Coping with Drought: An Analysis of Crisis Responses in the Yaqui Valley

by

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Submitted to the Earth Systems Program
in Partial Fulfillment of the Master of Science Degree Requirements

May 20, 2005

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ACKNOWLEDGEMENTS

First and foremost, I would like to thank Texaco and the Center for Environmental Science and Policy at Stanford (via the Packard Foundation) for the financial support that allowed this research to happen.

This project would not have been possible without the support of my Stanford advisors - Wally Falcon, who always made time to provide guidance and inspiration, and Roz Naylor, who was an excellent source of wonderful advice.

My research benefited immensely through collaboration with other members of the Yaqui Valley research team. Thanks especially to Pam Matson for her leadership of the team, Ivan Ortiz-Monasterio for his warm welcome at CIMMYT and thoughtful insight, Jose Luis Minjares for arranging countless interviews in the Yaqui Valley and being so generous with his time, Lee Addams for invaluable field counsel, David Lobell for asking all the right questions, and David Battisti for his climate insight. Thanks also to Ashley Dean, Lori McVay, Mary Smith, Amy Luers, Karen Seto, and Marshall Burke.

I would also like to thank individuals in Mexico who continuously amazed me with their willingness to converse openly and generosity in sharing data and insight. I would especially like to thank all of the farmers in the Yaqui Valley who so graciously participated in the field surveys. Thanks to Dagoberto Flores for coordinating the second survey and providing an interesting historical perspective on the Valley's development. I would also like to thank the employees of the *Distrito de Riego del Rio Yaqui*, especially Guadalupe Chavez and Ing. Humberto Borbón for being incredibly generous with irrigation records. Thanks also to Dolores Vasquez and Gustavo Adolfo (CIMMYT), Ing. Ramón Romero and Ing. Raúl Safinas (*Unión de Crédito Agricola Cajeme*), Profr. Pedro Valenzuela (*Distrito de Riego del Rio Yaqui*), Victor Aviles (AAVY), Dr. Pedro Brajchich (PIEAES), and Ing. Felix Gonzalez (SAGARPA).

Thanks also to Julie Kennedy and Deana Fabbro-Johnston from the Earth Systems program for their endless support and encouragement.

ABSTRACT

This study addresses regional responses to a drought in the Yaqui Valley, an irrigated, wheat-dominated coastal plain in Northwestern Mexico. An eight-year period of low rainfall culminated in the 2003-2004 crop year, when reservoir storage reached an unprecedented low. This paper includes discussion of major factors that contributed to the onset of the 2003-2004 water crisis and analysis of both the long-term and short-term responses of policymakers, water managers, and farmers. The content is largely based on two surveys conducted with Yaqui Valley producers during the peak of drought conditions, interviews with regional decision makers, irrigation data, and public records. Although rainfall deficits in Northwestern Mexico have been linked with climate change induced by greenhouse gases, the onset of the water crisis was precipitated by a failure of institutions to respond dynamically to falling reservoir levels. In 2003-2004, the user-operated Yaqui River Irrigation District doubled the volumetric price of water and replaced conjunctive use of surface and groundwater with groundwater pumping only, which allowed for irrigation of only 17% of the district. Policymakers responded to water shortages by drilling new wells to augment supply, rationing available water by crop and field location to limit demand, and adjusting social support programs to mitigate the drought's effects on incomes. Records and surveys confirmed that farmers who gained access irrigation water applied it to crops in the same doses as in other years. Regulations surrounding government authorization of planting area limited farmers' ability to decrease volumetric use, as did constraints imposed by credit providers. Producers more commonly adjusted their irrigation water requirements through cropping decisions rather than decreasing the volume of irrigation water applied per crop. Farmers switched to priority crops, which included safflower, cotton, fruits, vegetables, maize, and alfalfa, in order to gain water access. Fruit and vegetable cultivation were sill uncommon due to by high production costs, volatile markets, and difficulty obtaining credit. A few farmers invested in pressurized irrigation systems but only for use on fruits and vegetables. The drought also catalyzed long-term responses from valley decision makers to modernize water transport infrastructure and adopt risk-minimizing rules for reservoir management. Combining system-level and field-level efficiency improvements without compromising groundwater resources or coastal ecosystems will be a major challenge for water managers and farmers alike over the next years. However, current regulatory disincentives and farmer risk adversity create sizeable barriers against a transition towards a more sustainable operational paradigm within the agricultural sector.

Keywords: drought; irrigation; drought management; conjunctive use; agricultural diversification; agricultural development; Mexico; Yaqui Valley.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS iii

ABSTRACT iv

TABLE OF CONTENTS v

LIST OF TABLES vi

LIST OF FIGURES vii

OVERVIEW AND HISTORY 1

- Introduction 1
- History and Background 3
- Shocks to the Yaqui Valley 7
- Drought Strikes the Yaqui Valley 8

DROUGHT RESPONSES 12

- System-Level Drought Adjustments 12
- Producer Adjustments in Supply 15
- Producer Adjustments in Demand 18

POLICY OPTIONS AND FUTURE OUTLOOK 23

- Farmer Incentives to Adjust Water Use 23
- Drought Impacts in the Yaqui Valley 28
- Improving Water Management 33
- Future Trajectories 37

REFERENCES 42

TABLES AND FIGURES 46

APPENDIX A 60

LIST OF TABLES

1. Regional policies responding to drought…………………………………………...46

2. Role of credit unions in farmer decision-making…………………………………..46

3. Preventative drought investments in the Yaqui Valley……………………………..47

LIST OF FIGURES

1. Location of the Yaqui Valley……………………………………………………………48

2. Comparison of world wheat yields to the Yaqui Valley…………………………...49

3. Aggregate agricultural revenue of the Yaqui Valley over time and in 2003-2004, based on average prices and yields……………………………..…………….50

4. Yaqui River reservoir system, October reservoir storage………………………….51

5. Crop area planted with public irrigation water in the Yaqui Valley, 1999-2004….52

6. Relative decrease in area irrigated between 2002/03 and 2003/04, compared with relative decrease in water application rates…………………………………..53

7. Spatial representation of cropping differences between 2002-2003 and 2003-2004…………………………………………………………………………….54

8. Average district-wide irrigation rates per crop, 1999-2004………………………..55

9. (a) Total revenue, production costs, and net revenue generated by crop…………..56
   (b) Gross and net water productivity by crop …………………………………...57
   (c) Water as a percentage of net revenue and production costs by crop…………...58

10. Categorization of typical wheat production costs using different water prices……59

OVERVIEW AND HISTORY

Introduction

Drought affects water users, water managers and regional policymakers particularly in agricultural and industrial systems where economic activity depends entirely on water use. Water shortages in irrigated agricultural systems with high capacities for water storage can result not only from prolonged periods of sub-average rainfall but also from the water management decisions made in the context of a rainfall regime. Drought's interesting combination of physical and anthropometric causes, as well its far-reaching impacts, make it an excellent subject for an integrated, interdisciplinary study addressing its effects and responses.

Drought has been investigated from a wide range of disciplines across a wide range of regions. Some climatologists have studied drought in the context of climate variability (Hare 1985), while others have developed models to predict it (Cordery 1987; Klemes 1987). Studies have attempted to measure drought's economic impacts (e.g. Easterling and Riebsame 1987), and to devise methods to plan for or respond to drought with regional policies (Fontane and Frevert 1995; Lovett 1973; Sonka 1987; Wilhelmi and Wilhite 2002). Economists have looked to water markets to inform drought responses (Characklis et al. 1999), while agronomists have studied crop responses to water application in drought settings (English 1990; Miller 1993; Ortiz-Monasterio et al. 2001). More recently, a drought study by Ray and Gul used predictive models to evaluate economically optimal responses to drought both for farmers and water managers (1999).

Although drought studies have pervaded many different disciplines, few have approached drought from multiple disciplines and scales at the same time. This paper aims to integrate economic, agronomic, ecological and social analyses, all of which provide vital insight into how drought has affected the Yaqui Valley region and provoked responses within it. The Yaqui Valley is an irrigated coastal plain in southern Sonora, Mexico where lower-valued crops, mostly wheat, are intensively cultivated. An eight-year period of low rainfall culminated in the 2003-2004 crop year[1], which brought historically low reservoir levels - including the pumping of dead reservoir storage - to the valley. Water managers were then forced to cease agricultural surface water diversions and reassess water's role in the Yaqui Valley's agricultural sector.

In this study, the current Yaqui Valley drought is examined in the context of other recent social, economic, political and biophysical shocks to the agricultural system. The paper discusses major factors that contributed to the onset of the 2003-2004 water crisis and analyzes both the long-term and short-term responses of policymakers, water managers and farmers to the drought. Factors that limited dynamic adjustments in response to the drought are considered. The paper describes the drought's social, economic, and environmental impacts on different groups within the valley and analyzes current public and private investment trends that could affect future water-use decisions in the Yaqui Valley.

The content of this paper is largely based on two farmer surveys conducted in the Yaqui Valley during the 2003-2004 crop year. In the first, administered in November of

[1] The agricultural crop year, in this piece and in the Yaqui Valley, starts on October 1 and ends the following September 1. The fall-winter crop cycle concludes at the end of March and is followed by the spring-summer crop cycle.

2003 by the author, 76 producers were surveyed at subsidy distribution centers and credit unions throughout the valley. The second survey, conducted by Dagoberto Flores in March of 2004, reached 88 producers, who were sampled randomly from a complete list of those who sowed wheat in the Yaqui Valley during the previous year[2]. While the first survey focused on farmer responses to drought specifically during the 2003-2004 crop year, the second addressed farmer decision-making processes more generally[3]. Key producer variables which are discussed in this paper, such as access to irrigation water during the 2003-2004 crop year, *ejido* status, irrigation water sources, and credit sources, were similarly represented in both surveys. Complete valley-wide irrigation records, generously made available by the Yaqui River Irrigation District, provided field-level cropping and irrigation data. Finally, the author relied heavily on interviews held with 40 different public officials and representatives from local agricultural organizations to form the arguments in this analysis.

History and Background

The Yaqui Valley, home of the wheat Green Revolution for wheat, makes an excellent subject for a case study on intensive agriculture in the developing world. The Yaqui Valley consists of 233,000 hectares of intensively cultivated land in southern Sonora, Mexico (Figure 1). Modern day agriculture in the Yaqui Valley has its roots in private investments made around the turn of the century (Naylor et al. 2001). By 1936, shares of the private company were transferred to the Mexican federal government,

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[2] A survey conducted by the Center for Environmental Science at Stanford during the 2002-2003 crop year sampled producers randomly from the very same list.
[3] Both producer questionnaires can be found as Appendix A to this paper.

which soon began to construct the three dams in the Yaqui River watershed that were originally designed by the private irrigation company. Construction of the first two dams was completed by 1953 and was soon followed by rapid expansion in total cultivated area, which swelled from 50,000 ha in 1937 to 210,000 ha in 1955.

During the 1960's, improved Green Revolution wheat varieties were introduced to Yaqui Valley farmers by an international team of scientists working at the Yaqui Valley research station of the International Maize and Wheat Breeding Center (*Centro Internacional de Mejoramiento de Maiz y Trigo*, or CIMMYT) [4]. Within one year, virtually all wheat germplasm planted in the valley descended from the Green Revolution varieties. Since 1965, CIMMYT varieties have remained universal among Yaqui Valley wheat farmers, and total area cultivated has hovered around 300,000 ha per year, divided amongst fall-winter, spring-summer and perennial cultivation.

Wheat has always dominated the cropping patterns in the Yaqui Valley, thanks to favorable biophysical conditions for its cultivation, locally developed breeding innovations, and a generous, reliable endowment of surface irrigation water. Cotton, soybeans and maize have all, successively, played important roles during the spring-summer crop cycle, a cropping period left largely vacant since 2002 due to drought. While some farmers in the Yaqui Valley have cultivated a diverse set of grains, oilseeds, vegetables and fruits, most have not expanded their cropping portfolios beyond wheat, maize, cotton and soybeans.

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[4] CIMMYT is one of 15 agricultural research centers, known as "Future Harvest" centers, that are funded by the Consultative Group on International Agricultural Research (CGIAR). CIMMYT's main research station is located in the Yaqui Valley and develops virtually every wheat variety planted there.

The Yaqui Valley is home to around 400,000 people, most of whom live in Ciudad Obregón, one of Sonora's largest cities (INEGI 2000). A number of very small towns located throughout the valley house the remainder of its population. Land in the Yaqui Valley is owned and operated by three distinct types of producers: private sector, public sector (or *ejiditarios*), and the Yaqui Amerindians. Private sector farmers retain full property ownership, and in the Yaqui Valley, they tend to supplement their land holdings by renting in more land. Public sector farmers own *ejidal* land. *Ejidos* were established in Mexico after the Mexican Revolution in 1917, when the government expropriated vast amounts of land from large private landholders for peasant settlement. In the Yaqui Valley, it is still quite common for *ejiditarios* to farm their land, yet many have begun to rent out their land to other producers, most commonly from the private sector (see Lewis 1999). *Ejiditarios* own about 50% of the Yaqui Valley, but they operate only 20% of it, citing difficulty in obtaining credit as a common reason for their egress from agricultural production (Leyva Mendivil 2004). A third group of landowners, the Yaqui Amerindians, collectively owns land in and around the Yaqui River to the north of the valley, which is serviced by a different irrigation district. The Yaqui Amerindians rent the majority of their land holdings to private producers. Yaqui territories differ from the rest of the valley in that, by Presidential decree, they have first priority to reservoir water (Addams 2004), and therefore were the only ones to receive reservoir water for irrigation during the 2003-2004 crop year[5] (Minjares 2003).

[5] It is also interesting to note that the Yaqui Territories are one of two agricultural areas in Mexico that have not been incorporated into privatized irrigation districts. The National Water Comission still handles water allocation to individual producers in the territories, and water is sold by irrigated area, not volume (CNA 1992).

Perhaps the Yaqui Valley's heavy reliance on irrigation water is its most defining characteristic. Hot temperatures mean high rates of evapotranspiration, yet the Valley commonly receives little to no appreciable rainfall during the entire wheat growing season (INEGI 1993). Today, the Yaqui Valley is still served by irrigation infrastructure conceived by entrepreneurs at the start of the 20th Century. This system includes over 2,700 km of main, lateral and secondary irrigation canals that deliver over 2 billion m^3 of reservoir water each year to the valley's farmers (Distrito de Riego del Rio Yaqui 2003). Fed with water from the Yaqui River that is stored in three upstream reservoirs, the irrigation infrastructure reaches 220,000 of the valley's 233,000 ha. Throughout virtually all of the Valley's history, surface water supplies have been generous and relatively stable due to the generous endowment provided by the Yaqui River watershed, which drains nearly 72,000 km^2 in Sonora, Chihuahua and Arizona.

Traditionally, surface water has accounted for over 90% of irrigation water applied in the Yaqui Valley (Addams 2004); however, groundwater played an increasing role as a source of irrigation water as the drought progressed. Until 2003, groundwater was used conjunctively with reservoir water to stretch diminishing surface supplies. Conjunctive use allowed the Irrigation District to expand the total deliverable volume of water without increasing its salinity or cost of delivery to intolerable levels. In 2003-2004, drought conditions forced the Irrigation District to replace conjunctive use with groundwater use only. Farmers paid more than double the highest historical price for the worst quality water they had ever bought[6].

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[6] Even after water prices doubled (from M$ 65 to M$ 135 per thousand cubic meter), water remained a bargain by international standards (Dinar 2000).

Most wells in the Yaqui Valley are publicly owned by the Irrigation District and release water directly into the irrigation canals. However, 113 of the valley's 265 wells are privately owned. These private wells together pump 25% of the valley's total groundwater concession. Water from private wells is subject only to regulation of total pumping. Farmers using private well water, in theory, can apply as much or as little as they wish to their crops. Water from public wells is distributed through the Irrigation District and sold volumetrically to farmers just as surface water is. The presence of both public and private wells in the valley allow for an interesting opportunity to study the consequences of the Irrigation District's water management policies.

Shocks to the Yaqui Valley

Drought arrived in the Yaqui Valley chasing the heels of several other major shocks – both sociopolitical and natural – that have rocked the agricultural system over the past decade. Trade liberalization spurred by the North American Free Trade Agreement (NAFTA) in 1994 has led to continued tariff reductions and significant changes in factor and output price supports, exposing farmers to more volatility for both factors and prices. Farmers were hit both by sharp rises in commodity prices in 1996 and plummeting of world prices in 1997 (Naylor et al. 2001). In 1991, amendments to Article 27 of the 1917 Mexican Constitution enabled *ejiditario* landowners for the first time to sell their land, which has led to a decrease in production from the public sector and land consolidation in the private sector (Lewis 1999).

In addition to the economic shocks and policy reforms that occurred in the 1990's, farmers in the Yaqui Valley were severely affected by biological shocks caused by pest infestations. In the 1994-1995 crop year, the silverwing white fly decimated summer soybean production, which had been a key element of cropping diversity in the Yaqui Valley because it of its ability to fix atmospheric nitrogen and its robust profitability during the spring-summer cycle. Neither soy nor any other crop has since become a viable option for farmers during the spring-summer cycle, due to the pest's persistence, diminishing water availability, and extremely high evapotranspiration during the summer months (Naylor et al. 2001). Also, a series of wheat pests, including Karnal bunt, aphids, and rusts has plagued the valley since the early 1990's, causing farmers difficulty both in wheat production and in finding markets.

In recent years, the Yaqui Valley has become, essentially, a wheat monoculture, with wheat cultivars constituting upwards of 80% of the valley's irrigated area in 2003-2004. And, despite generous fertilizer and water application (Naylor et al. 2001; Matson et al. 1998), unparalleled breeding resources provided by the CIMMYT research station, and favorable phytosanitary conditions, farmers in the valley are witnessing a wheat yield decline relative to yields worldwide (Figure 2). The profitability of the agricultural sector has suffered concurrently (Figure 3).

Drought Strikes the Yaqui Valley

Since 1995, a nine-year regional drought has transformed the face of agriculture in the Yaqui Valley. Located in the semi-arid Sonoran Desert, the Yaqui Valley is highly dependent on stored runoff from the Yaqui River basin for irrigation. Precipitation in the valley is highly variable, yet averages only 30 cm annually, while 200 cm are potentially lost to evapotransiration each year (INEGI 1993). Although farmers in the Yaqui Valley have been endowed with an immense reservoir system that can store over 7 billion m^3 (which is more than double average annual diversions from the reservoir), they have gambled throughout this drought on expected precipitation levels that simply have not materialized.

Between 1995 and 2003, precipitation levels were below average in 8 of 9 consecutive years, and farmers diverted more irrigation water than they received as reservoir inflow in 6 of the most recent 10 years (Addams 2004). A crisis situation has resulted in the valley, with storage at the start of the 2003-2004 crop year amounting to less than the reservoir dead storage volume of 1 billion m^3 (Figure 4). During the 2003-2004 crop year, only 70,000 ha – a mere fraction of the Yaqui River Irrigation District – was irrigable. Such widespread use of groundwater and minimal use of surface water was without precedent in the valley's history.

Climatologist David Battisti's analysis of seasonal rainfall patterns in the Yaqui River watershed has suggested that winter precipitation accounts for less volume than summer precipitation, but with equal variation (Battisti 2004). Winter rainfall carries an especially important role in filling the reservoirs, which was made apparent after a series of below average winter rainfall years (7 of 8 consecutive years) rendered those reservoirs empty, even though summer rainfall varied around the long term mean during that period. Several sea surface patterns have been shown to explain variations of winter rainfall in the state of Sonora. These include the El Niño Southern Oscillation (ENSO) and the Western Pacific pattern, which together explain over 50% of winter rainfall variability. When the Western Pacific pattern is in the warm phase, northwestern Mexico receives less precipitation (Battisti 2004). The Western Pacific warm pool has been growing consistently warmer since 1980, and many have argued that this trend has resulted from increasing greenhouse gas concentrations (e.g. Hoerling and Kumar 2003). The 1996-2004 drought in the Yaqui Valley may therefore be a prognosticator of what is to come in a future climate with more greenhouse gases.

Mexico's National Water Commission (CNA, *Comisión Nacional del Agua*) oversees allocation of water among the domestic, industrial, and agricultural sectors. Since 1992, when irrigation management was transferred from the CNA to water users, the Yaqui River Irrigation District Limited Responsibility Society (*Distrito de Riego del Rio Yaqui, Sociedad de Responsabilidad Limitada*, hereafter referred to as the Irrigation District), has jointly operated and maintained the irrigation infrastructure and water sales and delivery. Overall, the privatization of irrigation management has been hailed as a success throughout Mexico (Johnson 1997), and also in the Yaqui Valley, where the Irrigation District reports that average efficiency of delivering water to farmer fields increased from 63% (1970-1991) to 69% (1992-2001) (Distrito de Riego del Rio Yaqui 2003).

The Irrigation District oversees 42 different irrigation modules, which sell water volumetrically to farmers and cover operational costs from water fees. Typically, water is allocated uniformly to farmers throughout the valley's surface based on the simple ratio of available water to total irrigable area. The irrigation modules also facilitate water trading at the district's set price so that farmers can potentially procure the volume from nearby farmers necessary for the crops they had planted. In 2002-2003, the per-area water availability was 5.9 tm^3/ha, substantially lower than the 7.5 tm^3 dosage recommended for wheat. The district responded in 2003-2004 by allocating water to each farmer based on the water demands of the crop planted instead of making one valley-wide blanket allocation. Cropping area is controlled by the *Secretaría de Agricultura, Ganadaría, Desarrollo Rural, Pesca y Alimentación* (SAGARPA - Secretary of Agriculture, Livestock, Rural Development, Fish and Feed) which authorizes the sale of planting permits for each crop in the valley. Planting permits are legally required and necessary for farmers to purchase irrigation water, receive federal subsidies, and purchase public or private credit. A farmer cannot purchase a planting permit without demonstrating he/she has procured the irrigation water necessary for the crop he/she wishes to plant. Planting permits cost M$ 60.0 /hectare. The federal government then controls water demand in the Yaqui Valley through both the CNA, which allocates a total volume of water to the agricultural sector, and through the Secretary of Agriculture, which issues planting permits. The user-owned Irrigation District controls water demand through its crop-based water allowances, through the design and implementation of irrigation plans, and through the development and maintenance of irrigation infrastructure.

The three agencies involved in regulating water demand in the valley were nevertheless unable to enforce water limitations effectively until the 2003-2004 crop year, when there was no more reservoir water left to distribute (Addams 2004). The management failure became most apparent in the 2002-2003 crop year. At the onset of the fall cycle, the CNA allocated a record low volume to agriculture – 840 Mm^3, enough to irrigate about 60% of the valley. The Irrigation District, which had demanded more water from the federal government, proceeded with its own irrigation plan, and was backed by the Secretary of Agriculture, which authorized the sale of planting permits for

200,000 ha, exceeding "rational" irrigation capacity by 40% (Addams 2004). Disaster ensued as the Irrigation District struggled to fulfill the water obligations it had made to farmers and was therefore bound to by the National Water Law (CNA 1992). The Irrigation District made good its commitment to farmers only by installing many expensive, high volume pumps to access the reservoir's dead storage capacity, which drew down reservoir levels even further – literally to zero (Grácia 2004)!

DROUGHT RESPONSES

System-Level Drought Adjustments

Events of the 2002-2003 crop year precipitated the onset of a severe water crisis in 2003-2004. After yet another disappointing monsoon season in the summer of 2003, it became clear that water managers could not make the same decisions in the 2003-2004 crop year that they had the year before. By October of the 2003-2004 crop year, the CNA announced that only the Yaqui Amerindians, who by presidential degree have the highest priority of access to water from the Yaqui River system, would receive reservoir water for their territorial lands, located outside of the Yaqui River Irrigation District (Minjares 2003). Based solely on the pumping capacity of the valley's 180 publicly owned wells, roughly 400 Mm^3, the Irrigation District set out to irrigate the valley.

In appropriating well-water access between the district's 20,000 water users for the 2003-2004 crop year, representatives of the Irrigation District tried to maximize the area that could be planted and the economic activity that could be generated with available water (Valenzuela Zarate 2003). The Irrigation District doubled the price of water to M$ 130/tm^3 to account for an increased cost of water delivery due to groundwater pumping costs[7]. The district also gave priority to those who were planting closest to wells or major irrigation canals, those who would plant safflower (which requires relatively little water), vegetables and cotton (which bring greater labor demand and economic return per hectare), and those planting perennials such as fruits (who had already invested in crops that would be lost if not irrigated) (Figure 5). Water was also allocated to alfalfa in order to sustain crops that had already been planted for a second year.

The Irrigation District also operated for the first time under the temporal constraint of well pumping capacity, to which it responded by diversifying its cropping plan to include crops with minimal overlaps in the timing of irrigation demands. It authorized 5,600 ha of maize and only 279 of wheat, largely because maize demands its first irrigation much earlier than wheat and safflower, which both require their first irrigation at the same time (Valenzuela Zarate 2003). Generally, farmers prefer to grow wheat because it tends to have lower production costs, better marketing outlets in the valley, and is resistant to frosts, which are more than occasional in the Yaqui Valley and very damaging to maize (Romero Arreola 2003; Luque Favela 2003). In total, the district was able to irrigate 40,000 ha with public water – only 17% of the valley's irrigable area.

Policymakers in the Valley, representing federal, state and local agencies, issued an emergency drought plan to reach producers, landowners, and related parties who would be affected by the sharp drop in cultivated area during the 2003-2004 drought year (Table 1) (Gobierno del Estado de Sonora 2003). The federal government created a special PROCAMPO-*sequía* (drought) program so that income payments would continue

[7] The new price approximated $12.30 per tm^3 in 2004 US dollars.

on land forced out of production for lack of water; however, instead of being paid to producers, the PROCAMPO subsidy went to landowners even when land had already been rented[8,9] (Gonzalez 2003). The prior decade had seen a rapid flux out of farming and into land rental (Lewis 1999). Groups representing such landowners were responsible for lobbying policymakers, on grounds of social equity, to allow PROCAMPO-*sequia* payments to go to landowners instead of producers for the 2003-2004 crop season, even in the instance that landowners had already received advance rent payments for the crop cycle (Leyva Mendivil 2004).

The federal and state governments have funded a weed control program through the *Junta Local de Sanidad Vegetal del Valle del Yaqui* (JLSV, Local Phytosanitary Committee) to encourage farmers to prevent weeds from taking hold in fields left fallow for the 2003-2004 cycle. The payment consisted of 600 M$ per ha, roughly equal to the cost of 2 plowings, as the program required. Producers, who internalize the incentives for long-term weed control, participated in the plowing program rather than landowners. The emergency drought plan involved several other programs. Federal and state level governments provided limited operating funds to local public organizations that were financially distressed because of reduced fees paid by producers in the Valley. These organizations include the Agricultural Research and Experimentation Board of the State of Sonora (*Patronato para la Investigación y Experimentación Agrícola del Estado de Sonora*), the Irrigation District, the Irrigation Modules, and the Local Phytosanitary

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[8] Land rental is very common in the Yaqui Valley. On average, roughly half of cultivated land area is rented.

[9] PROCAMPO is a farmer income-support program designed by the federal government to comply with NAFTA and multilateral WTO agreements by transforming input subsidies and price supports into direct income payments to producers that are scheduled to phase out by 2009, 15 years after the program's initiation (Naylor et al. 2001).

Committee. Finally, policymakers attempted to provide social protection, such as insurance, for the many rural farm workers put out of work by the drought (Gobierno del Estado de Sonora 2003).

Producer Adjustments in Supply

On average, over 95% of cultivated land in the Yaqui Valley is irrigated with public water, distributed to farmers through the Irrigation District; however, use of "private" water (water pumped from one of the valley's 150 active privately owned wells) played a greater role in 2003-2004 than ever before. In 2003-2004, private water accounted for over 40% of the area irrigated. Regulation of private irrigation water is largely nonexistent in the Yaqui Valley beyond the groundwater pumping cap associated with each private well permit. Farmers must simply be able to demonstrate that they have access to sufficient private irrigation water in order to purchase any planting permit of their choosing. Cropping decisions, as well as quantities and timing of irrigations, are left to the discretion of the private water user (Valenzuela Zarate 2003). Of particular interest is how producers have responded to the drought by drilling new wells and purchasing water from both public and private sources.

Well drilling activity peaked in the Yaqui Valley between 1955 and 1975 then subsided until the late 1990's. Of the 20 well owners in both surveys who reported drilling dates, 12 were drilled before 1975 and 8 between 1998 and 2003. However, the CNA reports that the valley's entire 400 Mm^3 pumping capacity has been granted, although 60 of the 200 new wells associated with the Irrigation District's Modernization Plan and the subsequent expansion of the aquifer's "Sustainable Yield" to 600 Mm^3 will be private wells (Vargas Romero 2003). The CNA received more applications from producers than it could approve and reported that it chose permit recipients based on a desired spatial distribution and the quality of the site proposed (Vargas Romero 2003). Non-sanctioned drilling of new wells seems unlikely because official well permits are required for well owners to qualify for subsidized pumping electricity, as well as government income subsidies and marketing programs for crops grown with private well water. The cost of drilling and equipping a deep well, which approaches M$ 1 million, is somewhat prohibitive for producers to risk under illegal circumstances. Over 40% of producers surveyed expressed the serious desire to drill a private well, but only 11% thought they would receive a permit to do so. Several unsuccessful permit applicants expressed frustration that the permit granting process was not transparent.

Some producers have turned to water markets to procure water for planting. The Irrigation District, through its modules, handles public water transactions at the set district price[10]. Most producers participate as buyers – purchasing activity peaked in 2002-2003, when 12 of 75 surveyed producers bought extra water from their irrigation modules. Over 80% of all reported public water purchases occurred during that year, an anomaly most likely explained by the fact that farmers planted their crops without assured access to the full irrigation requirement that year. The Irrigation District was able to respond mid-season to meager on-plant water availability for wheat by installing industrial pumps into the lowest reservoir so that emergency dead storage could be accessed. Many farmers who had planted wheat were then able to buy extra irrigation water mid-season only because emergency Irrigation District investments made that possible. In 2003-2004, however, only 4 of 163 surveyed farmers bought public water

[10] Transaction prices are fixed in order to discourage water prospectors, more commonly known as *coyotes*, from trading water between farmers at a profit.

beyond their allocation. This was attributable to the combination of strictly limited supplies, which constrained potential water markets, and strictly limited sales of planting permits, which limited irrigation demand to what was available at the start of the crop year.

In absolute terms, private water transactions have been much less common in the Yaqui Valley. Around 10% of all producers surveyed have ever bought private water, and only 3% managed to do so during 2003-2004. As owners of private wells tend to sow much more area than non-owners, the lack of private water transactions reflects the necessity for well owners to personally use all they can pump. In fact, in 2003-2004, private well owners still had more land left fallow for lack of water than non-owners. This apparent paradox stems from the fact that private well owners tend to cultivate larger areas than the average non-well owner. A typical well irrigates between 150 and 300 ha, depending on flow rate and the timing and volume of crop irrigation requirements. Since well owners, on average, plant nearly 500 ha each year, they experienced water shortages themselves and therefore were unwilling to sell water to other producers during the 2003-2004 crisis.

Although market prices for “private” water have increased since the early 1990’s, they have decreased relative to the Irrigation District’s prices in the past two years, and equaled the district’s price this year. Although demand for all forms of irrigation water greatly outstripped supply, private water prices surprisingly did not rise above the district’s price, apparently reflecting a general reluctance by farmers to treat water as a market good[11]. Institutionalized price rigidity in public water markets and limitation of private well drilling permits also hampered producers' efforts to procure water supplies outside of the conventional district allocation system. At district water prices, total quantity of water demanded greatly exceeded available supply. Water pricing increases during the 2003-2004 crop year reflected added costs of delivery rather than higher scarcity value. Farmers who tried to purchase water from private sources, which were not constrained to the irrigation district's prices, had trouble finding anyone willing to sell water. Farmers hoping to secure water supplies by drilling a new well had difficulties obtaining permits to do so.

Producer Adjustments in Demand

Producers more commonly adjusted their irrigation water requirements through cropping decisions rather than adjustments to the volume of irrigation water applied per plant (Figure 6). In 2003-2004, the prevalence of wheat decreased dramatically, while safflower increased to unprecedented levels. Area planted to cotton in the Yaqui Valley also increased tenfold, from 1,300 ha to 10,000 ha while area planted to beans increased. Most other crops (maize, alfalfa, forage, vegetables and fruits) decreased absolutely in area, but increased relative to their share of area planted in the Valley during the 2003-2004 crop year. Planting permit data from the entire Yaqui Valley and producer surveys both confirm that fields planted to wheat in the 2002-2003 crop year were most likely to be planted to safflower or left fallow in 2003-2004. The valley's many traditional wheat

[11] When asked to provide the highest price they would pay for water or the lowest price they would accept to sell extra water, 47% of producers demonstrated some form of reluctance to consider water as a tradable market good, either refusing to give a price or stating that it is unfair to profit from water sales.

farmers (accounting for nearly 75% of all area planted in 2002-2003) were largely ineligible to purchase planting permits or receive irrigation water unless they planted safflower, maize, cotton or vegetables. Permission to plant was granted by the Irrigation District, which designed its 2003-2004 cropping pattern in order to maximize irrigable area and total economic returns to agriculture despite constraints in water supplies and timing of delivery (Acosta Felix 2003). Safflower was chosen for its low water requirements; maize because its periods of irrigation demand did not overlap with those of safflower; and cotton and vegetables because they generated more income and labor demand than other options. Producers could also receive irrigation water for perennial crops, such as fruits and vegetables, that were planted prior to the 2003-2004 crop year. Although producers could receive water allocations by planting vegetables or fruits, few of them did so. High production costs, volatile markets, and difficulty obtaining credit were important factors that prevented farmers from planting vegetables. Those who were able to make the switch generally came from the private sector, and either self-financed their production or obtained credit through private credit unions. In general, drought during the 2003-2004 crop year brought unprecedented changes in cropping patterns, made especially apparent when viewed over a map of the valley (Figure 7).

Without installing a pressurized irrigation system, farmers can choose to reduce their water use through "deficit" irrigation, defined as the deliberate under-irrigation of a crop relative to recommended levels. Deficit irrigation can involve reducing the number of irrigations or volume of water applied with each irrigation. There are a variety of ways to increase the efficiency of irrigation application. Land leveling cuts losses, with an average 2001 cost of M$ 3304 per ha (Puente-Gonzalez 2003). Decreasing the length of irrigation furrows allows farmers to reach entire fields more evenly with less water, while avoiding crop stress at the end of furrows. Surge irrigation allows for more even application of irrigation water. Tailoring water application more specifically to soil properties, which vary in their ability to retain soil moisture and in their performance under water stress, can ensure that application rates more closely match crop demand as conditions vary. The economically optimal level of a farmer's water use depends on both economic and biophysical parameters involved in the crop's production. These include, but are not limited to, the price of irrigation water, physical crop responses to water and other inputs, soil properties, and the market price of the crop in question (English 1990). During the 2003-2004 crop year, farmers actually made minimal adjustments in the volume of water applied to each crop either by reducing the total number of irrigations or the size of each irrigation. Almost 90% of surveyed producers reported that, over the last five years, they have not reduced the number of irrigations and total volume of water used (Figure 8).

Valley-wide Irrigation District data confirm that volumes of public irrigation water to crops have decreased slightly since 1999-2000, with the aggregate valley-wide application decreasing by around 1 tm^3/ha. The average volume of water applied to wheat and annual vegetables decreased by about 1 tm^3/ha, while water used to irrigate cotton, alfalfa and perennial fruits decreased by 3 tm^3/ha since 1999. However, valley-wide irrigation data do not confirm that either the number of irrigations or volume of water applied to each crop decreased significantly during the 2003-2004 crop year[12].

[12] Average volume applied to wheat also decreased from 5.1 to 1.7 tm^3/ha. However, only 30 producers planted wheat with public irrigation water and most likely supplemented their district allocations with private well water. Cultivating wheat with

Private water users reported in surveys that they applied slightly higher volumes of irrigation water to their crops – by 0.75 tm^3/ha in wheat, 1.7 tm^3/ha in cotton, and 0.8 tm^3/ha in safflower.

Most farmers in the Yaqui Valley irrigate their crops by flooding their furrows with water. It is estimated that less than 60% of applied irrigation water is consumed by a crop when flood irrigation is used[13] (Addams 2004; Brouwer et al. 1989). Pressurized irrigation systems, such as sprinkler and drip systems, could result in plant uptake of 75% to 90% of irrigation water applied, respectively. While such irrigation systems could significantly reduce the quantity of water necessary to irrigate the valley by eliminating up to 75% of water wasted at the field level, they have been installed on very few fields. Fewer than 5% of the farmers surveyed reported having a pressurized irrigation system of some sort on part of their land in production, with drip being the most popular. All of them installed their pressurized systems after starting to cultivate vegetables or fruits, and they only use these systems on fields growing these crops. 62% of all surveyed farmers planting fruits or vegetables irrigate at least part of their fields with pressurized systems, which is much higher than the valley-wide average of 5%. Many of the valley's producers reported that the costs of such systems simply are not justified on low-value crops like wheat, maize and safflower, since the profit margins tend to be so low. Nearly half of all producers surveyed expressed a desire to install a pressurized irrigation system in the near future. Producers with plans to diversify into vegetable production were more

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1.7 tm^3/ha would not be economically feasible given Yaqui Valley agroclimatic conditions.

[13] In this text, consumptive water use refers to that which is taken up by the plant's roots and either transpired through stoma or incorporated into the plant's biomass.

likely to express such a desire than producers who wished to continue growing grains in the future.

Recently, use of center pivot irrigation systems on grains has become common in agricultural areas that rely heavily on groundwater pumping, such as the Great Plains region of the US or California's Central Valley. Adoption of center pivot systems in these regions was tied with peaking prices for agricultural commodities during the 1970's (Zilberman et al. 1992). However, as long as water prices remain low and until more farmers start to plant higher valued crops, it is unlikely that pressurized irrigation systems will become more common in the Yaqui Valley. Important pricing and allocation differences between the irrigation district's public water and private well water have caused pressurized irrigation systems to be more attractive investments for well owners than for farmers who rely solely on surface water resources. Irrigation systems can decrease variable water costs for farmers, but they cannot serve as a source. Until a guaranteed water supply is secure, a farmer is unlikely to invest in a pressurized irrigation system. Surveys confirmed that farmers who do not own wells are less likely to use such irrigation systems. Per unit of water extracted, well owners pay pumping costs that have historically greatly exceeded volumetric water prices. Well owners often irrigate crops in the spring and summer when evaporation losses peak, further exaggerating these cost incentives. Finally, private well owners are concerned with localized aquifer drawdown, which can be reduced through demand-decreasing investments like pressurized irrigation systems.

POLICY OPTIONS AND FUTURE OUTLOOK

Farmer Incentives to Adjust Water Use

The 2003-2004 water crisis, precipitated by 8 preceding drought years, dramatically increased the scarcity value of water in the Yaqui Valley. Even after accounting for constraints imposed on irrigation and cropping activities through regulatory barriers, individual producers made surprisingly few adjustments that would suggest an increase in the economic value they place on irrigation water. At the irrigation district's recent prices, variable water costs account for between 2% and 9% of total crop production costs in the Yaqui Valley (Figure 9). In 2003-2004, water's share was comparatively lowest for vegetables (3%) and highest for wheat (8%) and alfalfa (9.3%). Vegetables, cotton and fruit generate the highest economic output per unit of water applied to crops in the Yaqui Valley, while maize, alfalfa and wheat generate the lowest. This comparison might suggest that policymakers, preparing for a future with less water, would be wise to discourage the widespread planting of thirsty, low value crops like wheat, maize and alfalfa.

In Hermosillo, an agricultural valley located near the Yaqui Valley, historically low availability of surface irrigation water has been associated with more productive use of water resources and heavier reliance on groundwater. In Hermosillo, fruits, vegetables and other high-value crops are much more frequent, as are pressurized irrigation systems that reduce per-area crop irrigation requirements (SAGARPA). Although water comprises a larger part of the costs of producing wheat, maize and alfalfa than it does for all other crops in the Yaqui Valley, farmers remain unlikely to reduce their water use or diversify their production portfolios as long as they continue to operate within their existing incentive framework, which is driven by water pricing and allocation policies, the agricultural credit system, crop markets, and crop subsidies.

A recent paper by Isha Ray asserts that a few major assumptions must be upheld before increases in water prices would actually incur an elastic demand response (2002). Her assumptions include the following, which are violated in the Yaqui Valley agricultural system: water prices should be significant in the farmer's overall budget; farm level inefficiencies should be significant in relation to overall irrigation district inefficiencies; water pricing should be the reason farmers do not irrigate with less wasteful methods or diversify into higher valued crops. The Irrigation District doubled water's volumetric price in 2003-2004, from M$ 65 pesos/tm^3 to M$ 130, in response to their increase in water delivery costs arising from operating well pumps. Even after the price hike, water and all associated irrigation costs did not surpass 15% of total wheat production costs (Figure 10).

Other economists recognize different barriers to the efficacy of water price mechanisms for inducing demand responses, such as appropriate crop options, soil type, reliability of water supply, water institutions, prices of other inputs and outputs, extension services and availability of technology, production quotas, credit, and market access (Tsur et al. 2003). As addressed in the following discussion, most of these factors proved to be of some importance in the Yaqui Valley.

Absent opportunity-cost water pricing, farmers have little incentive even in theory to adjust their water use, either through irrigation adjustments or cropping changes, in response to price changes. Irrigation water is inexpensive in the Yaqui Valley[14], and while unpublished data from local irrigation trials suggest that farmers can eliminate one to two on-plant wheat irrigations without yield responses (Ortiz Munoz 2003), the fear of crop failure is pervasive in the credit system and the minds of most producers. Therefore, rationally behaving individuals will use all that the irrigation district will allow as long as it stays cheap although additional irrigation water brings diminishing returns to farm productivity. This point is demonstrated by the fact that private water users, who paid pumping costs (if pumped) or volumetric prices (if bought from a well owner) similar to the Irrigation District's price in 2003-2004, applied, crop by crop, at least as much irrigation water as the district allowed public users. Water pricing and allocation rules, as managed in the Yaqui Valley, do not encourage elastic price responses in water demand. To receive water or not to receive water was the major question for most producers, as irrigation proved to be an all-or-nothing event for water recipients in 2003-2004. The Irrigation District's water allocation process did not reward (with higher water priority) those who could or would plant a particular crop with less water. The only reward was the district's price for water, which happened to be only a small share of that water's value to farmers, as the water brought with it nothing short of the possibility of earning an income from agriculture in 2003-2004.

However, the credit system affected water use even beyond regulations of water institutions. Over 90% of all producers surveyed in the Yaqui Valley finance their agricultural endeavors with credit. Smaller producers, or those who farm less than 100

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[14] By international standards, water prices in Mexico are fairly low. Volumetric prices in the United States roughly double those in Mexico. In Switzerland, Yemen, Denmark, France, and Israel, water prices exceed those in Mexico by more than an order of magnitude (Dinar 2000).

hectares, tend to receive loans from the Federal Government's public agricultural credit institution, *Financiera Rural*[15]. The Yaqui Valley's larger producers, and more from the private sector, take credit from membership-based private credit unions in the Yaqui Valley. Individual producers hold memberships in a credit union by paying area-based dues each cropping cycle, which fund the union's operational costs. Eight private credit unions currently operate in the Yaqui Valley, and each boasts a different personality. Credit unions vary in reputation, services provided, number of members and total representative area, typical cropping preferences and operational sizes of members, etc. Members of private credit unions usually come from the private sector and typically must plant a minimum of 100 hectares to qualify for credit. However, most of Yaqui Valley's credit unions operate within a group of businesses that provide, in addition to agricultural credit, insurance, discount sales of inputs, and grain storage.

Each year, a Credit Committee, comprised of technical representatives from the valley's different credit institutions, both public and private, as well as representatives from the Secretary of Agriculture and several other groups in the valley, publishes area-based Production Cost data for each crop grown in the valley based on INIFAP's official crop recommendations. Credit institutions, in return, finance producers up to the official production cost for a given crop each year. In return, they require producers to follow the production guidelines by which the costs are determined (Romero Arreola 2003). Regulated production factors include varieties planted, land preparation, planting, harvest, as well as the use of water, fertilizer, pesticides, herbicides, and other inputs.

[15] In September of 2003, *Financiera Rural (*previously known as *Banrural*) reopened under its new name and new management in response to charges of institutionalized corruption.

Credit union representatives, water managers, and policymakers throughout the valley overwhelmingly report that the credit system dictates management practices at the farm level. Although many surveyed producers recognized that they could face consequences for deviating from official recommendations, over 90% nevertheless claimed they felt free to do so (Table 2). All but one of those who did not feel free to deviate from recommendations obtained finance through a private credit union. Credit institutions regulate management by withholding insurance payments in the event of crop failure if farmers do not follow the management protocol defined by the union. They report that they increase their involvement in the production process with higher risk farmers -- those who have defected their loans or had crop failures in the past (Romero Arreola 2003).

Due to the institutional and economic obstacles that individual producers face when reducing their water demand, cropping decisions remain the farmer's simplest way to affect his total water demand as well as the economic productivity generated by water use. Farmers in the Yaqui Valley claim that water is the most important factor in choosing which crop to plant this year, but in a normal year, they identify markets and profitability as key determinants of crop choice. The Mexican government guarantees prices and develops marketing outlets for a subset crops designated as very important to domestic food security (Luque Favela 2003). These crops include wheat, maize, safflower and cotton. While marketing outlets are most reliable for wheat and maize, cotton and vegetable crops are notorious in the Yaqui Valley for rapidly fluctuating prices and difficulty securing contract sales to decrease market risk. Both price volatility and easily saturated commercialization outlets can contribute to poor market development that is common to many of the higher valued crops in the Yaqui Valley. According to many producers in the valley, market uncertainty is a major risk that farmers must be able to overcome before the valley can undergo a productive "reconversion" into higher valued crops that use water more effectively.

Drought Impacts in the Yaqui Valley

Failure of policymakers, water managers, and individual producers to respond dynamically to the water crisis in the years preceding its onset greatly magnified the intensity of its economic impacts. In the 2003-2004 crop year, the aggregate value of the Yaqui Valley's agricultural output plummeted to M$ 383 million, less than 40% of the average agricultural revenue during the preceding decade[16]. Agriculture directly employs over one fifth of the Yaqui Valley's work force and is the predominant source of income for the 600,000 residents of the Yaqui Valley (INEGI 2000). According to some estimates, income multiplication within the agricultural sector can double effective agricultural revenue (Lanjouw and Lanjouw 2001). Agriculture's importance to the economy became apparent in the 1990's, when the white fly outbreak, followed by drought, decimated the spring-summer cropping season. A halving of cultivated area in the Yaqui Valley resulted in significant income shocks that are still fresh in the minds of many of the valley's residents.

Over 90% of producers surveyed say that their household income in 2003-2004 was lower than the previous year's income as a result of the water crisis. Farmers reported in surveys that they normally rely on agriculture to account for 85% of their

[16] Agricultural output estimated using valley-wide average yields, and official SAGAR cropping areas and prices (in 1999 Mexican pesos).

household income, on average, but the water crisis has brought agriculture's average share down to 50%. Access to irrigation water was an important determinant of the drought's economic impacts on a farm household. All farmers with no access to irrigation water responded in December that their income would certainly be lower as a result. Fewer than half of farmers that had access to any irrigation water, even a reduced amount, reported that their income would be lower in the 2003-2004 year. Drought impacts affected off-farm income as well. Farmers with other means of employment besides income from crop cultivation reported resoundingly that their other income sources decreased during 2003-2004[17].

Unusually favorable winter rains that fell in January 2004 eased the drought's impacts by allowing many producers to plant safflower solely on the residual moisture of the winter rains. Although rainfed cultivation had never been common in the region, valley-wide records estimate that over 60,000 ha were planted with rainfed safflower[18]. Since credit unions perceived this to be a risky endeavor, they were reluctant to approve production loans for rainfed agriculture. The Secretary of Agriculture in the Yaqui Valley attempted to increase incentives for farmers to plant rainfed by allowing price and marketing subsidies that previously did not exist for rainfed agriculture in the region. In spite of the incentives, lack of access to sources of finance constrained many farmers from planting rainfed crops. Close to half of all producers surveyed in March of 2004

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[17] The average producer household contained 4.5 members and generated income both from agricultural production and one salary-earning job.

[18] Cropping area estimates were made from the irrigation district's records, with the exception of rainfed crop areas. Because farmers typically buy planting permits and irrigation water together in the same transaction, many farmers planting rainfed during 2003-2004 did not purchase permits. Regional data compiled by SAGARPA proved to be a better estimate of rainfed cultivated area.

had planted some of their non-irrigated land with safflower, with an average rainfed area of 100 ha per producer. Over 70% of these producers came from the private sector, emphasizing the difficulty of this endeavor for *ejiditarios*, who tend to be more constrained by availability of finance and more averse to risk.

Yet another unusual climate event impacted many of the producers who planted maize, beans, potatoes and vegetables during the 2003-2004 crop year. On December 29 and 30 of 2003, temperatures dipped below –10 °C in the valley, severely damaging over 10,000 ha of irrigated crops, mostly maize (SAGARPA). In the March survey, almost 40% of farmers who planted irrigated crops reported frost damage. Most of these producers left their crops to mature until harvest, although they expected very low yields (1.8 kg/ha, well below the valley's 2002-2003 average maize yield - 6.4 kg/ha). Insurance payments covered a maximum of 80% of production investments and did not address foregone income. Although producers were aware of the danger frost posed to maize cultivation in the valley, they chose to plant it nevertheless. Perhaps they had become complacent after nearly a decade of frost-free winters; perhaps they were willing to accept the risk that frost posed to maize in order to receive a planting permit; or maybe they were swayed by recent memories of high maize yields and low wheat yields resulting from unusually warm temperatures in 2002-2003. Ironically, rainfed cultivation proved to be the most profitable option in the end. Farmers who planted rainfed safflower faced lower production costs while harvesting yields comparable to those of irrigated safflower.

Ejidal producers and private sector producers differed in household vulnerability to income shocks and their ability to adjust dynamically to the crisis by seeking alternate income sources. While farmers from both groups rely equally on agriculture as an income source, *ejiditarios* were less likely to receive irrigation water from the district, and they bore a greater income effect from the drought as a result (57% income decrease vs. a 43% income decrease, t statistic for difference of means=2.99, P<0.002). *Ejiditarios* were more likely to adjust to income losses by seeking work as an agricultural day laborer in the fields of a producer with available irrigation water, although such employment opportunities were limited by area under cultivation. Private sector producers, in turn, were more likely to mitigate income losses by undergoing the risky endeavor of rainfed cultivation, relying more heavily on a livestock operation, or diversifying their crops in order to receive irrigation water. In the Yaqui Valley, private sector producers historically tend to plant larger areas in non-drought years than *ejiditarios*. Private producers also tended to leave fallow a much smaller portion of their land in 2003-2004 for lack of water than *ejiditarios*, and they were more effective in compensating lost income[19]. *Ejidal* households were more likely than their private sector counterparts to have no response to the water crisis. Due to their increased ability to make adjustments in the face of drought crisis, private sector producers suffered smaller shocks to their incomes than did *ejidal* producers. In general, most producers were very uncertain of how they might respond in the future should drought conditions persist. Some expressed a desire to diversify their crops, while others considered leaving the agricultural sector or migrating to the United States.

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[19] In the Lagunera Irrigation District of Coahuila, also in Northern Mexico, records demonstrate that ejiditarios rely more heavily on surface water than do private sector farmers. While surface resources account for 75% of water use for *ejidal* farmers, they make up only 25% for private sector farmers, who depend on wells to meet irrigation demands (Levine et al. 1998).

Landowners continued to bear much of the brunt of the 2003-2004 water crisis into the 2004-2005 agricultural year. Land is rented concurrently with water access, and land rental contracts specify that, when access to water is not possible, the rental contracts are transferred to the next agricultural year in which irrigation water is available. Most producers signed rental contracts with landowners prior to water allocation decisions. As a result, many landowners simultaneously received rent and an unprecedented area-based PROCAMPO-*sequía* payment for land that would be, at least in theory, ineligible for rental payments (or PROCAMPO payments) in the following cycle. Juan Leyva Mendivil, an outspoken advocate for small land holders who rent out their land instead of cultivating it, defended drought policies for their equity impacts, claiming that they distributed badly-needed income amongst many more people who depend more vitally on rural economic activity. He argued that, once planting had begun again in the valley, landowners would be in a better situation to forego rent from one season since labor employment opportunities would be more readily available.

The drought also had impacts on livestock and aquaculture, two important, secondary components of the Yaqui Valley's agrarian economy. In 2003, the Yaqui Valley was home to 1.3 million hogs and 200,000 cattle (SAGARPA). Livestock producers in the Yaqui Valley usually benefit from high-quality, locally produced feed that is available to them with minimal transportation costs. However, recent events have placed the Yaqui Valley into a grain deficit – for the first time ever, with more cereals being imported into the valley for feed than are leaving it as surplus harvest.

Improving Water Management

In the surveys, farmers showed mixed opinions regarding the origin of the water crisis – many perceived it as a purely natural event, some thought it was a management problem. Many believed the drought could have been avoided had water resources been managed differently. When asked the best way to invest funds in order to mitigate or prevent future droughts, farmers ranked system-level water transport infrastructure improvements highest (83%), followed by proliferation of more efficient irrigation methods (77%), better surface and groundwater resource management (74%), drilling more wells (66%), and breeding for drought resistance (53%). Currently, public investments in the Yaqui Valley address all of these farmer-identified priorities (Table 3). While the 2003-2004 water crisis had direct, major impacts on all economic activity in the Yaqui Valley, it also catalyzed investments and policies that may prevent such crises from recurring. José Luis Minjares, Senior Consultant for the National Water Commission and former head of its Yaqui Valley district office, has written the first set of reservoir operational rules in all of Mexico. The operational model determines optimal reservoir storage and release levels, with the objective of maximizing net agricultural benefits while minimizing risk of shortages and spills in the reservoir system (Minjares 2004). As a result of collaboration between Mexico's National Water Commission and Stanford University hydrogeologists, the reservoir model is currently being linked with a groundwater operation model to determine optimal conjunctive use of water resources. The expectation is that this work will soon be enacted at the federal level of Mexico's government. The Yaqui Valley also holds potential to develop and integrate climate forecasts into the reservoir management rules. Winter precipitation accounts for most of the interannual variability in the Yaqui River watershed. Decision makers allocate freshwater resources in October for the following year, based partly on anticipated winter precipitation and their acceptable level of risk that these precipitation levels will not be exceeded. David Battisti has linked sea surface temperature measurements from the Western Pacific Warm Pool and El Niño Southern Oscillation with winter precipitation in Southern Sonora, and is developing a new tool for the National Water Commission to make better allocation decisions using predictions of in-season runoff (Battisti 2004).

The Irrigation District has long been preparing itself for encroaching water shortage by developing an expansive project to modernize the valley's hydrological infrastructure. Although it was initially conceived in 1986, the modernization plan finally began in late 2003, as diminishing reservoir levels forced agencies to turn the plan into reality. The infrastructure improvements, which bear a price tag of M$ 713 million[20], will be jointly funded by the Mexican federal government and water users, who will pay a small area-based fee to the Irrigation District until 2013. Principally, the plan calls for the installation of 200 new deep wells in the valley, which will increase pumping capacity by 50% to 600 Mm^3 [21]. The plan also calls for the lining of over 300 km of irrigation canals to minimize conductance losses during water transport[22]. Smaller components of the modernization plan include floodgates, gauges, checkpoints, and other improvements that should allow the Irrigation District to improve its water

[20] Roughly $65 million USD according to July 2004 exchange rate (XE 2004).
[21] The expansion of federally-sanctioned groundwater pumping capacity was authorized through a hydrological study that deemed the added pumping "sustainable" (INEGI 1993; Addams 2004).
[22] The effects of simultaneously decreasing aquifer recharge rates (by lining canals) and increasing aquifer extraction rates (by drilling new wells) were not explicitly studied and could negatively impact aquifer dynamics (Addams 2004).

measurements. Overall, the Irrigation District estimates that the modernization plan will recover 550 Mm^3 each year, enough to irrigate over 50,000 ha (Distrito de Riego del Rio Yaqui 2003).

Investments like the Irrigation District's modernization plan demonstrate a legitimate desire on the part of the water users to improve the efficiency at which they transport their scarce water resources throughout the valley. Combining system-level efficiency improvements with field-level efficiency improvements without compromising underground water resources or coastal ecosystems that rely on fresh groundwater inputs will be a major challenge borne by water managers and farmers alike. Perhaps efficiency improvements at the field level are easier to obtain. IWMI analysis of the Lagunera Irrigation District in Coahuila, Mexico demonstrated that investing in water application efficiency at the field level holds more promise than investments in water delivery improvement at the system level (Levine et al. 1998). Researchers concluded that, even with scarce water supplies, the Irrigation District was consistently able to deliver water uniformly to different user types located throughout the irrigated area. They suggested that simple technical improvements, such as shortening furrows, using surge irrigation, land leveling, cutback streams, and investing in diversification could improve water productivity within farmer fields, which was shown to be demonstrably poor.

In the Yaqui Valley, overall field level irrigation efficiency roughly equals the conveyance efficiency for the delivery system. Field level irrigation efficiency averages 66%, roughly, for wheat, while district-wide conveyance efficiency averages 65% (86% in primary canals and 77% in secondary, module-level canals) (Addams 2004). Investments at all levels will be necessary to increase water productivity in the Yaqui

Valley. Farmers stand to gain from improving their irrigation infrastructure by decreasing variable water and fertilizer costs in the long run[23]. However, required capital investments at the outset provide a sufficient barrier to action. Over two thirds of farmers surveyed doubted their ability to purchase such equipment, while many expressed the desire to do so. Many of these farmers claimed that they had no available source of multi-year finance for such a capital investment, even though public funds available through a program known as *Alianza Para el Campo* will cover up to 50% of the investment.

However, increasing conveyance and irrigation efficiency in the Yaqui Valley bears other costs besides the required capital. Groundwater recharge depends on surface infiltration from farmer fields and transport losses from primary and secondary canals. In recent years, groundwater resources have provided a significant share of total irrigation water. Most of the Yaqui Valley's water managers insist that groundwater resources will not be threatened by decreases in surface losses from district modernization and reduced cropping areas, although such losses coincide with increases in groundwater extraction from drilling new wells and expanding aquifer concessions. However, escalating reliance on groundwater resources increases both the probability of depletion in the aquifer and the severity of depletion's consequences for total irrigation water supplies. Appropriate conjunctive management of the entire hydrological system requires proper accounting of the impacts of infrastructure modernization along with the benefits. Disrupting the complex balance between groundwater inflows and outflows also bears environmental

[23] With pressurized irrigation systems, fertilizer can be mixed with irrigation water, thereby reducing the cost applying fertilizer separately and increasing the efficiency of nitrogen delivery to plant roots.

consequences for coastal estuaries, whose ecosystems depend on subsurface freshwater flows from the aquifer.

Future Trajectories

At the end of the 2003-2004 crop year, returning storage to the Yaqui River's three reservoirs remained the most daunting task for water managers. Many policymakers in the Yaqui Valley stress that, as soon as reservoirs return to operational levels, they plan to manage water for the prevention of future shortages, even in the face of a highly variable and possibly transitioning climate. Restoring normal levels of agricultural activity while also returning environmental flows to the Yaqui River channel poses an additional challenge. The valley's farmers remain optimistic at least in the near term – two thirds believe they will be able to irrigate once again in the 2004-2005 crop year, but most of those have already returned to planting low value grains. Over 70% of farmers reported that they definitely intend to cultivate their land in 5 years' time, while an additional 15% said they probably would.

Currently, researchers at institutions and universities in Mexico and the United States are addressing important information gaps and providing water managers and other policymakers with the tools to enable quicker drought recovery and more effective drought prevention. A key first step in this process centers around understanding the hydrologic-agronomic-economic interface of the Yaqui Valley's dynamic surface-groundwater system. Stanford hydrogeologists have collaborated with senior engineer Jose Luis Minjares at Mexico's National Water Commission to conjunctively model surface and groundwater resources and propose management policies for the system (Addams 2004; Minjares 2004; Schoups et al. 2004).

CIMMYT actively produces drought resistant varieties of wheat and maize tailored to both rainfed and irrigated systems and a variety of agroclimatic regimes (Pfeiffer 2003). While these varieties have not been adopted in the Yaqui Valley, they have become widespread in many other regions worldwide, including Northern Africa and Western Asia. Mexico's National Institute for Forestry, Agriculture and Livestock Research (INIFAP) has engaged in trials testing a range of techniques to increase the application efficiency of farm irrigation. These include eliminating up to two on-plant irrigations for wheat (bringing total irrigations down to four), shortening furrows, land leveling, and using center-pivot irrigation systems on grains (Ortiz Munoz 2003). Innovative producer groups have been instrumental in validating INIFAP techniques in a realistic economic setting, facilitating their transfer to other producers, and informing water planning decisions at the level of the Irrigation District (Ramirez Diaz 2004).

Emerging research on climate forecasting's technical feasibility and economic potential in the Yaqui Valley might encourage more productive water use in the region. Stanford and CIMMYT researchers David Lobell and Ivan Ortiz-Monasterio have evaluated the effect of predicting growing season climate on optimal fertilizer application rates. Their analysis suggested that estimations of soil nitrogen storage in a field might be more useful than climate predictions (2004). However, the analytical framework for optimal fertilizer application could be used to evaluate the potential of different climate and biophysical indicators for enabling more precise water application. Possible indicators include spatial measurements of residual soil moisture and soil capacity for water retention, or seasonal predictions of evapotranspiration rates and minimum nighttime temperatures. These indicators might be used to increase water productivity by predicting optimal rates and timing of irrigation application, as well as optimal crop selection, for specific fields and seasons.

Available science and technology offer promise for developing more productive methods of water use while still more innovations are forthcoming. Even so, actual utilization of these management techniques has been minimal and slow to grow, although they are widely used in other regions to increase factor productivity[24]. Since farmers in the Yaqui Valley display risk adverse behavior, they are unlikely to adopt these innovations unless otherwise compelled by the proper incentive structure. Surveys suggest that farmers are more concerned with the possibility of foregoing yields than they are drawn to the opportunities for lowering production costs and increasing net income. Furthermore, water pricing offers minimal incentive to use it more productively, while institutional rigidity in the water allocation process and constraints imposed by credit organizations actively provide disincentives to do so. Ultimately farmer shifts towards profit-oriented production methods will drive change within the agricultural organizations that influence behavior, as these organizations are responsive to their constituents. However, the coupling of regulatory disincentives and farmer risk adversity create a significant obstacle to transitioning towards a different operational paradigm within the agricultural sector.

Already, drought has paved the way for the enactment of new reservoir management rules. And, overwhelmingly, institutions within the valley have emphasized

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[24] Technologies that are used to increase factor productivity in other places include surge irrigation and optimal timing of nitrogen application.

the magnitude of the drought's impact and their commitment to prevent future drought recurrence. Despite its terrible immediate impacts, the water crisis of 2003-2004 may well be what catalyzes meaningful changes in the types of management technologies and regional leadership that farmers demand. Lasting memory of the 2003-04 water crisis will be essential for maintaining the political will to continue with policy reforms for more productive water use. Priorities should focus on pricing water correctly and relaxing institutional constraints so that farmers can respond to market incentives. Water pricing does not necessarily impact farmer incomes adversely. Many studies of irrigation economics indicate that tiered pricing systems (whereby water prices increase stepwise as per-hectare volume purchases increases) provide important incentives to reduce water demand without adverse income effects (Tardieu and Prefol 2002; Zilberman et al. 1992; Tsur et al. 2003). The Irrigation District is in a good position to implement such pricing reforms because it already has the capacity to sell water volumetrically. The 2004-2005 Irrigation District water prices of M$ 150/tm^3 may even be reasonable if tiered pricing provides incentives to demand less water[25].

The right set of policies can encourage crop diversification and investment in irrigation infrastructure to use water more efficiently and productively in the Yaqui Valley. There is some indication that individuals and institutions are headed in that direction. However, key institutions that govern water use should be prepared to make wise allocation decisions with any surpluses that become available as precipitation

[25] A recent World Wildlife Fund study estimates M$ 122 pesos/tcm for the "shadow price" of water in the nearby state of Chihuahua (Puente-Gonzalez 2003). In the absence of a free market, the shadow price of water is the price farmers are willing to pay to relax their volumetric constraint by one unit. This price is slightly lower than recent volumetric prices in the Yaqui Valley.

returns. Most likely, farmers will expect to resurrect the spring-summer cropping cycle and return to business as usual as the drought ends. Water planners should exercise leadership in envisioning a regional goal for water allocation based on growth in other sectors. Dynamic resource management might enable water to enhance, rather than dampen, opportunities for sustainable economic development.

REFERENCES

Acosta Felix, Ruben A. "Personal Communication." Ed. Ellen McCullough. Ciudad Obregon, Mexico, 2003. Gerente de Operacion, Distrito de Riego del Rio Yaqui.

Addams, Lee. "Personal Communication." Ed. Ellen McCullough, 2004.

---. "Water Resource Policy Evaluation Using a Combined Hydrological-Economic-Agronomic Modeling Framework: Yaqui Valley, Sonora, Mexico." Stanford University, 2004.

Battisti, David. "Drought and the Yaqui Valley, Mexico: Past, Present and Future." Stanford, California, 2004.

Brouwer, C., K. Prins, and M. Heirbloem. Irrigation Water Management: Irrigation Scheduling. Rome, Italy: Food and Agricultural Organization of the United Nations, 1989.

Characklis, Gregory W., Ronald C. Griffin, and Philip B. Bedient. "Improving the Ability of a Water Market to Efficiently Manage Drought." Water Resources Development 35.3 (1999): 823-31.

CNA. Ley De Aguas Nacionales. Mexico City, Mexico: Comision Nacional del Agua, 1992.

Cordery, Ian. "Forecasting Drought Probabilistically." Planning for Drought: Toward a Reduction of Societal Vulnerability. Eds. Donald A. Wilhite, William E. Easterling and Deborah A. Wood. Boulder and London: Westview Press, 1987.

Dinar, A., ed. The Political Economy of Water Pricing Reforms. New York: Oxford University Press, 2000.

Distrito de Riego del Rio Yaqui. Proyecto De Mejoramiento Del Distrito De Riego Del Rio Yaqui, S. De Rl De I.Y. Y C.V. Ciudad Obregon, Sonora, Mexico: Distrito de Riego del Rio Yaqui, 2003.

Easterling, William E., and William E. Riebsame. "Assessing Drought Impacts and Adjustments in Agriculture and Water Resource Systems." Planning for Drought: Toward a Reduction of Societal Vulnerability. Eds. Donald A. Wilhite, William E. Easterling and Deborah A. Wood. Boulder and London: Westview Press, 1987. 189-213.

English, Marshall. "Deficit Irrigation. I: Analytical Framework." Journal of Irrigation and Drainage Engineering 116.3 (1990): 399-412.

Falcon, Walter P. Recent Pork-Related Developments in the Yaqui Valley. Informal report/analysis.

Fontane, Darrell G., and Donald K. Frevert. "Water Management under Drought Conditions: Overview of Practices." Journal of Irrigation and Drainage Engineering 121.2 (1995): 199-206.

Gobierno del Estado de Sonora. Plan Integral Especial Para Enfrentar Los Efetos De La Sequia Dn El Valle Del Yaqui. Hermosillo, Mexico: Gobierno del Estado de Sonora, 2003.

Gonzalez, Felix. "Personal Communication." Ed. Ellen McCullough. Ciudad Obregon, Mexico, 2003. Local Administrative Head, Secretaria de Agricultura, Ganaderia, Desarrollo Rural, Pesca y Alimentacion (SAGARPA).

Grácia, Rodrigo. "Personal Communication." Ed. Ellen McCullough. Ciudad Obregon, Mexico, 2004. Gerente del Consejo de Administracion, Distrito de Riego del Rio Yaqui.

Hare, F. Kenneth. Climate Variations, Drought, and Desertification. Ed. World Meteorological Organization. Vol. 653. Geneva, Switzerland: World Meteorlogical Organization, 1985.

Hoerling, M. P., and A. Kumar. "The Perfect Ocean for Drought." Science 299 (2003): 691-94.

INEGI. Estudio Hidrologico Del Estado De Sonora, Instituto Nacional De Estadistica, Geografia Y Informatica. Hermosillo, Mexico: INEGI, 1993.

---. "Sistema Municipal De Basa De Datos, Instituto Nacional De Estadistica, Geografia Y Informatica". 2000. July, 2004 2004. <http://sc.inegi.gob.mx/simbad/index.jsp >.

Johnson, Sam H. III. Irrigation Management Transfer in Mexico: A Strategy to Achieve Irrigation District Sustainability. Colombo, Sri Lanka: International Irrigation Management Institute, 1997.

Klemes, Vit. "Drought Prediction: A Hydrological Perspective." Planning for Drought: Toward a Reduction of Societal Vulnerability. Eds. Donald A. Wilhite, William E. Easterling and Deborah A. Wood. Boulder and London: Westview Press, 1987. 81-94.

Lanjouw, Jean O., and Peter Lanjouw. "The Rural Non-Farm Sector: Issues and Evidence from Developing Countries." Agricultural Economics 26 (2001): 1-23.

Levine, G., et al. Performance of Two Transferred Modules in the Lagunera Region: Water Relations. Colombo, Sri Lanka: International Water Management Institute, 1998.

Lewis, Jessa. The Impact of Agrarian Law Reform in the Yaqui Valley, Sonora. Stanford, California: Center for Environmental Science and Policy, Stanford University, 1999.

Leyva Mendivil, Juan. "Personal Communication." Ed. Ellen McCullough. Ciudad Obregon, Mexico, 2004. President, Alianza Campesina Noroeste (ALCANO).

Lobell, David B., J. Ivan Ortiz-Monasterio, and Gregory P. Asner. "Relative Importance of Soil and Climate Variability for Nitrogen Management in Irrigated Wheat." Field crops research 87 (2004): 155-65.

Lovett, J. V., ed. The Environmental, Economic and Social Significance of Drought. Australia: Angus and Robertson, 1973.

Luque Favela, Rafael. "Personal Communication." Ed. Ellen McCullough. Ciudad Obregon, Mexico, 2003. Jefe de Operacion y Logistica, Associacion de Organismos de Agricultores del Sur de Sonora (AOASS).

Matson, P. A., Rosamond L. Naylor, and J. Ivan Ortiz-Monasterio. "Integration of Environmental, Agronomic, and Economic Aspects of Fertilizer Management." Science 280 (1998): 112-15.

Miller, David E. "Deficit Irrigation and Strategy for Optimizing Yield." Arid Land Irrigation and Ecological Management. Ed. S. D. Singh. Jodhpur, India: Scientific Publishers, 1993. 199-234.

Minjares, Carlos. "Personal Communication." Ed. Ellen McCullough. Ciudad Obregon, Mexico, 2003. Comision Nacional del Agua.

Minjares, Jose Luis. Anexo Tecnico Del Reglamento Para La Distribucion, Explotacion, Uso O Aprovechamiento De Las Aguas Nacionales Superficiales Y Subterraneas En La Cuenca Del Rio Yaqui. Ciudad Obregon, Mexico: Comision Nacional del Agua, Gerencia Regional del Noreste, Distrito de Riego No. 041, Rio Yaqui, 2004.

---. Yaqui River Reservoir System Operation Rules. Ciudad Obregon, Mexico: Comision Nacional del Agua, Gerencia Regional del Noroeste, Distrito de Riego No. 041, Rio Yaqui, 2004.

Naylor, Rosamond L., Walter P. Falcon, and Arturo Puente-Gonzalez. Policy Reforms and Mexican Agriculture: Views from the Yaqui Valley. Mexico, D.F.: CIMMYT, 2001.

Ortiz Munoz, Jose Eliseo. "Pesonal Communication." Ed. Ellen McCullough. Ciudad Obregon, Mexico, 2003. Investigador, Centro de Investigacion Regional del Noroeste (CIRNO).

Ortiz-Monasterio, J. Ivan, R. J. Pena, and W. H. Pfeiffer. "Grain Yield and Quality of Cimmyt Durum Wheat under Water and Nitrogen Stress." CIMMYT, 2001.

Pfeiffer, Wolfgang. "Personal Communication." Ed. Ellen McCullough. Ciudad Obregon, Mexico, 2003. Senior Scientist, Centro Internacional de Mejoramiento de Maiz y Trigo.

Puente-Gonzalez, Arturo. Towards a Sustainabile Use of Water in Agriculture: Assessment of an Investment Project for Irrigation District 005 Delicias/Chihuahua. Chihuahua, Mexico: World Wildlife Fund Mexico, Chihuahuan Desert Program, 2003.

Ramirez Diaz, Juan Manuel. "Northwest Regional Director, Instituto Nacional De Investigaciones Forestales Y Agropecuarias (Inifap)." Ed. Ellen McCullough. Ciudad Obregon, Sonora, 2004.

Ray, Isha. "Farm-Level Incentives for Irrigation Efficiency: Some Lessons from an Indian Canal." Water Resources Update (2002): 121: Incentives and Trading in Water Resource Management.

Ray, Isha, and Serap Gul. "More from Less: Policy Options and Farmer Choice under Water Scarcity." Irrigation and Drainage Systems 13 (1999): 361-83.

Romero Arreola, Jose Ramon. "Gerente General, Fondo De Aseguramiento Agropecuario De Vida Campesina Y Conexos Grupo Cajeme." Ed. Ellen McCullough. Ciudad Obregon, Mexico, 2003.

Schoups, Gerrit, C. Lee Addams, and Steve Gorelick. "Sustainable Groundwater and Surface Water Management in the Yaqui Valley." San Carlos, Mexico, 2004.

Sonka, Steven T. "Adaptation and Adjustments in Drought-Prone Areas: Research Directions." Planning for Drought: Toward a Reduction of Societal Vulnerability. Eds. Donald A. Wilhite, William E. Easterling and Deborah A. Wood. Boulder and London: Westview Press, 1987. 351-67.

Tardieu, Henri, and Bernard Prefol. "Full Cost or "Sustainability Cost" Pricing in Irrigated Agriculture. Charging for Water Can Be Effective, but Is It Sufficient?" Irrigation and Drainage 51 (2002): 97-107.

Tsur, Yacov, et al. Irrigation Water Pricing: Policy Implications Based on International Comparison. Washington DC: The World Bank Group, 2003.

Valenzuela Zarate, Pedro A. "Tesorero Del Consejo De Administracion, Distrito De Riego Del Rio Yaqui." Ed. Ellen McCullough. Ciudad Obregon, Mexico, 2003.

Vargas Romero, Feliciano. "Personal Communication." Ed. Ellen McCullough. Ciudad Obregon, Mexico, 2003. Residente General de Rehabilitacion y Conservacion.

Wilhelmi, Olga V., and Donald A. Wilhite. "Assessing Vulnerability to Agricultural Drought: A Nebraska Case Study." Natural Hazards 25.1 (2002): 37-58.

Zilberman, David, et al. Individual and Institutional Responses to the Drought: The Case of California Agricultural. Berkely, CA: UC Berkeley, 1992.

Table 1. Regional policies responding to drought.

	Water Allocation	Water Pricing	Income Supports	Weed Control	Capital Investments
Agency:	Yaqui River Irrigation District	Yaqui River Irrigation District	Secretary of Agriculture (SAGARPA)	Local Phytosanitary Committee (JLSV)	National Water Commission & Irrigation District
What:	Maximize area planted and economic returns despite scarce supplies	Water price doubles to $130 pesos / TCM.	PROCAMPO-sequía	Environmental Plowing Program	District Modernization Plan
Details:	Priority given to fields closest to canals Prioirity also given to crops with high value or low water demand	Price change reflected increased pumping costs Resulted in little effect on per-area demand	Revised area-based income transfer program Normally, eligibility requires planting a crop; stipulation was removed in 2003/2004	Payment of M$600/ha for two plowings Purpose to prevent weeds from going to seed on fallow fields & stimulate economic activity	Drilling new wells & Increasing conveyance efficiency Jointly-financed project to line canals and improve measurement capabilities

Table 2. Role of Credit Committee recommendations in farmer decision-making. When asked how their management practices compared with official credit recommendations, farmers answered "same" if they followed the recommendations and "different" if they did not.

	Water Use	Soil Preperation	Planting	Fertilizer Use	Herbicide Use	Pesticide Use	Technical Assistance	Labor
Same:	52.27%	15.91%	48.86%	37.50%	15.91%	21.59%	77.01%	34.48%
Different:	47.73%	84.09%	51.14%	62.50%	84.09%	78.41%	22.99%	65.52%

Table 3. Preventative Drought Investments in the Yaqui Valley.

Investment	Project	Time Frame
Water transport infrastructure	Irrigation District Modernization Plan	2003 on
More efficient irrigation methods	Alianza para el Campo - 50% finance of farmer investments in irrigation infrastructure	1995 on
Better conjunctive surface/groundwater resource management	National Water Commission - new reservoir and aquifer management rules	2004 on
Drilling more wells	Irrigation District Modernization Plan	2003-2004
Breeding for drought resistance	CIMMYT breeding program	ongoing

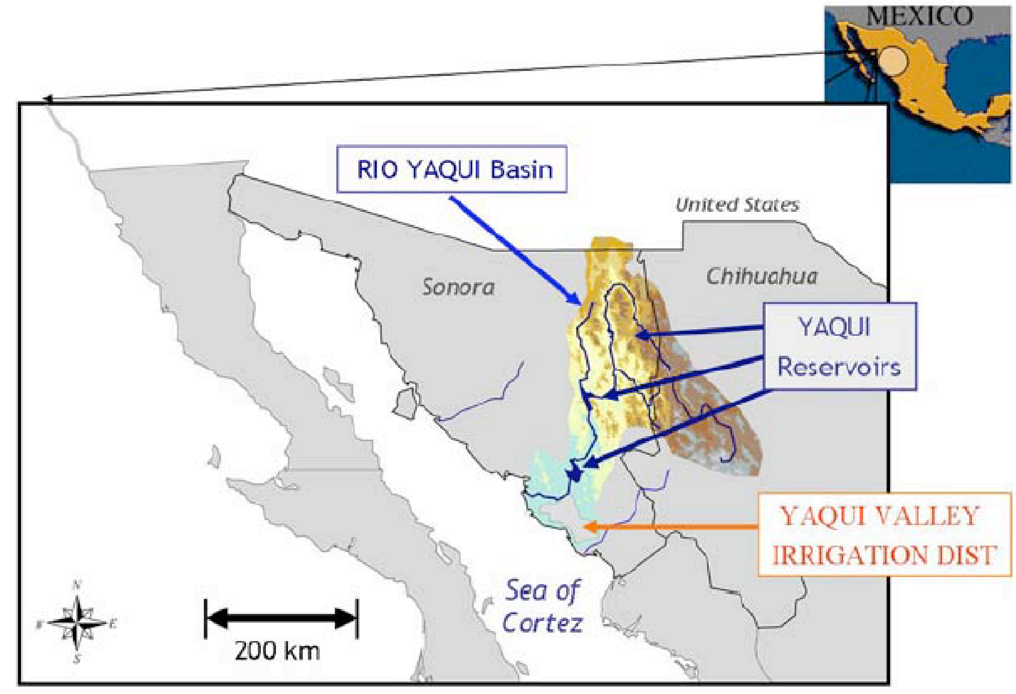


Figure 1. Location of the Yaqui Valley (Addams 2004)

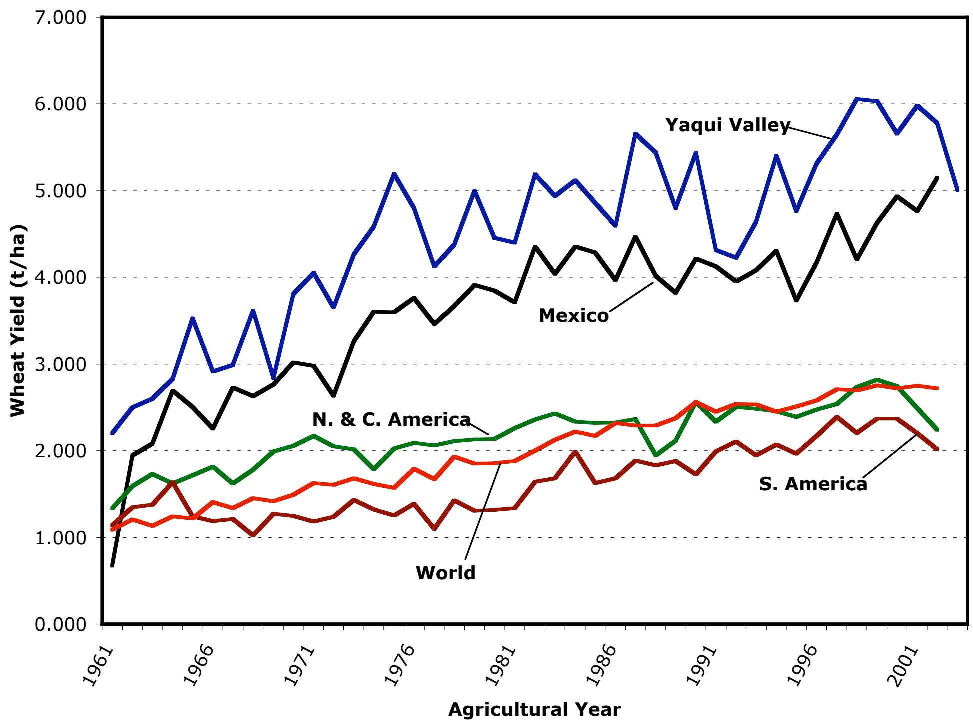


Figure 2. Comparison of world wheat yields to the Yaqui Valley (data from FAO 2003, SAGARPA)

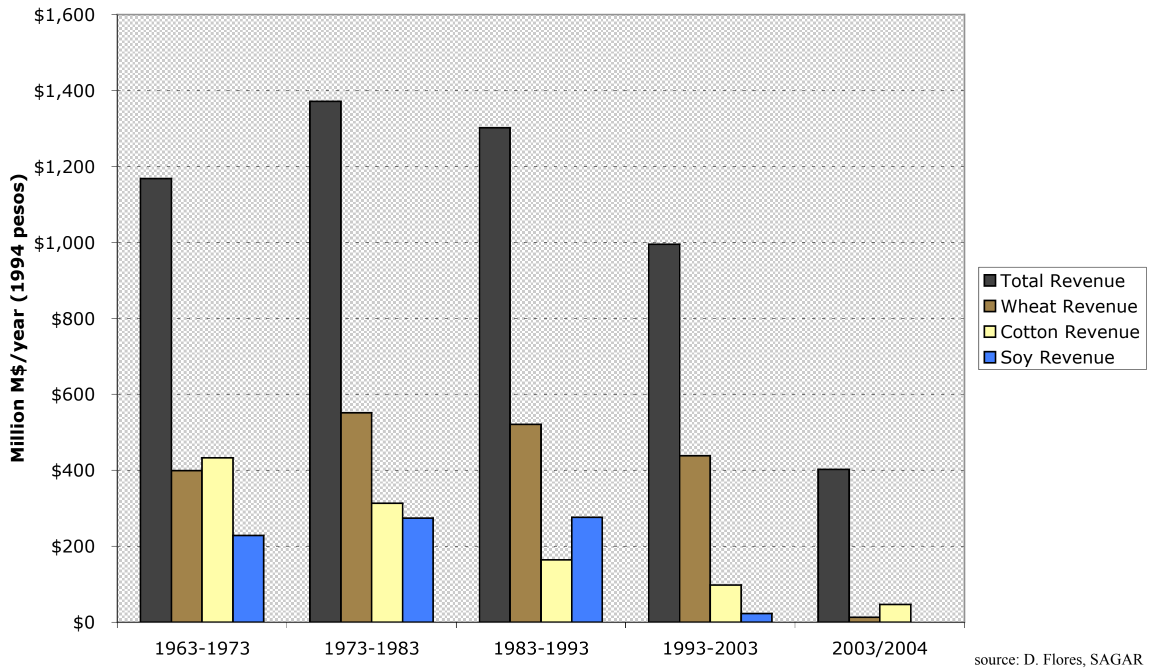


Figure 3. Aggregate agricultural revenue of the Yaqui Valley over time and in 2003-2004, based on average prices and yields. No multiplier effect is considered. (calculated from SAGARPA data).

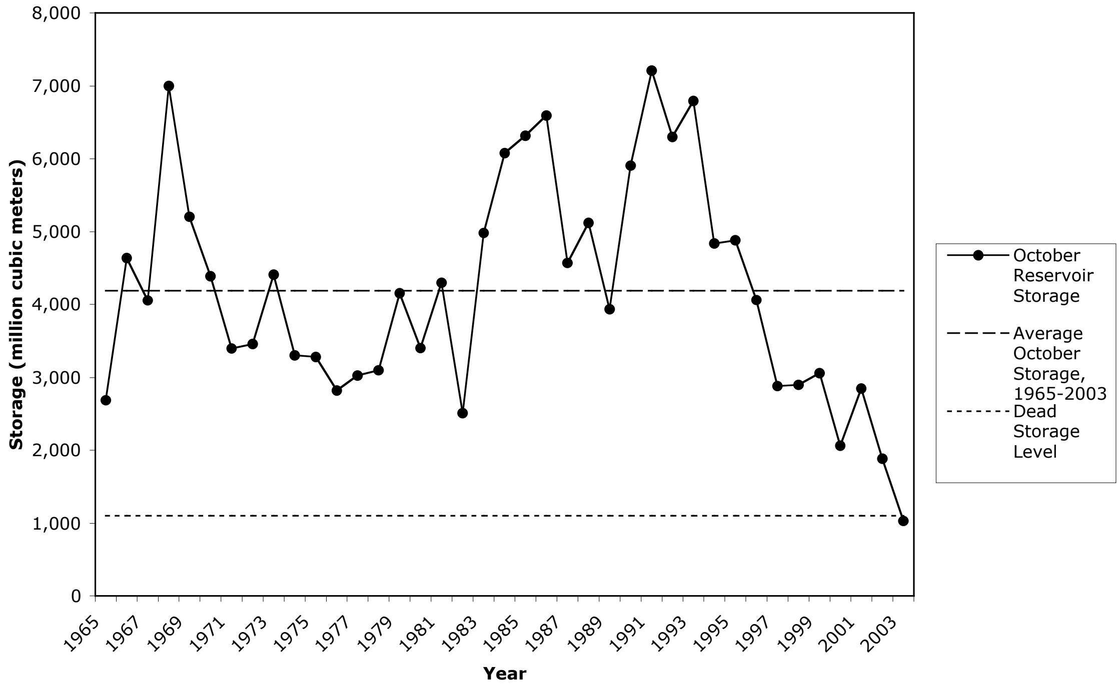


Figure 4. Yaqui River reservoir system, October reservoir storage (data from CNA 2003)

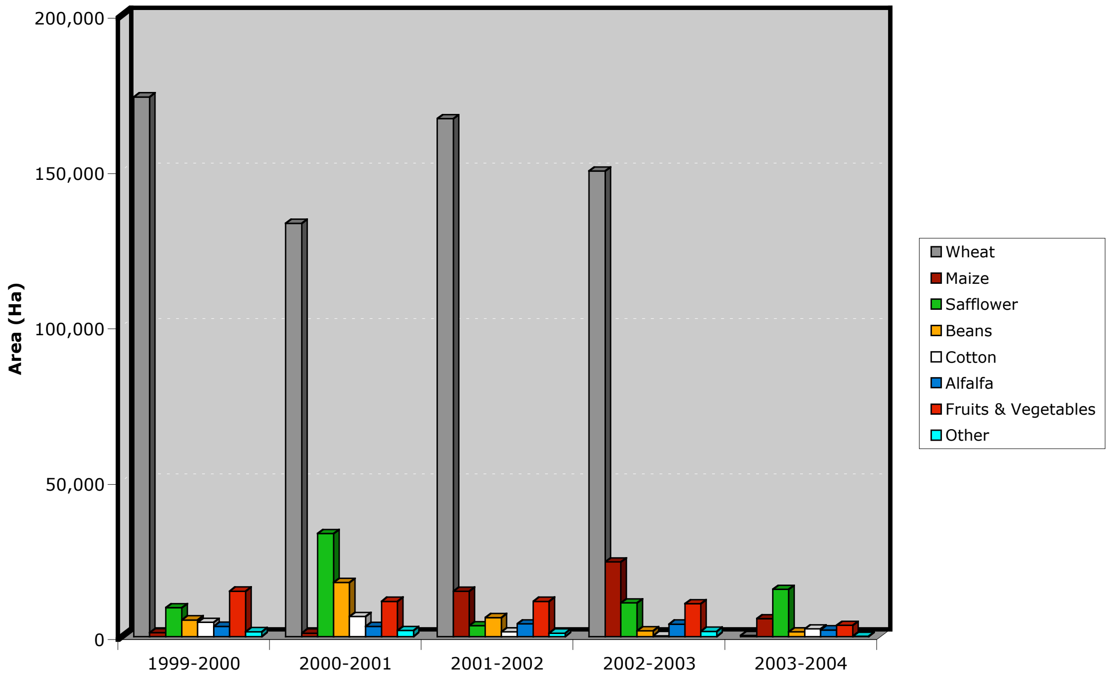
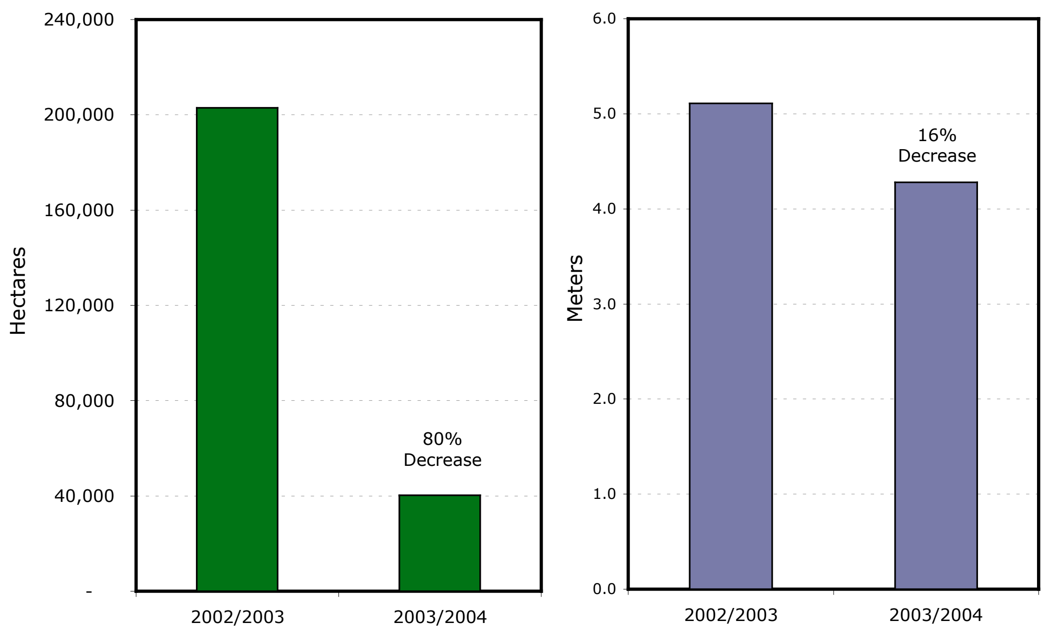


Figure 5. Crop area planted with public irrigation water in the Yaqui Valley, 1999-2004, Fall-winter cycle (data from Yaqui River Irrigation District).



(a) Total Area Irrigated

(b) Average water depth applied to fields

Figure 6. Relative decrease in area irrigated between 2002-2003 and 2003-2004, compared with relative decrease in water application rates.

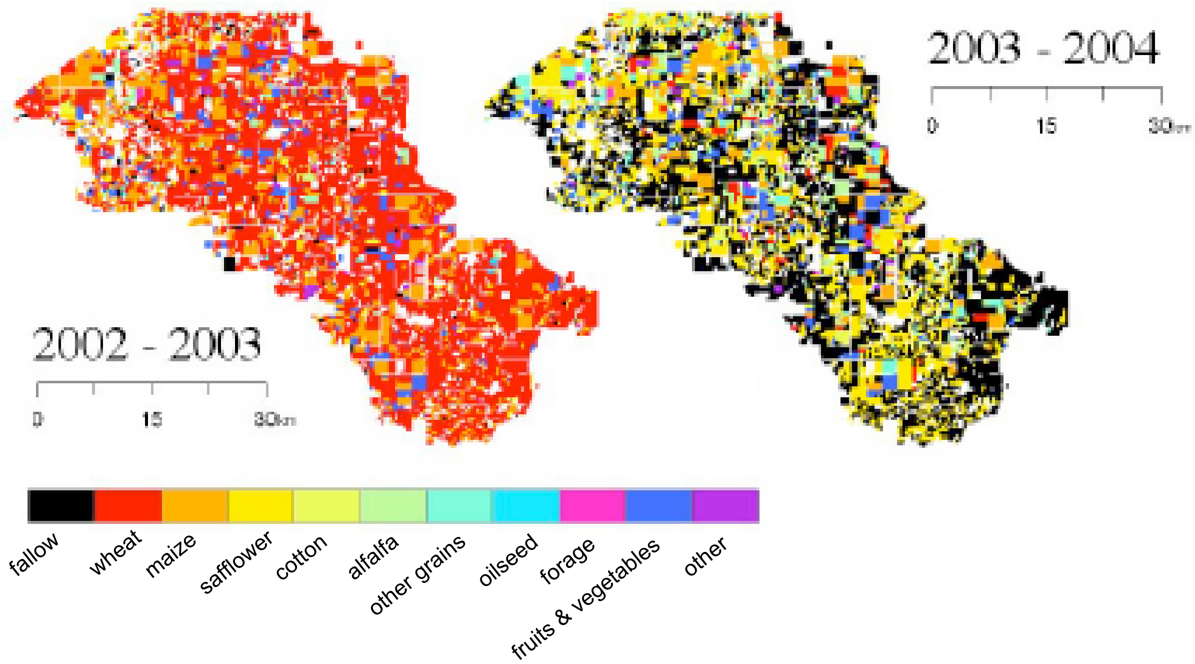


Figure 7. Spatial representation of cropping differences between 2002-2003 and 2003-2004 (Data from Yaqui River Irrigation District, Map by Woolley and Monroe).

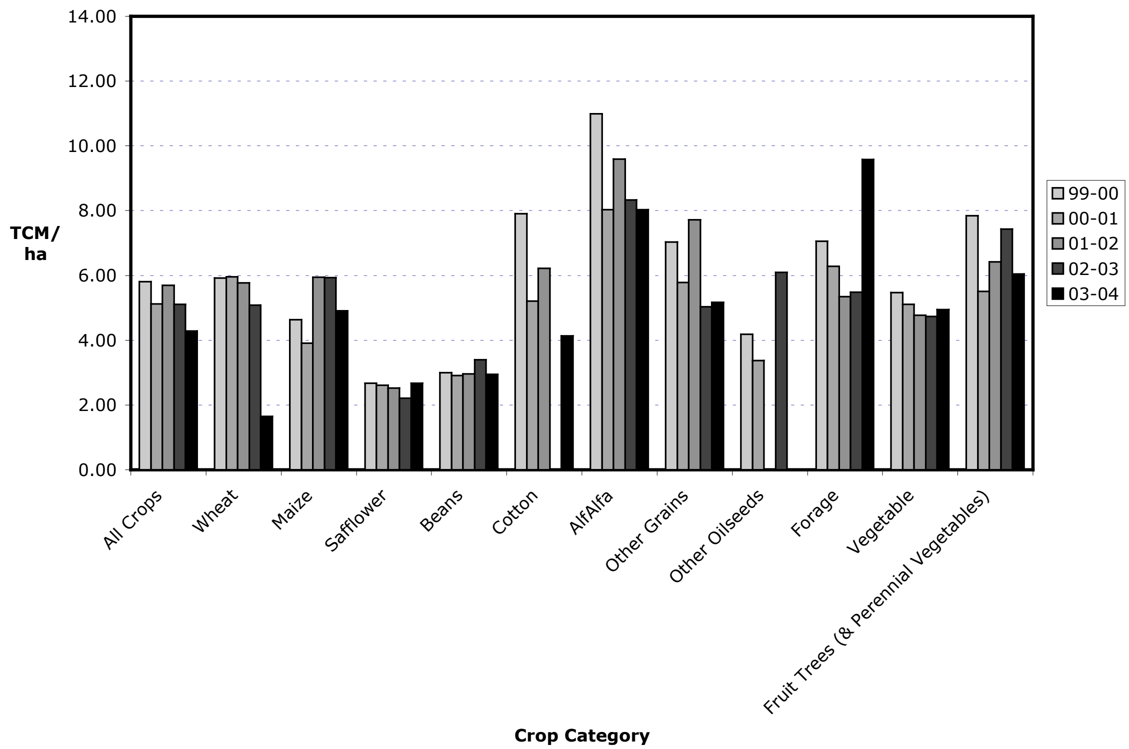


Figure 8. Average district-wide irrigation rates per crop, 1999-2004 (data from Yaqui River Irrigation District).

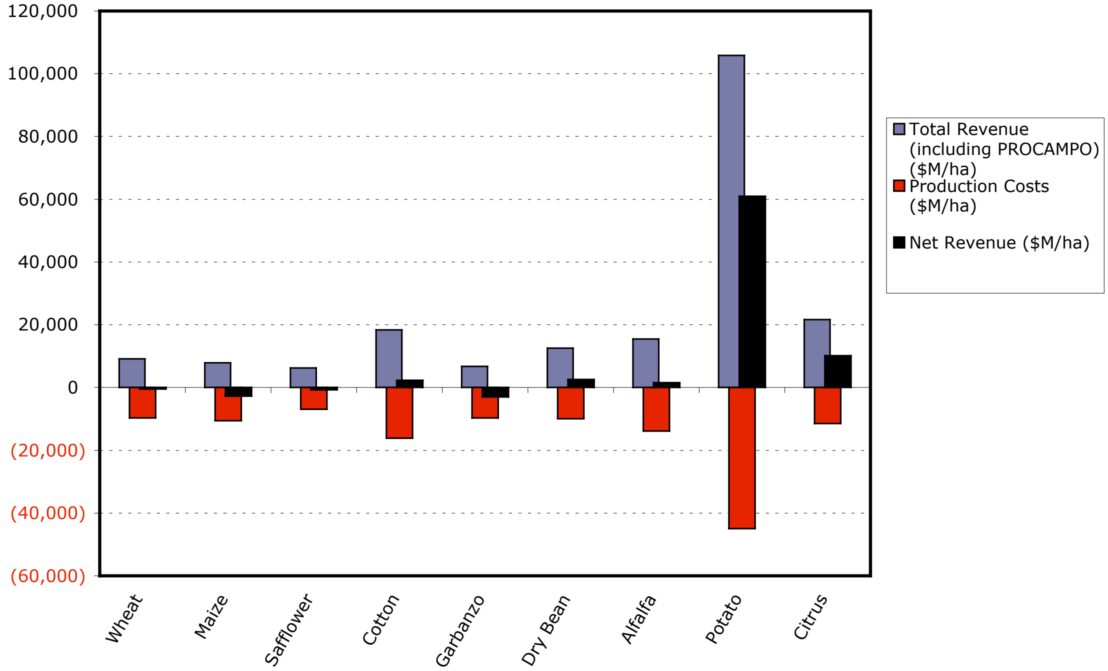


Figure 9. (a) Total revenue, production costs, and net revenue generated by crop (data from SAGAR).

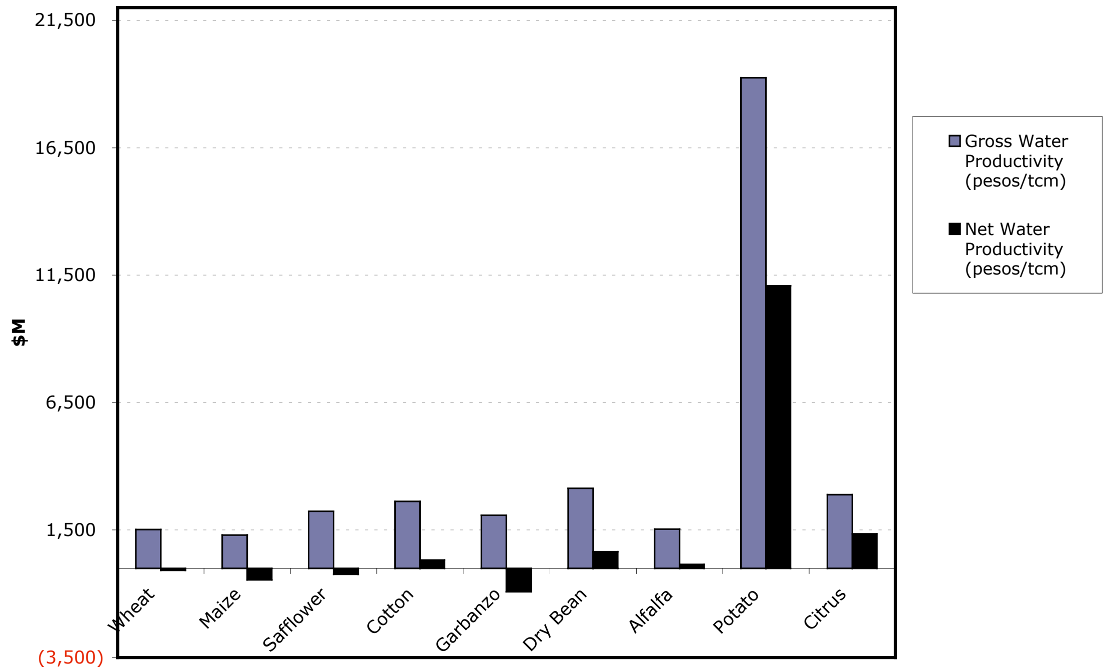


Figure 9. (b) Gross and net water productivity by crop (data from SAGAR).

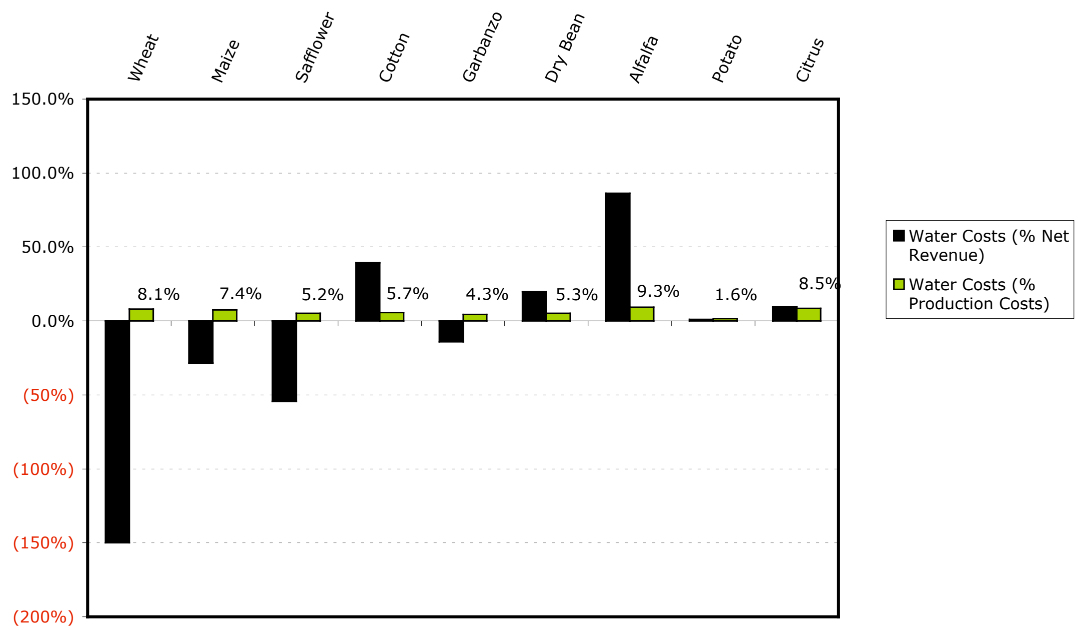


Figure 9. (c) Water as a percentage of net revenue and production costs by crop (data from SAGAR).

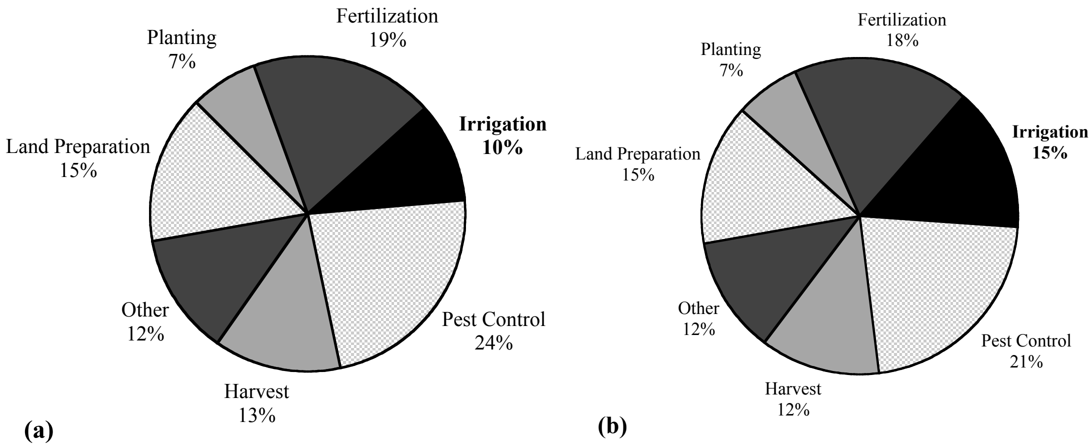


Figure 10. Categorization of typical wheat production costs using different water prices. (a) 2002-2003 crop year with water priced at M$65/tcm. Total costs were M$9,890/ha. (b) 2003-2004 crop year with water priced at M$130/tcm. Total costs were M$9,393/ha (data from SAGAR).

APPENDIX A. Producer Surveys

Yaqui Valley Producer Survey
Conducted November, 2004

Información del Productor

Nombre del Agricultor:		Teléfono:	
Años sembrando en el Valle Yaqui:		Dirección:	
Edad:		Escolaridad:	
Block / Lote:		Suelos:	

Numero del Padron:
Nombre del encuestador: ____________________
Fecha encuesta: ____________________

¿Tiene animales o granjas pecuarias o acuícolas? si no
Si es pecuaria ¿cuantos animales? _________
¿qué tipo? _________
Si es acuícola ¿qué superficie de estanques? _________ ha
¿qué tipo? _________

¿Tiene algún otro tipo de empresa rural? si no
¿Cual empresa? ________________
¿Hace cuánto tiempo ha tenido esa empresa? _________ años

¿Tiene otro trabajo? si no
¿Cuál?

¿Cuántas personas (incluyendo Ud.) viven en su casa? _________
¿Cuántas personas trabajan (con salario) en su casa? _________
¿Qué tipo de trabajo tiene cada persona?

¿Qué porcentaje de sus ingresos obtuvo directamente de la agricultura el año pasado? (octubre 2002 – septiembre 2003) _________%
¿Este año? (octubre 2003 – septiembre 2004, probable) _______%

Tipo de Tenencia

		Ejido individual	Ejido Colectivo	Propiedad Privada
Ciclo 2002-2003	tierra propia (ha):	(ha)	(ha)	(ha)
	tierra rentada (ha):	(ha)	(ha)	(ha)
Ciclo 2003-2004	tierra propia (ha):	(ha)	(ha)	(ha)
	tierra rentada (ha):	(ha)	(ha)	(ha)

Cultivos en la área sembrada (por Ud. mismo)

		Cultivos	Área (ha)	Rendimientos
Otoño – Invierno	2001-2002		(ha)	(ton/ha)
	2002-2003		(ha)	(ton/ha)
	2003-2004		(ha)	(ton/ha)
Primavera - Verano	2001		(ha)	(ton/ha)
	2002		(ha)	(ton/ha)
	2003		(ha)	(ton/ha)

Sí Ud. ha cambiado su cultivo en los 3 años pasados, ¿por qué lo ha hecho?

	¿Si?	¿No?	¿Por Qué?
Costo de producción			
Precios de mercado			
Disponilidad del agua			
Uso del agua			
Programa del gobierno			
Acceso al crédito			
Acceso al permiso de sembrar			
Otros (Cuál)			

¿Sí Ud. ha cambiado la área de producción en los 3 años pasados, porqué lo ha hecho?

	¿Si?	¿No?	¿Por Qué?
Disponilidad del agua			
Acceso al crédito			
Acceso al permiso de sembrar			
Costo de producción			
Precios del mercado			
Mayor ganancia			
Otros (Cuál)			

Crédito

¿De donde recibió el crédito el año pasado?

¿Tiene crédito este año? si no
¿Del mismo lugar?

¿Es más/menos difícil recibir crédito este año que el año pasado?

Renta de Tierra

Si Ud. siembra en tierra rentada:

Año	Área rentada (O-I)	Precio (pesos/ha)	Área rentada (P-V)	Precio (pesos/ha)
2001-2002				
2002-2003				
2003-2004				

¿Ha cambiado el mercado de la renta de tierras este año?
¿Como?

Acceso al Agua

¿Tiene agua disponible para el riego este ciclo agrícola?

Normalmente, de donde viene su agua de riego? (Pozo, presas, drenaje)
¿Este año?

Si es pozo este año, ¿qué tipo de pozo? (publico, plan colectivo, privado)
¿a que distancia de su parcela está el pozo?

¿Es bombeo directo o de plan colectivo?
¿Que distancia aproximada recorre en canales?

Riegos

¿Alguna vez en los últimos 3 años ha usado más agua que su dotación del distrito?
¿Cuándo y cuánto?

¿Alguna vez este año o en los últimos 3 años ha usado agua de pozo particular?
¿Cuándo?
¿Cantidad aplicado (mm^3/ha) y superficie regado (ha)?

¿Cuánta agua va a recibir Ud. este ciclo por hectárea? (probable) (mm^3/ha)
Ciclo 2003-2004 ________________

¿Cual es la cantidad mínima (mm^3/ha) necesita para establecer sus cultivos?

¿Cómo será diferente el número total de riegos este año a lo de los últimos 3 años (promedio)?

¿Cómo serán diferentes las fechas de riego este año a las de los últimos 3 años (promedio)?

¿Que método de riego usó el año pasado? (surcos, melgas, aspersión, goteo, pivote central, etc.)
¿Ha cambiado en los últimos 5 años?
¿Cuál y por qué?
¿Método de riego este año?

¿Cómo ha cambiado la eficiencia de su uso de agua en los últimos 5 años?

¿Piensa Ud. que va a cambiar en los próximos 5 años?
¿Cómo?
¿Cuales inversiones se necesitarán?

Generalmente, cuando Ud. pide agua al modulo de riego, ¿la recibe cuando la pide?
¿En cuántos días?

En este año, ¿es más difícil recibir el agua el día que Ud. la pide?

¿Le han reducido la dotación de agua en los últimos 4 años?

Si Ud. ha reducido su uso de agua desde 2000, ¿como lo ha hecho?

	¿Si?	¿No?	¿Qué años?
¿Siembra cultivos alternativos?			
¿Riega con aguas negras?			
¿Hace menos riegos / cultivo?			
¿Reduce la área de siembra?			
¿Castiga su cultivo?			
¿Compra agua de otro usuario?			
¿Compra agua del modulo?			
¿Tiene siembras de temporal?			

Si Ud. ha reducido el uso del agua desde 2000, ¿han bajado sus rendimientos?
¿Cuánto han bajado?

Si Ud. ha reducido el uso del agua desde 2000, ¿ha bajado la área sembrada?
¿Cuánto ha bajado?

Con una dotación escasa de agua, ¿Ud. prefiere reducir la área sembrada o el uso del agua por cada hectárea?
¿Por qué?

¿Es posible recibir permiso para sembrar un superficie más grande que lo a que tiene derecho de regar? (¿Ud. puede usar menos agua del modulo para sembrar más área?)

Salinidad

¿Qué salinidad tiene el agua que Ud. usa para regar su parcela?
2002-2003 (buena, regular, mala)
2003-2004 (buena, regular, mala)

¿Cual es la máxima salinidad en el agua de riego que piensa Ud. que su cultivo podría soportar?

¿Ha cambiado la salinidad de su agua en los últimos años?
¿Como y por qué?

¿Ha afectado sus rendimientos en el pasado?
¿Este año va a afectar sus rendimientos?

¿Le preocupa la salinidad del agua que usa en su parcela?

¿Ha cambiado la salinidad del suelo en su parcela en los últimos 5 años?
¿Ha afectado sus rendimientos?

¿Tiene problemas con la salinidad del suelo en su parcela?
¿Qué problemas?

¿Tiene problemas con drenaje en su parcela?

Si tenía dotación de agua de gravedad, ¿aceptaría más salinidad en su dotación de gravedad, aunque la dotación sea de mayor cantidad? (si o no)

Si usa agua de pozo, ¿tiene análisis del agua del pozo?
¿Que calidad de agua de pozo tiene? (Buena, regular, mala)

Entradas

Si Ud. está sembrando este año:

Este año, ¿es diferente su uso de fertilizante que el uso en los últimos 5 años (promedio)? (tipo de producto, cantidad, método de aplicar, número de aplicaciones)
si no ¿Como?______________________________

Este año, ¿es diferente su uso de insecticidas que el uso en los últimos 5 años (promedio)? (tipo de producto, cantidad aplicado, etc.)
si no ¿Como?______________________________

Este año, ¿es diferente su uso de herbicidas que el uso en los últimos 5 años (promedio)? (tipo de producto, cantidad aplicado, etc.)
si no ¿Como?______________________________

Si Ud no está sembrando alguna parte de su parcela este año, ¿está aplicando algunas entradas en su parcela (fertilizante, insecticidas, herbicidas)?
¿Cual producta y por qué?

Jornales

¿Cuántos jornales (además de los de Ud.) usó el año pasado (días de labor por hectárea)?
¿Cuántos va a usar este año?

¿Cuánto era el costo del jornal diario el año pasado?
¿Este año?
Si ha cambiado, ¿por qué cambió?

Preparación del Suelo

El año pasado, ¿como preparó el suelo? (surcos, corrugación, melgas, curvas de nivel, mínima labranza)
¿Este año?

El año pasado, ¿cual fue su método de siembra?
¿Este año?

Siembra

Este año, ¿Ud. está sembrando antes o después de la fecha de siembra de 2002-2003?
¿Por qué?

Este año, ¿ha cambiado la variedad sembrada?
¿Cuál? ¿Por qué?

El año pasado, ¿cual fue la fuente de semilla? (Unión de Crédito, PIEAES, Casa Comercial, Unión de Ejidos, otros)
¿Este año?
Si cambió, ¿por qué?

Control de las Malezas

El año pasado, ¿Cuántos rastreos hizo?
¿Cuánto costó un rastreo? (pesos/ha)
Jornales / deshierbe (incluso tractorista):
¿Con machina propia o rentada?
¿Hizo algún deshierbe manual?

Este año, ¿Cuántos rastreos va a hacer?
Costo de un rastreo este año: (pesos/ha)
Jornales / deshierbe (incluso tractorista):
¿Va a hacer algún deshierbe manual?

Este año, ¿está Ud. participando en el programa ambiental (Sanidad Vegetal) de rastreos?

Cosecha

¿Cómo será diferente las fechas de cosecha este año a las de los últimos 3 años (promedio)?

Tuvo contrato (en el pasado) para la venta de sus cosechas?
¿Qué cultivos, con quien?
¿Este año es lo mismo?

Destino de la paja el año pasado:
Este año:

Si incorpora Ud. la paja, ¿lo hace después de la cosecha o antes de sembrar en el siguiente ciclo?
¿Por qué?

Si sus rendimientos han cambiado en los últimos 5 años ¿por qué lo han hecho?

	¿Si?	¿No?	¿Por qué?
Cantidad del agua aplicada			
Calidad del agua aplicada			
Estado de los suelos			
Carbón parcial			
Plagas y enfermedades			
Malezas			
Clima			
Otro ¿Cual?			

Siembra Temporal (Sin Regar)

¿Ud. sembraría temporal este año si llueve?
¿Qué área?
¿Qué cultivos?
¿En cual fecha quiere sembrar?
¿Piensa recibir crédito para hacerlo?
¿Piensa recibir riesgo compartido del gobierno con relación a la semilla o el fertilizante?

¿Ud. ha sembrado temporal antes?
¿Cuando?
¿Qué cultivos?
¿Por qué?

Inversiones en Agua

¿Ud. ha invertido en un sistema de riego de goteo, aspersión o pivote central en los últimos 5 años?
Si sí, ¿Cual sistema?
¿Cuándo?
¿Cuánto costó?
¿El gobierno (La Alianza para el Campo) pagó la mitad del costo de instalación?

¿Ud. tiene plan de invertir en alguna tecnología de riegos en los próximos 5 años?
¿Cuándo?
¿Cual tecnología?
¿Cuánto va a costar?

Si Ud. no cuenta actualmente con un pozo, ¿instalaría uno si persiste la sequía?
¿Cuando?
¿Cuenta con permiso de perforar del CNA?

¿La SRL ha perforado algún pozo cerca de su parcela este año (o tiene plan de hacerlo más adelante)?

El Banco de Agua

¿Piensa Ud. que la SRL debe fijar el precio del agua (de las presas y de los pozos públicos) cuando dos usuarios quieren intercambiar entre ellos mismos?

		2001-2002	2002-2003	2003-2004 (previsto)
¿Ud. ha comprado agua al modulo de riego? (a parte de su dotación)	Volumen (mm3/ha)			
	Área (ha)			
	Precio (pesos/mm3)			
¿Ud. ha vendido agua al modulo de riego?	Volumen (mm3/ha)			
	Área (ha)			
	Precio (pesos/mm3)			

¿Alguna vez Ud. ha comprado agua directamente de otro usuario?
¿Donde estaba localizado el terreno del otro usuario?
¿A qué precio?
¿Cual era la fuente?

¿Tiene planes de comprar agua de otro usuario este año?
¿De quien?
¿A qué precio?

¿Alguna vez Ud. ha vendido agua directamente a otro usuario?
¿Donde estaba localizado el terreno del otro usuario?
¿A qué precio?
¿Cual era la fuente?

Si Ud. no tuviera ninguna agua este año, ¿cuánto es lo más que pagaría Ud. por mm^3 (para comprar agua)?
¿Cuánta agua compraría a este precio (mm^3/ha)?

Si Ud. tuviera agua de pozo privado este año ¿cuánto es lo menos que aceptaría Ud. por mm^3 (para vender la que sobra)?

¿Ud. tendría en cuenta la salinidad del agua cuando elige un precio?

Programas del Gobierno

¿Ud. está participando en un programa del gobierno para la sequía este año?
Nombre del Programa   Requisitos   Cuánta Paga / ha

¿Ud. va a hacer algo diferente en su parcela el próximo año si puede sembrar?

Si Ud. no va a sembrar este año (o si solamente esta esperando sembrar temporal), ¿qué gastos necesita hacer Ud. en su campo? (e.g. hacer pagos por la tierra o una máquina)

Si Ud. no ha sembrado este año, ¿tiene otros ingresos de su parcela? (e.g. pastorear ganado en la paja o en las malezas)
¿Tiene otros ingresos además de su parcela?

¿Este año, tiene ingresos perdidos (de agricultura)?
¿Qué va a hacer este año para compensarlos este año?
¿En el futuro (si continúa la sequía)?

¿Piensa Ud. que ha subido la frecuencia de migración a los EEUU por la sequía?

¿Ud. está pensando en cambiar su cultivo en el futuro?
¿A qué, por qué?

¿Cuales son los impedimentos más grandes para cambiar de cultivo?

Si continúa la sequía, ¿por cuantos años más Ud. pudiere continuar sin sembrar?

¿Qué piensa Ud. que va estar haciendo en 5 años?
¿Piensa que va a sembrar en 5 años?

Percepciones de la Sequía

¿Por cuáles razones Ud. piensa que existe la escasez de agua?
(manejo de recursos de agua, falta de lluvia, calentamiento mundial…)

¿Piensa Ud. que fue posible evitar la falta de agua de riego este año?

¿Cuales inversiones son **mas importantes** para que el valle del Yaqui pueda enfrentar de una manera mas eficiente la sequía? (clasificar los 5 superiores)

	Investigaciones en cultivos que resisten sequía		Antenas de ionización
	Métodos eficientes de irrigación		Investigaciones en hortalizas
	Más pozos		Poder predecir sequías
	Surcos mas cortos		Desarrollar acuacultura
	Revestimiento de los canales		Desarrollar ganadería
	Mejor manejo de las presas y el acuífero		Apoyo del gobierno de precios de cultivos resistente a las sequías
	Desarrollar industria no agrícola		
	Otro ¿Cual?		

¿Por cuántos años más Ud. piensa qué continuará la sequía?

¿Piensa Ud. que va a poder regar el próximo año?
Si si, ¿Cual cultivo quiere sembrar?

¿Cuántos años hace de la última sequía tan grande en el Valle Yaqui?

¿Piensa Ud. que las antenas de ionización van a traer lluvia? ¿Cuándo?

Si Ud. sabía en 1995 que la sequía continuaría hasta el 2004, ¿cuales cosas hubiera hecho diferente en su parcela?
¿Cuales inversiones Ud. hubiera hecho?

¿Ud. anticipó la falta de agua de riego este año?

¿Piensa Ud. que es sostenible la extracción actual del agua subterránea?
¿En cuántos años llegaría a ser un problema?

¿Ud. está de acuerdo que si alguien quiere perforar un pozo nuevo, necesite solicitar permiso de la CNA?

Nombre de su ejido (si hay):

¿Ud. es parte de un grupo de productores? Nombre:
¿Cuántos socios son? ¿Qué superficie representan?

Agua de Pozo (solamente si Ud. posee un pozo privado o de plan colectivo)

¿A qué profundidad está el agua? (metros)
¿Ha cambiado la profundidad del agua en los últimos años? ¿Como?

¿A qué profundidad está el pozo (en total - metros)?

¿Cuánto es el flujo del pozo? (litros / segundo)
¿Ha cambiado el flujo en los últimos 5 años? ¿Como?

¿Cuál es la salinidad del agua?
¿Ha cambiado la salinidad del agua en los últimos años? ¿Como?

¿Ha bajado el rendimiento de sus cultivos por usar solo agua subterránea?

¿Cuándo perforó el pozo?
¿El gobierno pagó la mitad del costo de perforación?

¿Cuánto costó, en total, perforar el pozo?
¿Piensa que la inversión fue buena?

¿Cuánto cuesta bombear el agua (pesos/hora)?
¿Ha cambiado el costo de la energía eléctrica en los últimos 5 años?
¿Como?

¿Existen otros costos de operación de la bomba o el pozo?

En el pasado, ¿ha vendido agua directamente a otros usuarios?
Cantidad vendido por ciclo:
Precio y método de cobrar:

Este año, ¿va a vender Ud. agua directamente a otros usuarios?
Cantidad que puede vender:
Precio y método de cobrar:

Yaqui Valley Producer Survey
Conducted February, 2005

Información del Productor:

Nombre del Productor: ____

Dirección: ____

Años sembrando en el Valle del Yaqui: ________

Teléfono: ____________________ **Años de escolaridad:** ____________

Edad del productor: ___________ **Fecha de entrevista:** _____________

Nombre del encuestador: ____

¿Ud. es ejidatario? **0=No 1=Si**
Nombre de su ejido: ______________________________
Ejido individual colectivo.______________________________

¿Ud. es parte de un grupo de productores (SPR)? **0=No 1=Si**
Nombre de SPR: ______________________________
¿Cuántos socios son? ______________________________
¿Qué superficie representan?____________________ha.

De estos cultivos, ¿cuales ha sembrado antes?_______________

	¿Si o No? 0=no 1=yes		¿Si o No? 0=no 1=yes
Trigo		Alfalfa	
Maiz		Soya	
Cártamo		Algodón	
Garbanzo		Papa	

	¿Si o No? 0=no 1=yes	¿Cuál? (sp)
Hortalizas		
Frutales		
Otro		

¿Tiene algunos empleados de jornada completa? **0=No 1=Si** ¿Cuántos tiene? ____________

¿Tiene algunos empleados de jornada parcial? **0=No 1=Si** ¿Cuántos tiene? ____________

¿Tiene asistencia técnica particular? **0=No 1=Si** ¿Con cuales cultivos? __________
___________ __________

Este año, ¿Cómo eligió el cultivo que sembró? ____________________________________

Llene la tabla. Incluya cada parcela que tenía el ciclo pasado (y también cada parcela de este año).

Block-Lote	Área (ha)	2002-2003 (1=propio 2=rentado 3=ótro)	2003-2004 (1=propio 2=rentado 3=ótro)	¿Si es rentada, de quien renta? 1=Ejido Individual 2=Ejido Colectivo, 3=P. Privada, 4=ótro	Número de años que renta o tiene la parcela	Cultivo 2002-2003 1=trigo,2=maiz, 3=algodón, 4=cártamo, 5=hort., 6=ótro	Rend. kg/ha	Cultivo 2003-2004 1=trigo,2=maiz, 3=algodón, 4=cártamo, 5=hort., 6=ótro	Rend. kg/ha	P-V o O-I?	Fuente de Agua 2003-2004 1=pozo público 2=pozo privado 3=aguas negras 4=temporal 5=ótro	Número de Padrón (del SRL)

Área total rentada en 2002-2003 (ha): _________
Área total rentada en 2003-2004, (ha): _________ (ya pagó la renta): **0=No 1=SI**
Área total propia en 2002-2003 (ha): ___________
Área total propia en 2003-2004 (ha): ___________

Área total sembrada en 2002-2003 (ha): _________
Área total no sembrada 2002-2003 (ha): _________
Área total sembrada en 2003-2004 (ha): __________
Área total no sembrada 2003-2004 (ha): __________

¿Ud. está participando en PROCAMPO-Sequía este año? **0=No 1=SI** N° de hectáreas: _______

¿Ud. está participando en el programa ambiental de dos rastreos (de Sanidad Vejetal)?
0=No 1=SI Si si, No. de hectáreas: __________

Heladas:
¿Se le dañaron algunos cultivos por las heladas este ciclo 2003/04? **0=No 1=SI**
Cultivo dañado: _________ área _______ha. Block y lote: ________________

¿Ud. dejó los cultivos en la tierra? **0=No 1=SI**
Rendimientos esperados: por cultivo dañado: ______________ ______________
______________ ______________

¿Sembró con otro cultivo en las parcelas dañadas? **0=No 1=SI**
Cultivo:________ Área resembrada: _______ ha.
Fuente de agua de riego para el siguiente cultivo: **1=presa 2=pozo 3=Aguas negras 4=lluvias 5=otro, especificar** ______

¿Ud. tuvo asegurados sus cultivos antes de las heladas? **0=No 1=SI**
¿De que fuente? ___________¿Cuánto recibió de bonificación? (pesos/ha) ________

¿Ud. recibió alguna compensación del gobierno (por el siniestro)? **0=No 1=SI**
¿Cuánto recibió por ha? _______$/ha

Siembras de Temporal:
¿Ud. sembró de temporal este año? **0=No 1=SI**
Área sembrada: ___________ ha.
Rendimientos esperados: Kg./ha. _________

Si no ha sembrado temporal, ¿por qué no lo hizo? ____________________________
____

¿Cuáles labores ya había hecho antes de las lluvias? ________________________
____

¿Cuánto le va a costar sembrar de temporal? (pesos/ha): _______________
¿Piensa que será rentable la siembra de temporal? **0=No 1=SI**
Porque si, o no será rentable? ____

Densidad de la siembra en la siembra de temporal (kg./ha): ___________
Cantidad de fertilizantes aplicado en la siembra de temporal (kg./ha): ___________
Numero de jornales promedio por ha en la siembra de temporal: ___________

¿Ud. recibió crédito para la siembra de temporal? **0=No 1=SI**
¿De donde fue el crédito? __________________________
¿Cuánto recibió? (pesos/ha) ________________________

¿Ud. está participando en el programa del gobierno de riesgo compartido? **0=No 1=SI**

¿Piensa que fue buena la decisión sembrar temporal? **0=No 1=SI**
¿Por qué? ____

Pozos Privados:
¿Ud. posee pozo particular? **0=No 1=SI** (Si sí, ¿cuántos pozos?) __________
Localidad de cada pozo

block y lote:___________
¿Cuándo perforó el pozo? _____año
¿Cuánto es el gasto del pozo? (litros/segundo) _________
¿A qué profundidad está el agua? __________________mts.
¿Cuánta salinidad tiene el agua? (ppm) ________________

block y lote:___________
¿Cuándo perforó el pozo? _____año
¿Cuánto es el gasto del pozo? (litros/segundo) ___________
¿A qué profundidad está el agua? __________________mts.
¿Cuánta salinidad tiene el agua? (ppm) ________________

block y lote:___________
¿Cuándo perforó el pozo? _____año
¿Cuánto es el gasto del pozo? (litros/segundo) ___________
¿A qué profundidad está el agua? __________________mts.
¿Cuánta salinidad tiene el agua? (ppm) ________________

¿Alguna vez ha vendido agua de su pozo? **0=No 1=SI** ¿Cuándo? ________año
Cantidad vendido: mm3 ________
número de turnos de 24 horas: ________

Área regada con el agua que vendió: _______ha.
Cultivos sembrado con el agua que vendió: **1maíz 2=garbanzo 3=trigo 4=hortalizas 5=Otro.**___
Método de cobrar (**1=volumen 2= tiempo**):
Precio que recibió para el agua: ___________$\mm3

¿Este año ha vendido agua de su pozo (o tiene planes de hacerlo): **0=No 1=SI**
Cantidad vendido: mm3 ____________
número de turnos de 24 horas: ________
Área regada con el agua que vendió: _______ha.

Localidad de las parcelas regadas con agua de su pozo: **Block y lote: __________**
Block y lote: __________
Cultivos sembrado con el agua que vendió: __________, __________, __________
Método de cobrar ((**1=volumen 2= tiempo**):
Precio que recibió para el agua: ___________$\mm3

Si tiene pozo particular y no ha vendido agua este ciclo, ¿por qué no lo hizo? ______________

Riegos:
¿De donde viene su agua este año? **1=pozo publico, 2=pozo privado, 3=drenaje, 4= lluvia, presas**

Localidad de cada pozo (block y lote): ___________ ___________ ___________

Nombre del dueño de cada pozo (si es pozo privado o de plan colectivo):
Dueño: _________________________ **1=privado 2=colectivo**
Dueño: _________________________ **1=privado 2=colectivo**

Cantidad de agua aplicada (mm^3/ha, para cada cultivo):

Cultivo,	**mm^3/ha**	**Número de Riegos**	**Método de Riego**
______,	______,	______________,	________________
______,	______,	______________,	________________
______,	______,	______________,	________________

¿Cómo pagó su agua este ciclo?
Agua del distrito:
Precio del distrito ($130 pesos/mm^3)? **0=No 1=SI**
¿Cuáles son sus módulos de riego?
¿Otro método de pagar? (cuál)_______

Agua de pozo particular:
¿Por volumen? **0=No 1=SI** precio por mm^3 _________
¿Por turno? **0=No 1=SI** precio por 24 horas _________

¿Por el costo de bombear? **0=No 1=SI**, precio por 24 hrs. _________
¿Otro método de pagar? (cuál) ________________________________

Este año, ¿recibió el agua cuando lo pidió? **0=No 1=SI**
¿Si no a los cuantos días se la dieron? _________________________
¿En cuáles riegos se tardaron? Primero_________, Segundo, ________ Tercero, _________
Este año, ¿es más difícil recibir el agua en el día que lo pide? **0=No 1=SI**
¿Piensa que van a castigar sus cultivos este ciclo? **0=No 1=SI**
¿Se los castigaron el año pasado? **0=No 1=SI**
¿Por qué se los castigaron? ___________

¿Alguna vez ha comprado más agua (aparte de su dotación) del distrito (incluso este año)?
0=No 1=SI

Año y Ciclo	**Cultivo Regado**	**Volumen (mm^3/ha)**	**Área (ha)**	**Precio (pesos/mm^3)**
______,	______,	_________,	_______,	__________
______,	______,	_________,	_______,	__________
______,	______,	_________,	_______,	__________

¿Alguna vez ha vendido agua al distrito (incluso este año)? 0=No 1=Si

Año Ciclo	**Fuente de Agua**	**Volumen (mm^3)**	**Precio (pesos/mm^3)**	**Módulo de Riego**
______,	______,	_________,	_______,	__________
______,	______,	_________,	_______,	__________
______,	______,	_________,	_______,	__________

¿Alguna vez ha comprado agua directamente de otro usuario (o de dueño de pozo particular (incluso este año)? **0=No 1=Si**

Año Ciclo	**Cultivo Regado**	**Volumen (mm^3/ha)**	**Área (ha)**	**Precio y Método de Cobrar**
______,	______,	_________,	_______,	__________
______,	______,	_________,	_______,	__________
______,	______,	_________,	_______,	__________

¿Alguna vez ha vendido agua directamente a otro usuario? **0=No 1=Si**

Año y Ciclo	**Fuente de Agua**	**Volumen (mm^3)**	**Precio (pesos/mm^3)**	**Cultivo regado Área sembrado**
______,	______,	_________,	_______,	__________
______,	______,	_________,	_______,	__________
______,	______,	_________,	_______,	__________

Si Ud. no tuviera ninguna agua este año, ¿Cuánto es lo más que pagaría?
Por mm^3 (para comprar agua) _________________________
Precio (pesos/mm^3): ____________________
Cantidad (mm^3/ha) y **Cultivo:** _________ _________ _________
Cultivo:_________ _________ _________

Si Ud. tuviera agua de pozo privado este año, ¿Cuánto es lo menos que aceptaría?
Por mm^3 (para vender la que sobra) _____________
Método de cobrar: _______________________
Precio (pesos/mm^3): _______________________

¿Ud. ha cambiado su método de riego en los últimos 5 años? **0=No 1=SI**
Método anterior: ______________
Método actual: ______________
Año de cambiar: ______________
¿Por qué cambió? ______________
¿Cuánto costó (pesos/ha) cambiar su método? __________$/ha.

¿Tiene plan de cambiar su método de riego en los próximos 5 años? **0=No 1=SI**
¿Por qué si, o por qué no? ____
¿Cuándo? _______________________año
¿A cuál método? ____________________
¿Cuánto va a costar (pesos/ha)? ________

Salinidad:
¿Ud. sabe la salinidad del agua que usa para regar su cultivo? **0=No 1=SI**

Si la salinidad no es conocida,

Año	**Salinidad (ppm)**	**Estime**
2001-2002	____________	1=buena, 2=regular, 3=mala
2002-2003	____________	1=buena, 2=regular, 3=mala
2003-2004	____________	1=buena, 2=regular, 3=mala

¿Cuál es la máxima salinidad en el agua que piensa Ud. que su cultivo podría soportar?

Cultivo	Salinidad (ppm)
__________	__________
__________	__________
__________	__________

¿La salinidad de su agua de riego ha afectado sus rendimientos en el pasado? **0=No 1=SI**

Año	Cultivo	Efecto (ton/ha)
______,	______,	______
______,	______,	______
______,	______,	______

Este año, ¿la salinidad de su agua de riego va a afectar sus rendimientos? **0=No 1=SI**

¿Le preocupa la salinidad del agua que usa en su parcela? **0=No 1=SI**

¿Tiene o ha tenido problemas con salinidad de los suelos en sus parcelas? **0=No 1=SI**

Año	Parcela (block/lote)	Problema
______,	______,	______
______,	______,	______
______,	______,	______

¿Le preocupa que Ud. tuviera problemas con salinidad de sus suelos en el futuro? **0=No 1=SI**

¿Tiene problemas con drenaje en algunas parcelas suyas? **0=No 1=SI**

Parcela (block/lote)	Problema
______,	______
______,	______
______,	______

Crédito y Aseguramiento: **0=No 1=SI**

Fuente de crédito (2002-2003): ______ **1=Unión de crédito, 2=Banca privada, 3=Recursos propios 4=Fondo de aseguramiento 5=Banrural 6=Otro.________**

Fuente de crédito (2003-2004): ______ **1=Unión de crédito, 2=Banca privada, 3=Recursos propios 4=Fondo de aseguramiento 5=Banrural 6=Otro.________**

Si usa unión de crédito, ¿por qué lo hace? ______________________

Si usa banco, ¿Por qué lo hace? ______________________

¿Ha cambiado su fuente de crédito en los últimos 5 años? **0=No 1=SI**

Origen anterior: **1=Unión de credito, 2=Banca privada, 3=Recursos propios 4=Fondo de aseguramiento 5=Banrural 6=Otro.________**

¿Por qué cambio? ______________________

¿Ha comprado seguro agrícola para sus cultivos en los últimos 5 años? **0=No 1=SI**

Años	Fuente	Cultivo Área	Tipo de cobertura
______,	______,	______,	______
______,	______,	______,	______
______,	______,	______,	______
______,	______,	______,	______

Grupos de Productores (SPR):

¿Porqué es (o no es) parte de un grupo de productores? ______________________

Este año, ¿el SPR recomendó que Ud. siembre un cultivo determinado o Ud. mismo eligió su cultivo? ______________________

¿Ud. recibe crédito individualmente o atrás de su SPR? **1=Individual 2= a través de la SPR**
Para recibir crédito, ¿es necesario ser parte de un grupo de productores? **0=No 1=SI**

¿Cómo hacen las decisiones en el grupo de productores? ______________________

¿Existen actividades de votar en su SPR? (si sí, descríbalas) ______________________

¿Cuáles decisiones de cultivos y producción se hacen por el SPR? ______________________

Entradas:

¿Cómo elige cuanto fertilizante aplica? **(1=tipo de cultivo, 2=tipo de suelo, 3=recursos económicos, 4=yo no elijo, 5=otro, especificar__________)**

¿Cuanto fertilizante aplica? ________**kg/ha** ________**Cultivo**
________**Kg./ha** ________**Cultivo**

¿Cuál es lo más importante en su decisión? **(1=fuente de crédito, 2=SPR, 3=preferencias individuas, 4=otro, especificar. __________**

¿Cómo elige cuanto agua aplicar? **(1=disponilidad de agua, 2=calidad de agua, 3=cultivo establecido, 4=tipo de suelo, 5=otro, especificar ________**

¿Cómo elige cuando la aplica? **(1=disponilidad de agua, 2=calidad de agua, 3=cultivo establecido, 4=tipo de suelo, 5=otro, especificar ________**

¿Cuál es lo más importante en su decisión? **(1=fuente de crédito, 2=SPR, 3=distrito de riego (SRL), 4=módulo de riego, 5=preferencias individuas 6=otro, especificar. __________**

¿Cómo elige cuales cultivos sembrar? ______________________

¿Cuál es lo más importante en su decisión? **(1=fuente de crédito, 2=SPR, 3=distrito de riego (SRL), 4=preferencias individuas, 5=otro, especificar.________**

¿Cómo son diferentes sus métodos de producción a los recomendado por el comité de crédito (de SAGAR)? (Mire los costos de producción oficiales antes de contestar).

	1=mismo, 2=diferente	¿Cómo es diferente?	¿Porqué es diferente?
Agua			
Preparación de la tierra			
Siembra			
Fertilizante			
Herbicidas			
Pesticidas			
Asistencia Técnica			
Jornales			
Ótro (cuál?)			

¿Ud. tiene libertad de desviarse de las recomendaciones de producción? **0=No 1=SI**
¿Porqué (o por qué no)?______________________

¿Existen consecuencias si Ud. se desvía de las recomendaciones oficiales? **0=No 1=SI**
¿Cuáles? ______________________

Otras Actividades:

¿Tiene animales o granjas pecuarias o acuícolas? **0=No 1=SI**

Si es pecuaria, ¿cuántos animales? **¿qué tipo? (1=vacuno, 2=lechero, 3=aves, 4=cerdos, 5=otro)** _____,
Si es acuícola, ¿qué superficie de estanques? ______m^2 **¿qué tipo? (1=camarón, 2=ostión, 3=peces, 4=otros**

¿Cómo se han afectado las granjas por la sequía? ______________________,

¿Tiene algún otro tipo de empresa rural? ________ **0=No 1=SI**
¿Cuál empresa? ______________________,
¿Hace cuánto tiempo ha tenido esa empresa? _________ (años)
¿Se ha afectado la empresa por la sequía? **0=No 1=SI**
¿Cómo? ______________________,

¿Tiene otro trabajo? **0=No 1=SI**
¿Cuál? ______________________,

¿Se ha afectado el trabajo por la sequía? **0=No 1=SI**
¿Cómo? ______________________,

¿Cuántas personas (incluyendo Ud.) viven en su casa? __________,
¿Cuántas personas trabajan (con salario) en su casa? __________,

Tipo de trabajo de cada persona:

Trabajo	Edad
______,	______,
______,	______,
______,	______,

¿Ud. sembró de temporal este año? **0=No 1=SI**
Área sembrada: __________ ha.
Rendimientos esperados: Kg./ha. _________

______,	______,
______,	______,
______,	______,
______,	______,
______,	______,

¿Serán más bajo los ingresos de su casa este año (octubre 2003 – septiembre 2004) comparando a los ingresos del año pasado (octubre 2002 – septiembre 2003)? **0=No 1=SI**
¿Cuánto se ha bajado (el porcentaje)? ________ %
¿Cuáles partes de los ingresos se bajaron lo más? ________, ________, ________, ________,

Normalmente, ¿qué porcentaje de sus ingresos vienen de agricultura? ________ %
Este año, ¿qué porcentaje de sus ingresos vienen de agricultura? ________ %

Este ciclo, ¿que está haciendo en su casa para compensar los ingresos perdidos de agricultura?
1.-__________, 2.-__________, 3.-__________,

En el futuro, ¿qué va a hacer para compensar los ingresos perdidos de agricultura?
1.- __________, 2.- __________, 3.- __________,

TLC

¿Conoce Ud. el trato de libre comercio? **0=No 1=SI** **En que año entro el TLC.** ________
¿Cómo le ha afectado el TLC? ______________________
¿Qué cultivos se han visto mas afectados o lo han beneficiado?
________, ________,
________, ________,
________, ________,

¿Uds. han desarrollado formas de enfrentar los bajos precios del mercado ? **0=No 1=SI**
¿Cómo? **(1=pignoración, 2=__________, 3=__________)**

¿Su cultivo principal, a quien lo vende?______________________
¿Tiene Ud. contrato de cobertura **0=No 1=SI**

¿Cuál es el precio que espera recibir? __________ pesos/ton Cultivo a comercializar.________