized that the transition will be gradual and evolve a manner similar to the Alternative II scenario, if existing conditions continue into the future.

Nevertheless, under Alternative II conditions, annual groundwater withdrawals will still be approximately twice the annual rate of recharge and the depth to water in the aquifer will continue to increase.

Table 12. Three future alternative scenarios for irrigated agriculture, Sonoyta Valley, Mexico.

	AREA (a)	CONSUMPTIVE USE (a-ft/a)	ANNUAL CONSUMPTIVE USE (a-ft/a)	ANNUAL ESTIMATED WATER WITHDRAWAL (a-ft)
ALTERNATIVE I				
80% Field Crops	18,000	2.8	50,400	84,000
20% Fruit/Veg.	4,500	2.1	9,450	15,750
TOTALS	22,500		59,850	99,750
ALTERNATIVE II				
50% Field Crops	7,500	2.8	21,000	35,000
50% Fruit/Veg.	7,500	2.1	15,750	26,250
TOTALS	15,000		36,750	61,250
ALTERNATIVE III				
20% Field Crops	2,000	2.8	5,600	9,330
80% Fruit/Veg.	8,000	2.1	16,800	28,000
TOTALS	10,000	-	22,400	37,330

MONITORING FUTURE AGRICULTURAL DEVELOPMENT

INTRODUCTION

Since the direction of future agricultural activities will be influenced by many factors that are unknown at the present time, establishment of monitoring procedures is necessary to identify new trends as they develop. The purpose of the monitoring activities is to estimate the annual water withdrawals by agriculture in the Sonoyta Valley. Early identification of changing conditions will enable managers to formulate appropriate mitigation and control programs.

A handbook has been developed that prescribes procedures and sets forth the protocol to monitor water withdrawals for agriculture. This handbook was designed to direct field data collection and analyses of periodic monitoring activities. In this section the general contents and procedures of the handbook are described with regard to monitoring agricultural development. The handbook will be available with other monitoring handbooks from ORPI at a later date.

MONITORING AGRICULTURAL DEVELOPMENT

Four different methods are recommended to monitor agricultural development in the Sonoyta Valley. The first method is based on establishing photo points, which cover the agricultural area, and comparing photographs from different periods in time to detect changes.

The second method is to take photographs of the agricultural area from the air. Again, the procedure is to compare photographs taken at different points in time and identify changing trends.

The third method is to rely on the annual data collected by SARH, which reports crops, acreages, and water volumes withdrawn for agriculture.

The fourth method is to compute the amount of water withdrawn for agricultural purposes based upon electrical consumption, pumping lifts and pump system efficiencies.

Photo Points

A series of photo points was established along the southern boundary of ORPI and just across the border in Mexico. The photo points are located on areas of high relief that offer a strategic view of surrounding lands. A total of 7 points was selected, 4 in the U.S. and 3 in Mexico. Locations of photo points listed below are shown in Figure 5.

Photo Point 1	Quitobaquito
Photo Point 2	T.V. Hill Southwest
Photo Point 3	Border Marker 171
Photo Point 4	T.V. Hill Northeast
Photo Point 5	Rio Sonoyta
Photo Point 6	Dos Lomitas
Photo Point 7	East Gate

The exact location of each photo point is identified with a metal tag attached to an iron rod driven about 2 ft into the ground. As shown in Figure 5, these points provide complete coverage of the agricultural area in the Sonoyta Valley with the exception of the lands to the extreme east, which are outside of the original study area.

Taking photographs from each point involves a procedure that produces both black and white prints and color slides of the land area within viewing range. The observer sets up a tripod over the metal tag and iron rod, and begins taking photographs starting from the north cardinal point. Using a compass, the observer rotates the camera 45° between pictures until he/she covers a complete 360-degree circle, resulting in eight photos. The observer then repeats this procedure using a second camera with color slide film. It is recommended that the entire procedure be repeated to provide backup photos. A total of 32 pictures will be taken from each photo point. A 360-degree circle of photographs is suggested to take advantage of these efforts and collect chronological information on non-agricultural lands and vegetation, as well as agricultural lands, for purposes of future reference.

New photographs will be compared with photographs taken from previous outings to determine if noticeable changes are occurring in agricultural activities. It is not possible to take measurements of land areas from the photos and, therefore, only subjective analyses can be made in terms of whether more or less land is in production. Another problem encountered with the photo points is that the angle from which the photographs are taken does not have the acuteness required for good overviews of the entire landscape. Nevertheless, the photographs will aid in the identification of emerging trends and provide lead information to managers and planners.

Aerial Flights

The technology of aerial photography has been evolving for a considerable period of time, allowing precise land area measurements to be made from photographs. Although this type of monitoring mechanism would provide very accurate data on agricultural activities in the Sonoyta Valley, it would also be quite expensive since a minimum of two flights per year would be

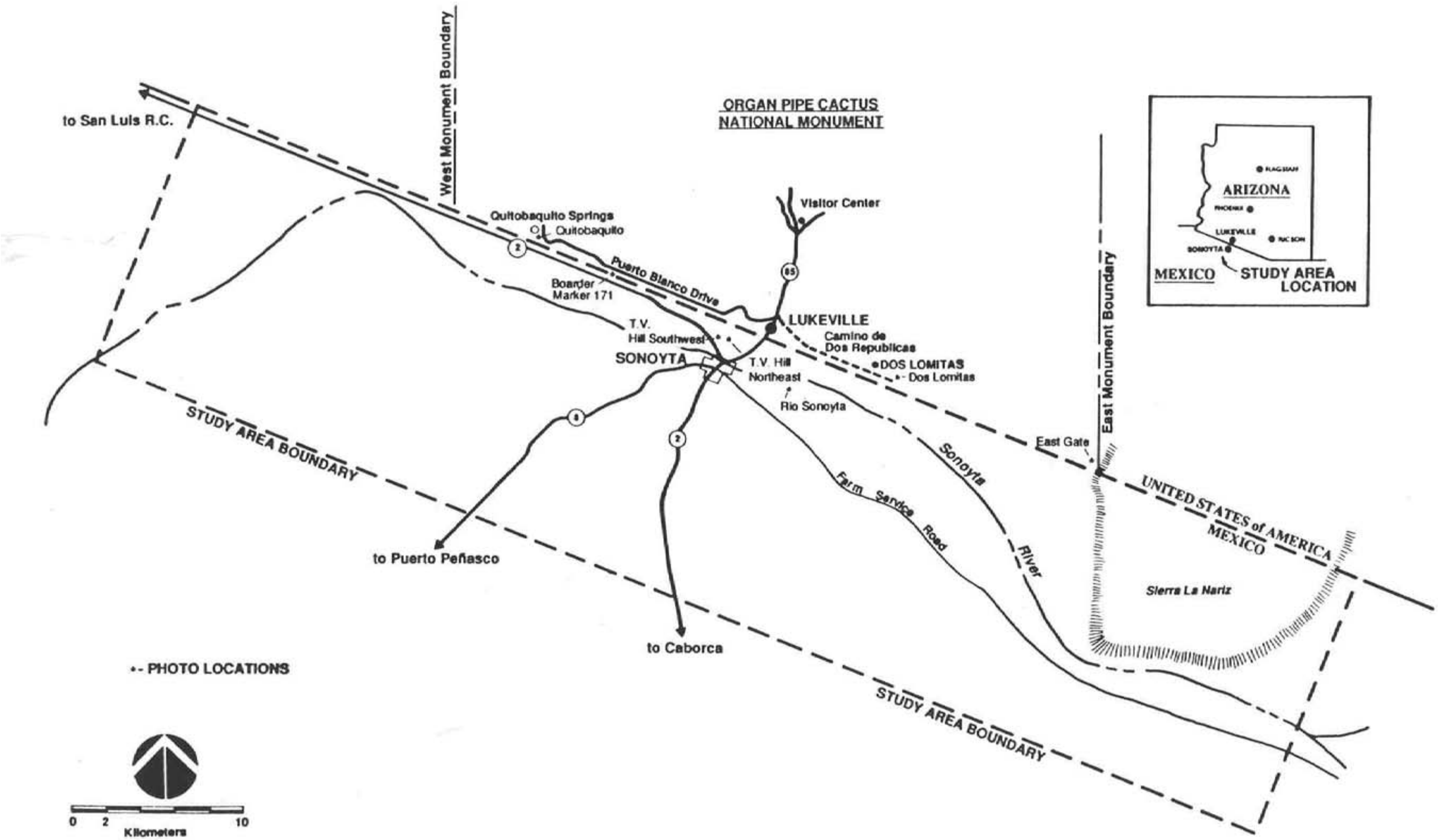

Figure 5. Agricultural photo points.

required. In order to develop a monitoring procedure that could be both useful and effective, it was decided to conduct overflights using both a video camera and a hand-held 35mm camera.

Two flights were completed over the valley at an altitude of 6,000 ft above sea level. Although the photographic angle was much better, the measurement problem still existed. It was concluded that only solid-mounted professional equipment taking photographs directly above the land would solve the measurement problem. This returns us to the problem of expensive professional aerial photography services mentioned above.

Nevertheless, overflights and hand-held photographs do provide improved information over the photo points. It is possible to make better estimates of the agricultural activities in the valley from this information.

SARH Annual Reports

An alternative to the previous two methods is the information contained in the annual reports produced by SARH. These reports provide data on the cropped acreage, production, and water volumes withdrawn from the Rio Sonoyta aquifer. The data are based on cropping plans for each ejido and do provide good estimates of the variables involved.

In addition, SARH conducts an annual well survey, collecting information on the depth-to-water throughout the valley. From these data, it is possible to determine the approximate depth of the water table in most parts of the valley and correlate this information to similar data taken from wells within ORPI.

Although this information is available from SARH with a minimum of effort, photographs and improved definition of several parameters described in "Past and Present Agricultural Water Use" would provide more precise estimates of water withdrawals.

Energy Consumption

As explained earlier, most of the wells in the Sonoyta Valley have been converted to electric motors due to inherent cost advantages. An excellent method for monitoring water withdrawal volumes is to utilize annual energy consumption data.

This method would require the combination of data from two sources: 1) well depth data from SARH; and 2) electrical consumption data from the Comisión Federal de Electricidad. These data are available and would enable the calculation of water withdrawals for each well. The results would provide a good cross-check to SARH data and help in the photographic interpretation of data from the photo points and overflights.

LIGHT POLLUTION

PRESENT CONDITIONS

Organ Pipe Cactus National Monument is an excellent place for nighttime viewing of celestial bodies. It is located away from major population centers and provides a night sky that is quite clear and pollution-free. The "dark sky" during moonless nights provides excellent observation of many of the brightest stars and an exceptional view of the Milky Way from most vantage points in ORPI.

Clear nighttime viewing within ORPI can be contrasted with more obscure views from major urban and metropolitan areas. An increase in outdoor lighting in urban population centers decreases the darkness of the nighttime sky, which provides the background for viewing stars, planets and other celestial bodies. As the dark sky background becomes increasingly brighter, nighttime viewing is increasingly hindered within and near urban light sources.

The atmosphere diffuses the light from urban sources causing a shape similar to a lighted, inverted dish that hovers over the metropolitan area. This type of light pollution is referred to as "urban sky glow," which decreases the darkness of the surrounding nighttime sky.

Urban sky glow is a form of "light pollution" that interferes with nighttime observations by the general public and astronomers. Another form of light pollution is "light trespass," which occurs when light is directed where it is not wanted or desired. Light trespass also interferes with the nighttime viewing and sighting of celestial bodies.

Most of the nighttime viewing in ORPI is in the area of the main campground and monument headquarters. Although ORPI does presently have a relatively unobscured nighttime viewing environment, minor amounts of light pollution do exist; there is concern that urban sky glow and light trespass will increase.

Sources of light pollution are located to the north, east and south of the headquarters. To the north, a faint urban glow can be observed which comes primarily from the community of Ajo. The Puerto Blanco Mountains (to the north and west of monument Headquarters) and the Little Ajo Mountains (just south of Ajo) shield most of the urban sky glow from nighttime observers. At the present time, the faint glow seen by observers does not interfere with the casual and amateur viewing most commonly practiced in ORPI.

To the east lies the city of Tucson, which on a clear night emits a sky glow that is also faintly perceptible to the nighttime viewer in ORPI. The Ajo Mountain range, bordering the eastern boundary of ORPI, and several other large mountain ranges shield all but a very small portion of the urban glow originating in Tucson. As with the Ajo area, urban sky glow from Tucson presents a minimal hinderance to the type of nighttime viewing presently conducted in ORPI.

The major source of light pollution for ORPI viewers comes from the south. Most of the light pollution originates from Lukeville, the U.S. Port of Entry, and from Sonoyta, a small but growing city of 15,000 which begins at the Mexican Port of Entry and extends about 5 km to the south.

Light pollution from the south consists of urban sky glow and light trespass. Most of the urban sky glow is emitted from the town of Sonoyta while lesser amounts originate from Lukeville and rural areas on both the east and west sides of the Sonoyta Valley. Even ORPI Headquarters and the main campground are minor sources of urban sky glow.

Sonoyta, the major source of sky glow, is located at the base of the southernmost extension of the Sonoyta Mountains. This is a small range of mountains which begins in ORPI, almost directly west of the headquarters and extends due south into Mexico where it terminates shortly after crossing the border. Although these mountains only reach a height of several hundred feet above the surrounding area, the range does effectively shield much of the city lights from direct view in the main campground and headquarters. Consequently, urban sky glow is not a significant hindrance to nighttime viewing under present conditions.

Sources of most light trespass are inconsequential and cause only minor annoyance to nighttime viewing in ORPI. Light trespass originates from Camino 2 and, to a lesser extent, Highway 85. Camino 2 extends north from Caborca to Sonoyta where it turns west and continues to San Luis and Tijuana. This highway is a major link between the northern border towns and the southern part of Sonora as well as with other parts of Mexico farther south. According to traffic counts for 1986, 52% of the traffic was passenger cars and the remaining 48% consisted of trucks and buses (Dórame, pers. comm. 1987).

During the evening, a steady stream of traffic can be observed from ORPI on the portion of Camino 2 extending west of Sonoyta to San Luis. Many of the vehicles are large tractor-trailers which, in addition to making substantial noise, are completely outlined with lights. As these vehicles travel Camino 2 near the southern boundary of ORPI, their lights trespass into the nighttime viewscape adjacent to this portion of the monument.

In the near vicinity, a noticeable amount of light trespass can be observed originating from Camino 2. Fortunately, most of this unwanted light is shielded from the campground and headquarters by the Sonoyta Mountains. Viewers on the western side of this mountain range have no shield from Camino 2 and nighttime skies are moderately trespassed by this source of light pollution.

Highway 85 is the northern entrance to ORPI and extends southward the entire length of the monument to Lukeville. Night traffic on this road is quite low due to closure of the border from midnight to 8:00 a.m. Nevertheless, the small volume of night traffic that travels Highway 85 is clearly visible from both the campground and headquarters. Light trespass is very minor at present but could increase, especially if the border crossing goes to a 24-hour schedule.

RESEARCH OBJECTIVES

The principal objective of the research described in this section is to establish a framework for monitoring light pollution and its effect on the nighttime viewscape of ORPI.

This objective is accomplished by achieving two sub-objectives: 1) documentation of baseline conditions of light pollution in ORPI; and 2) establishment of a methodology to measure changes in light pollution as compared to baseline conditions.

Documentation of baseline conditions provides a frame of reference for comparison to future conditions. Establishment of baseline conditions initiates the process of periodic documentation of light pollution conditions in ORPI and interpretation of changes as compared to previous periods. The interpretation of changes will be both subjective, in terms of detecting an increase or decrease in light pollution, and quantitative, which deals with magnitudes of change as compared to previous conditions. Procedures for monitoring light pollution in ORPI are presented in the next section.

MONITORING PROCEDURES

The basis to monitoring light pollution in ORPI is gathering data from photo points. It was considered important to select photo points that reflected the types and amounts of light pollution nighttime viewers would encounter from likely viewing areas in ORPI. Even though there are no formal viewing sites at present in ORPI, most nighttime observations are centered around monument headquarters and the main campground. Therefore, photo points were established to monitor light pollution as it affects viewing from these sites.

The intent in establishing photo points was to provide coverage of a 360-degree view with primary emphasis on the 180° south towards the border. It was decided that two photo points would best fulfill the needs for documenting light pollution.

Light Pollution Photo Point 1 was established in the Sonoyta Mountains along the Puerto Blanco Drive near the border. From this vantage point, it is possible to view the town of Sonoyta and all the area to the southwest and west.

The specific location and detailed procedures for collecting data and measuring light pollution from Photo Point 1 are presented in the handbook referred to earlier. Basic procedures require that periodic photos be taken to monitor changes in urban sky glow. The area to be covered has been divided into two sectors; one concentrates on the immediate vicinity of Sonoyta directly southward, and the other encompasses rural lands to the southwest (See Fig. 6). It is quite obvious that the southern sector includes most sources of current light pollution by focusing on Sonoyta. The southwestern sector includes very few sources of light pollution but will provide an excellent baseline should future growth and development expand into this area.

Light Pollution Photo Point 2 was established just south of monument headquarters near the main campground, the precise location is also given in the handbook. This site provides a 360-

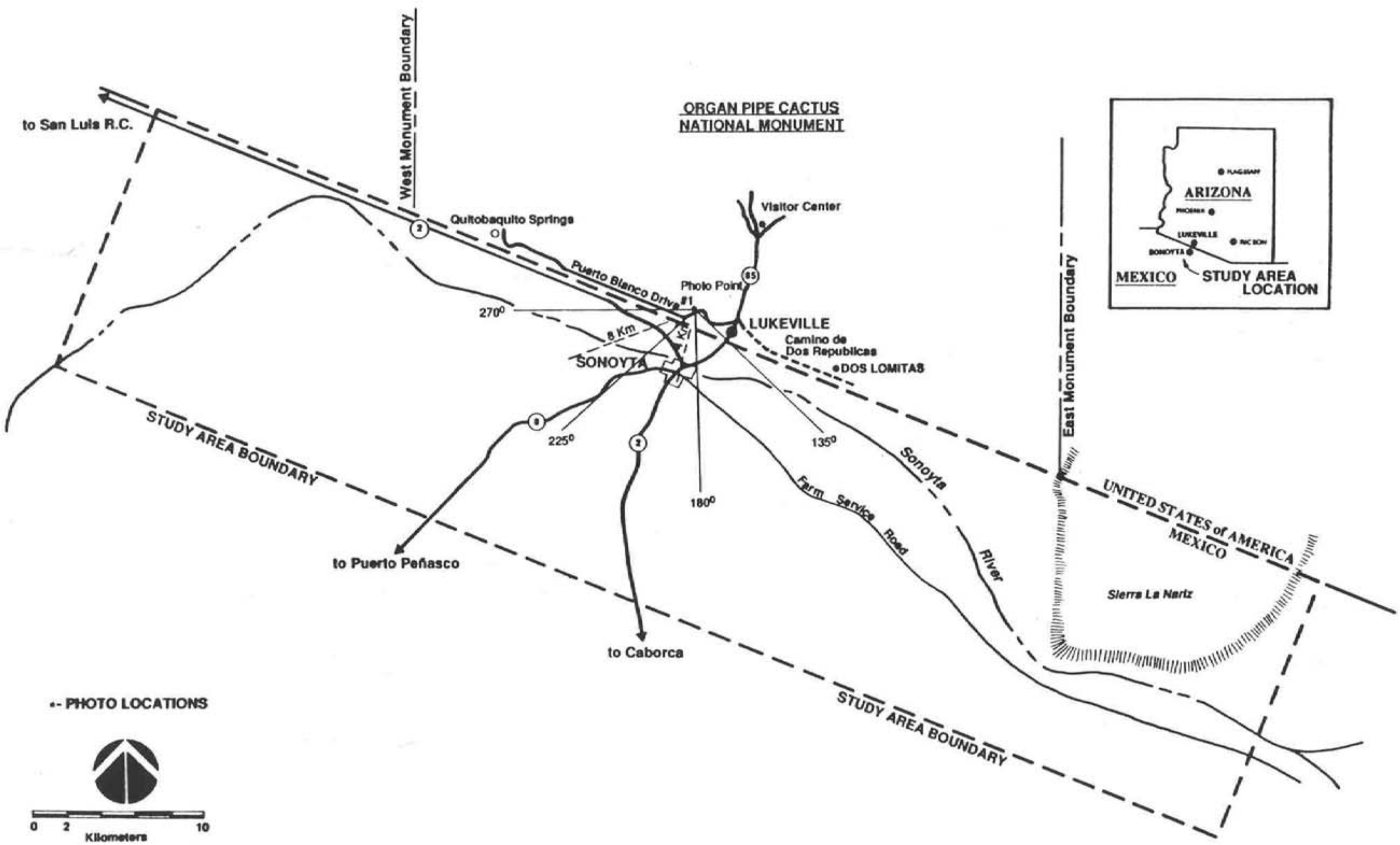

Figure 6. Light Pollution Photo Point 1.

degree view along with a direct view of Lukeville and areas to the east. Most nighttime viewers would encounter conditions similar to those experienced from Photo Point 2 when making observations. As mentioned previously, the town of Sonoyta is obscured from view by the Sonoyta Mountains and only a faint urban sky glow can be seen from Photo Point 2.

The framework for monitoring light pollution from Photo Point 2 involves a division of the area into two sectors as shown in Figure 7. The southeast sector covers the rural area located in the eastern portion of the Sonoyta Valley. The southern sector includes the area directly south of Photo Point 2 taking in the urban centers of Lukeville and Sonoyta.

Photo Point 2 provides a realistic portrayal of light pollution encountered by most ORPI viewers while Photo Point 1 is positioned to monitor Sonoyta, the main source of sky glow, from an unobscured vantage point. Photographs taken from each photo point will be used to subjectively evaluate the changes in light pollution. As shown in the time comparison photographs of Tucson in Figure 8, prima facie data can be collected which clearly demonstrate changes in the levels of light pollution. On one hand, it is obvious that light pollution has increased, and, on the other hand, it is difficult to determine quantitatively anything more than this. The significant difficulty is encountered when attempting to quantify increases or decreases in light pollution.

Research efforts in this area have developed procedures to measure light pollution in terms of change from a natural black-sky background. Changes are referenced to natural conditions and the difference is measured in terms of percentage increase and decrease. Therefore, observations from a photo point can provide data for both a subjective evaluation and quantification of light pollution changes in relative terms.

The method developed to quantify changes in light pollution for ORPI is a modified version of a formula developed by M. F. Walker called Walker's Law (Walker 1977). The formula for Walker's Law is as follows:

$$I = 0.01Pr^{-2.5}$$

Where I is the change in sky glow level as compared to a dark sky natural background,
P is population of the area under observation and r is the distance in kilometers from the point of observation to the source of sky glow looking at a zenith angle of 45° (Crawford 1985). This formula is used to estimate the change in sky glow at an observation site.

For example, suppose an observation site is located 20 km from the sky glow source which has a population of 30,000 people. The estimated value of I is 0.17 which indicates an increase in sky glow of 17 percent above the natural background. If the population increased to 50,000, the value of I would equal 0.28 or a 28% increase in sky glow and for a population of 5,000, there would be only a 3% increase. Results indicate that Walker's Law seems to have the best fit to communities where the average number of lumens per person is between 500 and 1,000. A lumen, in this case, is the average amount of light per capita emitted by outdoor lighting.

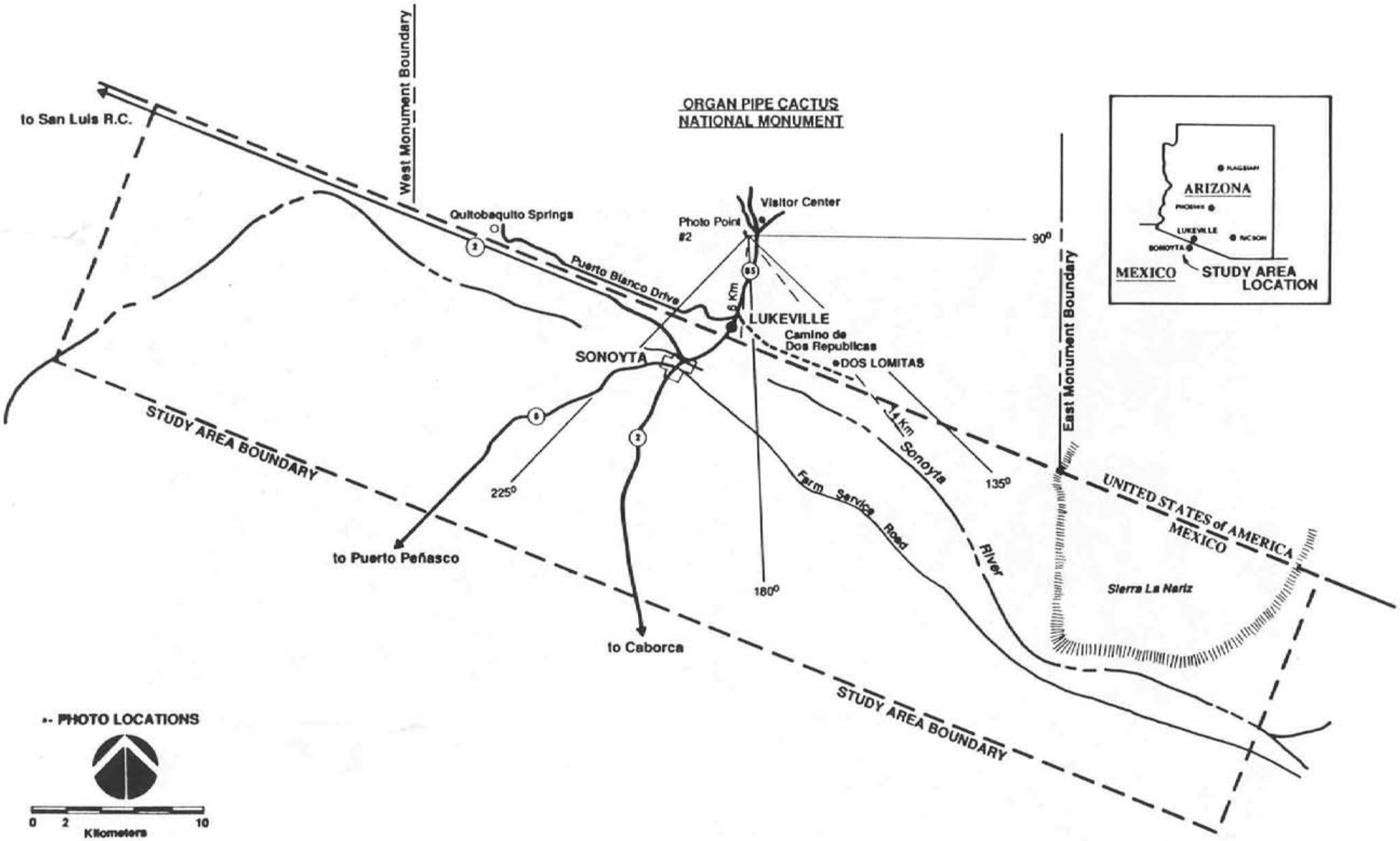

Figure 7. Light Pollution Photo Point 2.

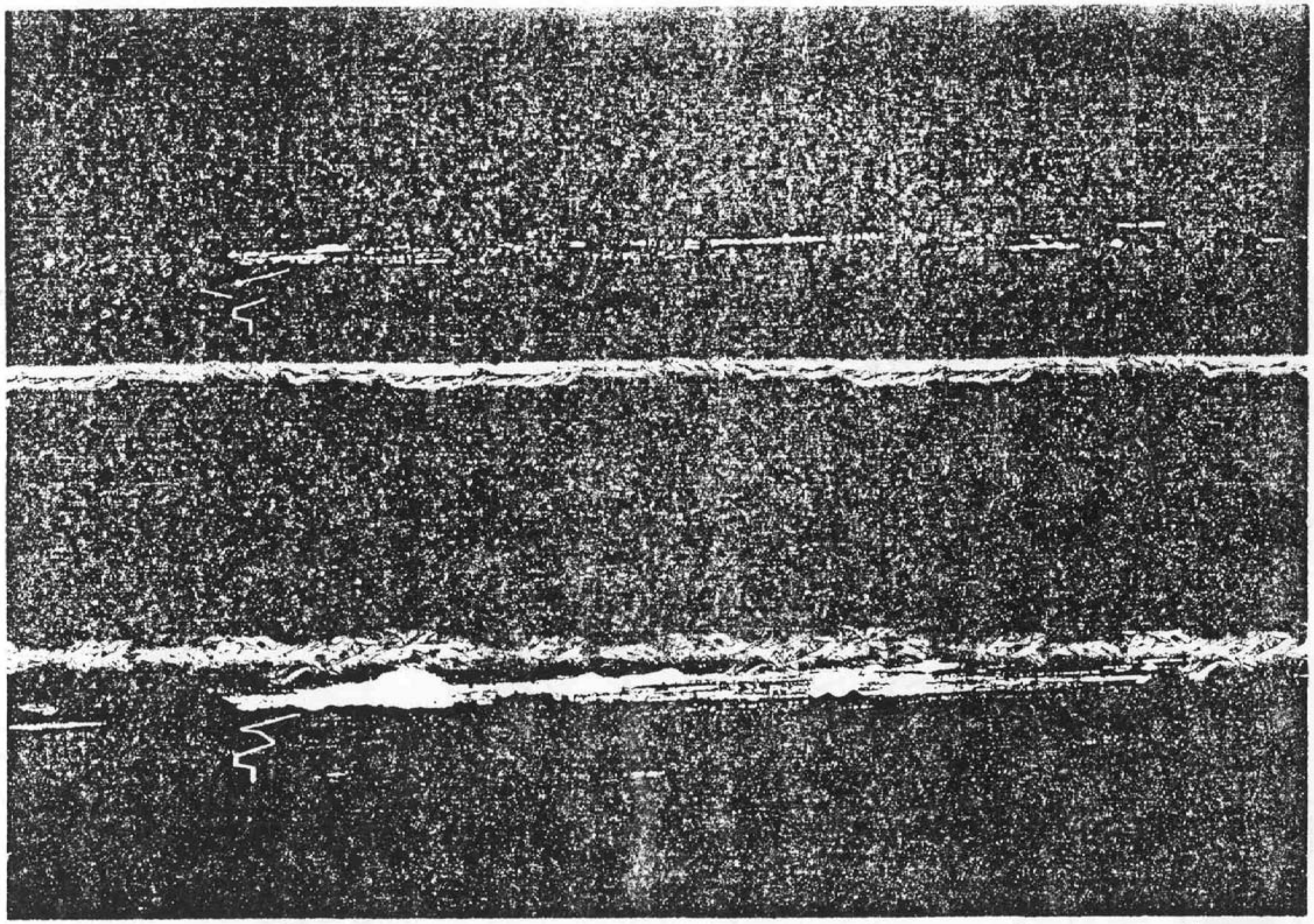

Figure 8. Composite photograph of Tucson, Arizona, from Kitt Peak National Observatory. Upper portion photographed in 1959 and lower portion photographed in 1980.

Source: "Light pollution: The adverse impact of urban sky glow on astronomy and on the environment," David L. Crawford, October 1985.

In applying Walker's Law, observations from a specific site will result in a constant distance or value of r and population is the variable reflecting changing conditions. Changes in population drive the end results of the equation. Therefore, once the distance is established for a designated observation site, the intensity of light pollution becomes a function of population growth.

One problem encountered with applying Walker's Law to the study area was estimating the lumens per person in Mexico. It is recognized that the lumens per person in the town of Sonoyta is substantially different from similar-sized urban areas in the U.S. This is primarily due to the differences in home and street lighting on a per capita basis as compared with similar lighting rates per capita in U.S. cities. Data related to specific light use or lumens per person for Sonoyta are not available.

A proxy variable was added to Walker's Law in order to take into account the difference in lighting characteristics mentioned above. This variable is based upon readily available data consisting of population and electrical use in Sonoyta. The variable has been developed to address a site-specific need of this study and is not intended as a universal modification to the formula.

The proxy variable is the estimated per capita use of electricity on a daily basis in the urban region of Sonoyta. It is developed by taking the average daily use of electricity in the month when observations are taken and dividing by the population of Sonoyta. For example, if observations were made from Photo Point 2 in November 1987, the total monthly use of electricity totalled 6,620,000 kwh (Comisión Federal de Electricidad 1987). When using the current estimated population of 15,000, the average daily per capita use of electricity is 14.711 kwh.

A basic assumption of the proxy variable is that the amount of electricity consumed per person is directly related to the intensity of nighttime sky glow. It is recognized that all electricity is not used for lighting. In fact, a significant portion of the presently consumed electricity in the Sonoyta Valley is used for pumping irrigation water. The largest amounts are consumed in the summer months of June, July and August and the smallest usage is during November and December. If data are taken from the periods where non-lighting usage is lowest, then the proxy variable will more closely reflect the amount of electricity consumed for illumination purposes. Inclusion of the proxy variable modifies the formula to the following:

$$I = (0.01Pr^{-2.5})E$$

Where E equals the per capita consumption of electricity in kwh. It is important to consider such a variable at the present time since electricity from the main grid has only been available to the Sonoyta Valley for the past few years and per capita use in the near future is expected to increase substantially.

BASELINE CONDITIONS

This section describes and quantifies baseline conditions for each of the light pollution photo points.

Photo Point 1

The area viewed from Photo Point 1 has been divided into two sectors as described in the previous section. Distances for each sector were estimated from the observation site to the main focal point of the observation. In the southern sector, the main focal point is the Rio Sonoyta at a distance of approximately 4.0 km.

The population of Sonoyta is estimated to be 15,000 as of November 1987. Total consumption of electricity for this same month was estimated to be 6,620,000 kwh, which results in a daily per capita usage rate of 14.711 kwh.

Employing the modified formula, a value of 68.96 is obtained which is equivalent to a 469% increase in sky glow over natural conditions. The reason such a large increase is calculated can be attributed to the proximity of the photo point to the source of urban sky glow. If the distance were doubled to 8 km, the resulting increase would only be 83 percent. Therefore, it is important to reiterate that the values derived for any one point are site-specific and should not be compared to values from other points. The values for any given photo point are relative and should only be used to measure changes from baseline conditions.

The southwestern sector covers a rural area containing only a few small farming communities. The distance to the main focal point of this quadrant is calculated to be 8.0 km and the population is estimated to be 200 people. Using these parameters in the modified formula results in a value of 0.1625, which equates to a 1.1% increase over natural black sky conditions. This value is quite representative of current baseline conditions in the area as very few nighttime illuminaries are observed.

In summary, baseline conditions for the southern sector have a value of 68.96 or a 469% increase over natural black sky. Baseline conditions for the southwestern sector are equivalent to a value of 0.1625 or a 1.1% increase over natural black sky.

Photo Point 2

Baseline conditions for Photo Point 2 are derived from the three sectors described above. The northeast sector has an estimated population of 1,000 people living throughout the area in rural households and communities. The focal point of this sector is calculated to be about 14 km from Photo Point 2. The distance and population parameters were used in the modified formula to calculate a value of 0.2006 which represents an approximate increase over a black-sky background of 1.4%, almost natural conditions.

Baseline estimates for the southern sector include a population of 16,000 and a focal point distance of 6 km. The modified formula value is 26.692 or about a 181% increase over natural conditions.

The southwestern sector is estimated to encompass a population of 200 people living in rural communities and farmsteads. A distance of 18 km has been calculated from Photo Point 2 to the focal point of this quadrant. This distance greatly influences the results of the modified formula as the value of 0.0214 is quite small and indicates a percentage increase of 0.15%, essentially natural conditions.

Baseline conditions for the two sectors in Photo Point 2 are as follows: southern, 26.692 (181% increase); and southwestern, 0.0214 (0.15% increase). The northeastern and southwestern sectors are not much different from a natural black-sky background.

Although present light pollution impacts on nighttime viewers in ORPI are not large, it is important to document existing conditions. This chapter has briefly described the procedure for monitoring light pollution which is more fully explained in the Land Use Monitoring Handbook.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Total cropped acreage increased steadily up to 1981 when approximately 20,000 a were in production. Farmed acreage and the numbers of wells have remained relatively constant since 1982. The most widely grown crop in 1987-88 was wheat, which occupied 44% of the total 22,455 irrigated acres in production. Percentages of the total area for other major crop acreages in 1987-88 were cotton, 16%; ryegrass, 9%; sesame, 8% alfalfa, 7%; and fruit trees, 6%. The remaining 20% consisted of vegetables, barley, sorghum, and assorted tree crops.

Groundwater withdrawals were approximately equal to recharge in 1978 and began to exceed groundwater recharge in 1979. Net depletion of the aquifer has steadily increased since 1979 to an estimated maximum level of 55,025 a-ft in 1987. The Mexican government is fully aware of the overdraft condition of the aquifer and has placed a moratorium on the drilling of new wells.

The estimated water withdrawal for 1987-88 estimated by Great Western Research is in the range of 80,000 a-ft, based upon available data. The overdraft of the groundwater aquifer is estimated to be 50,000 a-ft for this same period.

At the beginning of 1988, SARH listed a total of 212 wells in the Sonoyta Valley with 165 being used for irrigation. A moratorium is presently in effect which prohibits the development of new wells for irrigation.

Total pumping capacity and 1987-88 water withdrawals were also estimated by SARH to be 217,166 gpm and 83,152 a-ft, respectively. Total annual pumping capacity in the Sonoyta Valley is estimated to be 191,000 a-ft based on an average annual use of 200 days per year by all pumps. This is more than twice the rate of groundwater withdrawals for 1987-88. In view of the excess pumping capacity, groundwater withdrawals could easily double without drilling new wells by operating existing pumps more days throughout the year.

A moratorium is also currently in effect to limit the land developed for irrigated agriculture to the present 32,000 a. Approximately 20,000 a are currently being farmed, which is from 60 to 70% of the total developed area. Lands developed for irrigation are also in excess of the area currently being used for irrigated agriculture.

Although moratoria are currently in effect, a large increase in groundwater withdrawals could occur without the development of new water and land facilities due to the existing excess developed capacity in both resources. Nevertheless, under existing conditions, annual groundwater withdrawals will still be approximately 2.5 times the annual rate of recharge and the depth to water will continue to increase in the near future. Development of new agricultural lands and further development of water resources is highly dependent upon governmental funding of expansion programs.

Four different methods are recommended to monitor agricultural development in the Sonoyta Valley. The first method is based on establishing photo points which cover the agricultural area and monitor light pollution by comparing photographs from different periods in time to detect changes.

The second method is to take photographs of the agricultural area from the air. Again, the procedure is to compare photographs taken at different points in time and identify changing trends.

The third method is to rely on the annual data collected by SARH, which reports crops, acreages, and water volumes withdrawn for agriculture.

The fourth method is to compute the amount of water withdrawn for agricultural purposes based upon electrical consumption, pumping lifts and pump system efficiencies.

Light pollution impacts on ORPI consist of urban sky glow and light trespass. Most of the urban sky glow is emitted from the town of Sonoyta, while lesser amounts originate from Lukeville and rural areas on both the east and west sides of the Sonoyta Valley.

Sonoyta, the major source of sky glow, is partially shielded from direct view in the main campground and headquarters by the Sonoyta Mountains. Sources of most light trespass are inconsequential and cause only minor annoyance to nighttime viewing in ORPI. Light trespass is very minor at present but could increase, especially if the border crossing goes to a 24-hour schedule.

RECOMMENDATIONS

The following recommendations are made in order to systematically and effectively monitor land and water use in the Sonoyta Valley by ORPI personnel.

1. It is recommended that ORPI personnel maintain a working relationship with the SARH office in Sonoyta. Through this relationship it will be possible to:

    a. Obtain annual data on land and water use.

    b. Obtain annual electrical and water depth information.

    c. Estimate water withdrawals from SARH estimates and calculations using the energy consumption method.

2. It is recommended that ORPI personnel continue with the monitoring protocol using the agricultural and light pollution photo points. The agricultural photo points will provide visual information to support quantity estimates of land and water use. The light pollution photo points will document impacts and support calculations made of the relative values.

The estimated costs to perform the monitoring activities for 1988 are described below and assume that all activities are conducted by ORPI staff:

Field Work - 3 days	$ 600
Film and Processing	80
Evaluation - 5 days	1,000
Equipment	200
TOTAL	$1,880

FUTURE RESEARCH

Efforts expended in completing the results presented in this report have involved two areas outside of the scope of work that could be highly productive if additional research were conducted. The first involves improvements in monitoring the groundwater aquifer and the second area centers on enhancing the precision of measuring agricultural lands.

Groundwater Aquifer Database

The recommended research in this area involves expansion of the database containing information on the depth-to-water in the Sonoyta Valley initiated in the present report and development of a database on electrical consumption. The depth-to-water database developed in the present report contains information for years 1983 to 1987. Data for prior years can be obtained from SARH to expand the base of information. Annually, SARH measures the depths in most operating wells throughout the valley during the month of November and this information can be added to the database each year.

Concurrently, a database should be developed that includes the electrical consumption by well. Offices of the Comisión Federal de Electricidad in both Sonoyta and Puerto Peñasco should be consulted to obtain this information.

It will be possible to improve estimates of water withdrawals for many points throughout the valley using information from both databases. Once the initial databases are established, all information could be maintained and up-dated at ORPI Headquarters by members of the staff.

Measurement of Agricultural Lands

One of the conclusions of the present report was that, in order to effectively monitor the changes in agricultural land use, measurement of land areas was necessary. However, it should be noted that measurement of agricultural lands is not essential to developing reliable estimates of water use. Land measurement will involve aerial photography and an identification process for each field. Field measurements can be obtained from the photos along with cropped and non-cropped areas.

A procedure used by the Agricultural Stabilization and Conservation Service (ASCS) could be employed to establish and maintain up-to-date information on field sizes and areas in production. First, aerial photographs are taken of the area under consideration and then these photographs are used in a special machine to derive acreage estimates.

The procedure would involve aerial photography of the Sonoyta Valley and identification of ejidos and the various fields within each ejido. Measurements would be taken of all fields and a total agricultural area for each ejido could be estimated. Subsequent aerial photographs would be used to identify the fields in and out of production and changes in land use. It would be possible to identify most of the crops by supplementing the information on the aerial photographs with selected ground verification.

It is difficult to estimate the costs required to establish the type of land measurement system described above because of the uncertainty surrounding the potential arrangements and costs involved with a cooperative agreement between the Park Service and ASCS. Keeping this in mind, the costs to establish the system starting in 1988 are estimated below:

Aerial photographs	$1,000
Use of special machine	
ASCS?	
Private Company	8,000
Establishment of fields	4,000
Periodic changes	2,500

A safe estimate would be $20,000 for the first year and $10,000 for two flights per year and up-dating of land use changes each year thereafter.

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APPENDIX 1

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APPENDIX 2

AGRICULTURAL CHEMICAL USE IN SONOYTA VALLEY

Table 1. Application of agricultural chemicals, 1977-78, Sonoyta Valley, Mexico.

	Wheat	Cotton	Safflower	Alfalfa	Grapes	Fruit	TOTALS
FERTILIZERS*							
Urea	81.6	650.0	28.0	-	-	-	759.6
Triple Supersulphate	20.4	195.0	14.0	-	-	-	229.4
Ammonium Sulphate	-	-	-	160.8	-	9.6	170.4
TOTAL ACRES	204	1,300	140	268	-	16	1,928
PESTICIDES**							
Tamaron	-	0.8	-	-	-	-	0.8
Endrin	-	2.5	-	-	-	-	2.5
Azodrin	-	0.7	-	-	-	-	0.7
Parathion	-	2.4	-	-	-	-	2.4
Malathion	-	0.6	-	-	-	-	0.6
TOTAL ACRES	-	1,100	-	-	-	-	1,100

* Data in 1,000 kilograms applied, rounded to nearest 100 kilograms.
** Data in 1,000 liters applied, rounded to nearest 100 liters.

Source: Secretaría de Agricultura y Recursos Hidráulicos, Sonoyta, Sonora.

APPENDIX 2 (Continued)

Table 2. Application of agricultural chemicals, 1978-79, Sonoyta Valley, Mexico.

	Wheat	Cotton	Safflower	Alfalfa	Grapes	Fruit	Sesame	Beans	Corn	TOTALS
FERTILIZERS*										
Urea	93.2	330.0	14.0	-	5.0	-	40.2	-	9.0	491.4
Triple Supersulphate	69.9	285.5	-	-	-	-	20.1	-	4.5	380.0
Ammonium Sulphate	186.4	75.0	-	39.2	-	64.8	-	1.2	-	366.6
TOTAL ACRES	466	1,903	70	98	50	18	201	6	45	2,857
PESTICIDES**										
Tamaron	-	0.8	-	-	-	-	-	-	-	0.8
Endrin	-	3.0	-	-	-	-	-	-	-	3.0
Azodrin	-	1.5	-	-	-	-	-	-	-	1.5
Parathion	-	4.8	-	-	-	-	-	-	-	4.8
Folimat	-	0.6	-	-	-	-	-	-	0.6	
TOTAL ACRES	-	1,500	-	-	-	-	-	-	-	1,500

* Data in 1,000 kilograms applied, rounded to nearest 100 kilograms.
** Data in 1,000 liters applied, rounded to nearest 100 liters.

Source: Secretaría de Agricultura y Recursos Hidráulicos, Sonoyta, Sonora.

APPENDIX 2 (Continued)

Table 3. Application of agricultural chemicals, 1979-80, Sonoyta Valley, Mexico.

	Wheat	Cotton	Barley	Alfalfa	Grapes	Fruit	Sesame	Beans	Corn	Garlic	TOTALS
FERTILIZERS*											
Urea	95.7	1,347.6	1.2	61.6	9.1	-	17.0	-	12.6	1.8	1,546.6
Triple Supersulphate	47.9	336.9	0.4	60.8	-	-	8.	1.5	6.3	-	462.3
Ammonium Sulphate	63.8	30.0	-	90.0	-	3.6	-	4.5	-	-	191.9
TOTAL ACRES	319	3,369	4	608	91	18	85	15	63	6	4,578
PESTICIDES**											
Tamaron	-	1.5	-	0.5	0.1	-	-	-	-	-	2.1
Endrin	-	7.5	-	-	-	-	-	-	-	-	7.5
Azodrin	-	2.5	-	-	-	-	-	-	-	-	2.5
Parathion	-	13.5	-	-	-	-	-	-	-	-	13.5
Treflan	-	6.6	-	-	-	-	-	-	-	-	6.6
Thiodan	-	5.0	-	-	-	-	-	-	-	-	5.0
Folimat	-	0.8	-	0.4	-	-	-	0.01	-	-	1.2
TOTAL ACRES	-	3,150	-	600	91	-	-	15	-	-	3,856

* Data in 1,000 kilograms applied, rounded to nearest 100 kilograms.
** Data in 1,000 liters applied, rounded to nearest 100 liters.

Source: Secretaría de Agricultura y Recursos Hidráulicos, Sonoyta, Sonora.

APPENDIX 2 (Continued)

Table 4. Application of agricultural chemical, 1980-81, Sonoyta Valley, Mexico.

	Wheat	Cotton	Veg.	Alfalfa	Grapes	Fruit	Sesame	Beans	Corn	Forage	TOTALS
FERTILIZERS**											
Urea	170.0	917.8	-	161.4	2.5	-	3.0	-	2.7	5.0	1,262.4
Triple Supersulphate	85.0	367.1	0.8	-	-	-	1.0	2.5	1.4	2.5	460.3
Anhydrus Ammonia	60.0	310.0	-	-	-	-	-	-	-	-	370.0
Ammonium Sulphate	40.0	-	3.0	-	-	11.2	-	7.5	-	-	61.7
TOTAL ACRES	850	3,671	25	807	25	28	10	25	9	25	5,475
PESTICIDES**											
Tamaron	-	2.1	-	0.6	-	-	-	-	-	2.7	
Endrin	-	7.2	-	-	-	-	-	-	-	-	7.2
Sevin 80	-	5.5	-	-	-	-	-	-	-	-	5.5
Parathion	-	16.5	-	-	-	-	-	-	-	-	16.5
Decis	-	1.6	-	-	-	-	-	-	-	-	1.6
Thiodan	-	7.3	-	-	-	-	-	-	-	-	7.3
Treflan	-	8.4	-	-	-	-	-	-	-	-	8.4
Belmark	-	0.9	-	-	-	-	-	-	-	-	0.9
Folimat	0.3	1.8	-	0.2	-	-	-	0.1	-	-	2.4
TOTAL ACRES	500	3,671	-	607	-	-	-	25	-	-	4,803

* Data in 1,000 kilograms applied, rounded to nearest 100 kilograms.
** Data in 1,000 liters applied, rounded to nearest 100 liters.

Source: Secretaría de Agricultura y Recursos Hidráulicos, Sonoyta, Sonora.

Table 5. Application of agricultural chemical, 1981-82, Sonoyta Valley, Mexico.

	Wheat	Cotton	Veg.	Alfalfa	Grapes	Fruit	Sesame	Beans	Corn	Forage	TOTALS
FERTILIZERS*											
Urea	363.4	700.0	10.2	227.2	-	-	-	20.0	78.3	4.5	1,403.6
Triple Supersulphate	222.0	340.0	-	-	-	-	-	10.0	26.1	-	598.1
Anhydrus Ammonia	180.7	250.0	-	-	-	-	-	-	13.1	-	444.8
Ammonium Sulphate	-	-	-	-	12.6	60.0	204.0	-	-	-	276.6
TOTAL ACRES	1,817	3,000	34	1,136	42	20	51	100	261	15	6,476
PESTICIDES**											
Tamaron	-	3.0	-	0.7	-	-	-	-	-	-	3.7
Endrin	-	6.0	-	-	-	-	-	-	-	-	6.0
Sevin 80	-	6.0	-	-	-	-	-	-	0.5	-	6.5
Parathion	-	16.8	-	-	-	-	-	-	-	-	16.8
Decis	-	1.4	-	-	-	-	-	-	-	-	1.4
Thiodan	-	7.5	-	-	-	-	-	-	-	-	7.5
Treflan	-	6.8	-	-	-	-	-	-	-	-	6.8
Belmark	-	1.1	-	-	-	-	-	-	-	-	1.1
Folimat	0.3	0.6	-	-	-	-	-	0.04	-	-	0.9
TOTAL ACRES	817	3,000	-	700	-	-	-	100	261	-	4,878

* Data in 1,000 kilograms applied, rounded to nearest 100 kilograms.
** Data in 1,000 liters applied, rounded to nearest 100 liters.

Source: Secretaría de Agricultura y Recursos Hidráulicos, Sonoyta, Sonora.

Table 6. Application of agricultural chemicals, 1982-83, Sonoyta Valley, Mexico.

	Wheat	Cotton	Veg.	Alfalfa	Grapes	Fruit	Sesame	Beans	Corn	Sorgo G.	TOTALS
FERTILIZERS**											
Urea	603.3	640.0	4.2	297.9	-	-	60.0	3.4	4.0	0.6	1,613.4
Triple Supersulphate	201.1	320.0	2.1	-	-	-	30.0	1.7	1.6	-	556.5
Anhydrus Ammonia	201.1	279.0	-	-	-	-	18.0	-	1.6	-	499.7
Ammonium Sulphate	-	-	-	-	-	127.0	-	-	-	-	127.0
TOTAL ACRES	2,011	3,200	14	993	-	635	300	17	16	2	7,188
PESTICIDES**											
Tamaron	-	2.5	-	-	-	-	-	-	-	-	2.5
Endrin	-	7.8	-	-	-	-	-	-	-	-	7.8
Sevin 80	-	6.2	-	-	-	-	-	-	-	0.1	6.3
Azodin	-	4.5	-	-	-	-	-	-	-	-	4.5
Parathion	0.5	21.7	-	-	-	-	-	-	-	-	22.2
Decis	-	5.4	-	-	-	-	-	-	-	-	5.4
Thiodan	-	7.8	-	-	-	-	-	-	-	-	7.8
Treflan	-	6.2	-	-	-	-	-	-	-	-	6.2
Belmark	-	1.5	-	-	-	-	-	-	-	-	1.5
Folimat	-	-	-	0.4	-	-	-	-	-	-	0.4
TOTAL ACRES	4500	3,100	-	993	-	-	-	-	-	16	4,559

* Data in 1,000 kilograms applied, rounded to nearest 100 kilograms.
** Data in 1,000 liters applied, rounded to nearest 100 liters.

Source: Secretaría de Agricultura y Recursos Hidráulicos, Sonoyta, Sonora.

APPENDIX 2 (Continued)

Table 7. Application of agricultural chemicals, 1983-84, Sonoyta Valley, Mexico.

	Wheat	Cotton	Veg.	Alfalfa	Grapes	Fruit	Sesame	Beans	Corn	Forage	TOTALS
FERTILIZERS*											
Urea	42.6	1,021.0	-	218.1	-	20.3	68.8	5.0	20.7	3.2	1,399.7
Triple Supersulphate	21.3	510.5	1.8	-	-	-	31.9	2.5	6.9	1.6	576.5
Anhydrus Ammonia	21.3	510.5	-	-	-	-	7.2	-	-	-	539.0
Ammonium Sulphate	-	285.0	10.8	-	-	160.0	-	-	-	-	455.8
TOTAL ACRES	213	5,105	18	727	-	935	319	25	69	16	7,427
PESTICIDES**											
Tamaron	-	4.5	-	0.4	-	-	-	-	-	-	4.9
Endrin	-	10.2	-	-	-	-	-	-	-	-	10.2
Sevin 80	-	5.0	-	-	-	-	-	-	0.2	-	5.2
Azodin	-	4.1	-	-	-	-	-	-	-	-	4.1
Parathion	-	20.3	-	-	-	-	-	-	-	-	20.3
Decis	-	3.4	-	-	-	-	-	-	-	-	3.4
Thiodan	-	8.4	-	-	-	-	-	-	-	-	8.4
Bayleton	-	5.1	-	-	-	-	-	-	-	-	5.1
Treflan	-	9.4	-	-	-	-	-	-	-	-	9.4
Belmark	-	1.4	-	-	-	-	-	-	-	-	1.4
Folimat	-	1.0	-	-	-	0.1	-	-	-	-	1.1
TOTAL ACRES	-	5,105	-	727	-	135	-	-	69	-	6,036

* Data in 1,000 kilograms applied, rounded to nearest 100 kilograms.
** Data in 1,000 liters applied, rounded to nearest 100 liters.

Source: Secretaría de Agricultura y Recursos Hidráulicos, Sonoyta, Sonora.

APPENDIX 2 (Continued)

Table 8. Application of agricultural chemicals, 1984-85, Sonoyta Valley, Mexico.

	Wheat	Cotton	Veg.	Alfalfa	Sorgo G.	Fruit	Sesame	Beans	Corn	Forage	TOTALS
FERTILIZERS*											
Urea	449.4	540.0	-	140.8	9.9	13.0	23.4	37.8	15.6	5.2	1,235.1
Triple Supersulphate	224.7	270.0	9.0	-	3.3	120.0	11.7	18.9	7.8	2.6	668.0
Anhydrus Ammonia	198.1	270.0	-	-	-	-	7.0	-	-	-	475.1
Ammonium Sulphate	-	-	45.0	-	-	160.0	-	-	-	-	205.0
TOTAL ACRES	1,981	2,700	90	704	33	530	117	189	78	26	6,448
PESTICIDES**											
Tamaron	-	2.7	-	0.5	-	-	-	-	-	-	3.2
Endrin	-	5.4	-	-	-	-	-	-	-	-	5.4
Cimbu Sh.	-	0.9	-	-	-	-	-	-	-	-	0.9
Azodin	-	1.9	-	-	-	-	-	-	-	-	1.9
Parathion	-	13.1	-	-	-	-	-	-	-	-	13.1
Decis	-	0.9	-	-	-	-	-	-	-	-	0.9
Thiodan	-	6.8	-	-	-	-	-	-	-	-	6.8
Bayleton	-	2.7	-	-	-	-	-	-	-	-	2.7
Treflan	-	5.4	-	-	-	-	-	-	-	-	5.4
Belmark	-	0.9	-	-	-	-	-	-	-	-	0.9
Folimat	0.7	1.0	-	0.4	-	-	-	0.04	-	-	2.14
TOTAL ACRES	1,300	2,700	-	450	-	-	-	89	-	-	4,539

* Data in 1,000 kilograms applied, rounded to nearest 100 kilograms.
** Data in 1,000 liters applied, rounded to nearest 100 liters.

Source: Secretaría de Agricultura y Recursos Hidráulicos, Sonoyta, Sonora.

APPENDIX 2 (Continued)

Table 9. Application of agricultural chemicals, 1985-86, Sonoyta Valley, Mexico.

	Wheat	Cotton	Veg.	Alfalfa	Sorgo G.	Fruit	Sesame	Beans	Corn	Forage	TOTALS
FERTILIZERS*											
Urea	975.5	123.0	29.5	165.6	10.4	-	34.8	137.5	19.6	101.8	1,597.7
Triple											
Supersulphate	39.0	41.0	18.2	55.2	5.2	361.1	17.4	91.7	9.8	27.1	665.7
Anhydrus Ammonia	390.2	32.8	-	16.0	5.2	-	13.9	12.6	9.8	19.4	500.0
Ammonium Sulphate	-	-	-	-	-	357.8	-	-	-	-	357.8
TOTAL ACRES	3,902	410	114	552	52	578	174	917	98	271	7,068
PESTICIDES**											
Tamaron	-	0.4	-	0.2	-	-	-	-	-	-	0.6
Nuvacron	-	0.6	-	-	-	-	-	-	-	-	0.6
MZ 330	-	0.8	-	-	-	-	-	-	-	-	0.8 kgs
Sevin 80	-	0.8	-	-	-	-	-	-	0.2	-	1.0 kgs
Parathion	-	2.5	-	-	-	-	-	-	-	-	2.5
Decis	-	0.4	-	-	-	-	-	-	-	-	0.4
Thiodan	-	1.0	-	-	-	-	-	-	-	-	1.0
Bayleton	-	0.2	-	-	-	-	-	-	-	-	0.2
Treflan	-	0.8	-	-	-	-	-	-	-	-	0.8
Belmark	-	0.2	-	-	-	-	-	-	-	-	0.2
Folimat	-	0.2	0.1	0.2	-	0.2	-	0.1	-	-	0.8
TOTAL ACRES	-	410	47	496	-	496	-	180	98	-	1,727

* Data in 1,000 kilograms applied, rounded to nearest 100 kilograms.
** Data in 1,000 liters applied, rounded to nearest 100 liters.

Source: Secretaría de Agricultura y Recursos Hidráulicos, Sonoyta, Sonora.

APPENDIX 2 (Continued)

Table 10. Application of agricultural chemicals, 1986-87, Sonoyta Valley, Mexico.

	Wheat	Cotton	Veg.	Alfalfa	Sorgo G.	Fruit	Sesame	Beans	Corn	Forage	TOTALS
FERTILIZERS*											
Urea	832.0	154.2	32.4	274.4	40.8	16.8	109.8	7.8	33.6	154.0	1,655.8
Triple Supersulphate	414.7	77.1	8.1	68.6	13.6	336.8	54.9	3.9	16.8	398.5	1,393.0
Anhydrus Ammonia	413.4	92.5	-	23.7	13.6	-	43.9	2.0	16.8	62.3	668.2
Ammonium Sulphate	-	-	-	-	-	355.4	-	-	-	-	355.4
TOTAL ACRES	4,146	771	81	686	136	565	549	39	168	553	7,694
PESTICIDES**											
Tamaron	-	0.9	0.1	0.3	-	-	-	-	-	-	1.3
Nuvacron	-	1.2	-	-	-	-	-	-	-	-	1.2
MZ 330	-	3.1	-	-	-	-	-	-	-	-	3.1 kgs
Sevin 80	-	-	-	-	0.3	-	-	-	0.2	-	0.5 kgs
Parathion	-	4.6	-	-	-	-	-	-	-	-	4.6
Decis	-	0.4	-	-	-	-	-	-	-	-	0.4
Thiodan	-	1.9	-	-	-	-	-	-	-	-	1.9
Treflan	-	1.5	-	-	-	-	-	-	-	-	1.5 kgs
Belmark	-	0.3	-	-	-	-	-	-	-	-	0.3
Folimat	-	0.8	0.1	0.2	-	0.4	-	-	-	-	1.5
TOTAL ACRES	-	771	81	473	136	393	-	-	80	-	1,934

* Data in 1,000 kilograms applied, rounded to nearest 100 kilograms.
** Data in 1,000 liters applied, rounded to nearest 100 liters.

Source: Secretaría de Agricultura y Recursos Hidráulicos, Sonoyta, Sonora.

The cover photograph was taken October 4, 1935, in Saguaro National Monument by the first National Park Service photographer, George Alexander Grant (1891-1964).

As the nation's principal conservation agency, the U.S. Department of the Interior has responsibility for most of our nationally owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting fish, wildlife and plants, preserving the environmental and cultural values of national parks and historic places, and providing for enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.