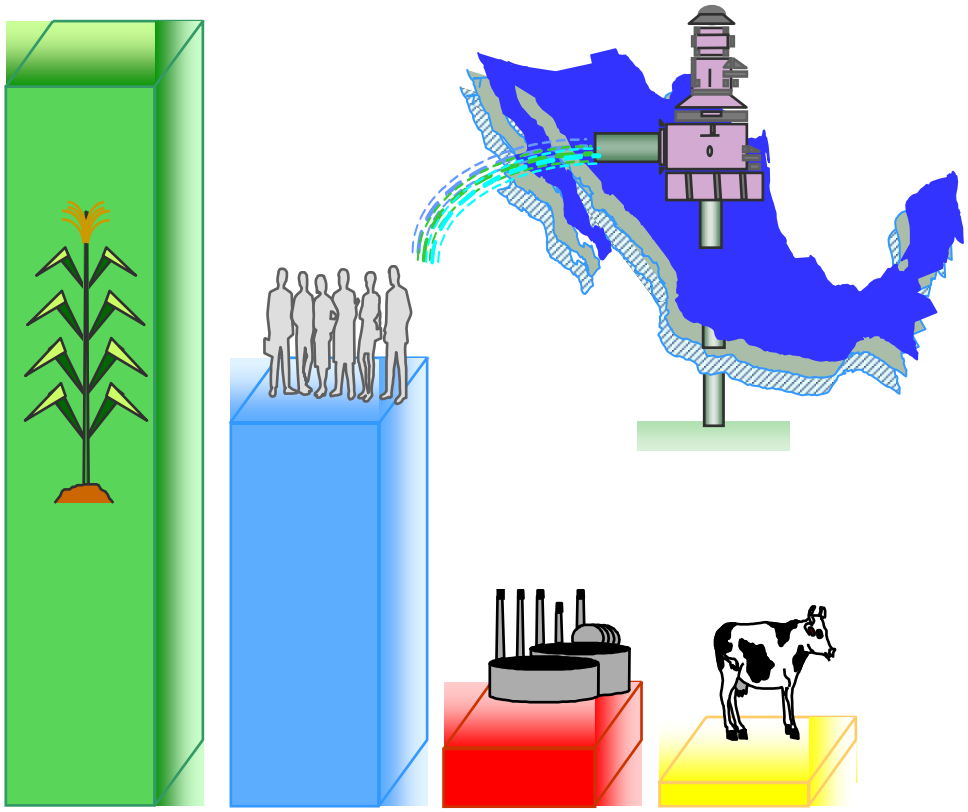
Mexico
Policy Options for Aquifer Stabilization

(In Two Volumes) Volume I: Policy Report

June 11, 1999

Environmentally and Socially Sustainable Development Department
Mexico Country Department
Latin America and the Caribbean Region

FINAL DRAFT



This study was conducted by the World Bank in collaboration with the Comisión Nacional del Agua (CNA) of the Federal Government of Mexico and received grant financing from the Government of Japan. It was prepared by a team composed of Karin E. Kemper, John Briscoe, Douglas Olson (World Bank), Ruben Chavez Guillen, Oscar Escolero (CNA), Jose Arreguín, John Bredehoeft, Octavio del Conde, Antonina Galván, Miguel Angel Gomez, Regina Martinez, Enrique Palacios, and Robert Young (Consultants). Additional comments were provided by José Simas, Fernando Gonzalez and Nguyen Trac. Questions and concerns may be addressed to Karin E. Kemper, e-mail kkemper@worldbank.org.

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Executive Summary

I. Background

The impetus for this study is the alarming deterioration of the condition of a large number of Mexico's most important aquifers, and the associated deterioration of the vital services these aquifers provide to people, industry, agriculture and environmental quality.

Mexico has a population of approximately 98 million inhabitants, of whom about 80 million (50 million urban and up to 30 million rural) are supplied with groundwater for domestic purposes. Of Mexico's 6 million irrigated hectares, 2 million depend on groundwater. In addition, industrial growth poles are mainly located in the central and northern areas, which have scarce water resources.

On top of these demands for groundwater, 100 of the country's 647 aquifers are over-exploited, with annual withdrawals significantly exceeding natural recharge. Many of these aquifers provide services to highly productive agricultural, urban and industrial areas, and withdrawals from them account for about one-half of the country's total groundwater abstractions. Groundwater levels are continuously falling, rendering pumping increasingly expensive and making groundwater use progressively less economically viable. Other detrimental effects include land subsidence with concomitant damage of infrastructure, and pollution due to intrusion of untreated wastewater or salt water in coastal aquifers. Thus, the current situation of continuously increasing over-exploitation of groundwater resources is of major concern not only to a few isolated areas, but to a major part of the country's population and its economic and environmentally sustainable development.

II. Objective of the Study and Analytical Approach

In an effort to address the situation, the present study was carried out by the Comisión Nacional del Agua (CNA) of the Federal Government of Mexico and the World Bank, with grant financing from the Government of Japan. The CNA and World Bank teams worked closely together to define the approach and details of the work to be done under the project. This included focusing on a sub-set of 20 of the 100 over-exploited aquifers for the hydrogeological study, and a sub-set of 5 for additional in-depth analysis related to economic, legal, and institutional issues. The aquifers selected for the in-depth studies are the coastal ones of Santo Domingo and Hermosillo, and the continental aquifers of Aguascalientes, Querétaro and Celaya, which were chosen so as to represent a broad range of hydrogeologic types and demand patterns. Volume II presents the study results in detail.

The ultimate objective of the study is to provide an analytical description of the extent of groundwater over-exploitation in Mexico, the reasons for this critical situation, and an analysis of the policy options that would help decision makers address the problems.

The background documents that were prepared as part of this effort thus take an interdisciplinary approach and analyze the problem from hydrogeological, economic, agronomic, engineering, legal and institutional perspectives so as to provide a comprehensive analysis of the situation. In addition, a national seminar on groundwater management (convened as part of this project) was held in Guanajuato in early June 1999 to present the preliminary results of the study and to get input from a broad group of stakeholders (including CNA, groundwater user groups (COTAS), the Comisión Federal de Electricidad (CFE), the Ministry of Finance, the Ministry of Agriculture, water utilities, NGOs, etc.). The recommendations of the seminar have been taken into account as part of the study.

The present document (Volume I) synthesizes the overall inputs to answer the following questions: Why are conditions as they are?; does it really matter?; and how might the situation be different?

Initial investigations, later confirmed during the study, showed that the main cause of groundwater over-exploitation in Mexico is related to institutional rather than technical issues. For this reason, an institutional economics approach was chosen for the present analysis. The central challenge for this approach was to examine why various actors—governments, farmers, their creditors and suppliers and marketers, industry, municipal water companies, as well as collective actors such as aquifer and irrigation management associations—behave the way they do, and how they might behave differently. This was done by consistently observing the incentives facing the actors, the information available to them, and the institutional framework (legal, regulatory, as well as informal and cultural) under which they operate. The same "three **i**'s"—**i**ncentives, **i**nstitutions and **i**nformation—are used to explore options for changing behavior, and ensure that the invaluable groundwater resources of Mexico are exploited in a sustainable and productive manner.

III. Major Findings

The results of the study show the way in which prevailing **i**ncentives have played an important role in aquifer over-exploitation. In past decades, agriculture received significant subsidies of both outputs and inputs, which in the early 1990s amounted to 30% of total agricultural production and provided incentives to grow low-value basic food crops. With the abolishment of most of these subsidies, farmers are now shifting towards high-value crops and producing more output per cubic meter of water. Another important issue relates to the insecurity of water rights prior to 1992. Since then, water and land rights have been separated with the passing of the National Water Law and its regulations, and substantial efforts have been made to register all water users and stimulate water trading, thus providing an incentive for users to use water more efficiently while facilitating reallocation of water rights from low-value to high-value activities.

While some positive key changes have occurred to encourage better (ground-) water use in the country, a number of problems still exist. These include exemption for farmers' from paying *derechos de agua* (a volume-based raw water tax), and a specific agricultural energy tariff (tarifa 09) which renders water pumping cheap for farmers and leads to further over-exploitation of aquifers.

Regarding urban water use, there is a lack of incentives to provide efficient water supply services. Due to the absence of a financing policy for investments in the sub-sector and lack of transparency, the federal and state governments provide indiscriminate subsidies to finance investments and cover operational deficits of water and sanitation utilities. Although subsidies have recently been decreasing, they are still considerable. Industries, in the end, are the ones compensating for others' lack of *derechos* tax payments, and most of the US$300 million collected each year for *derechos* comes from the industrial sector. This sector thus has an interest in conserving water. On the other hand, water quality issues are not well controlled and industry, as well as urban water utilities (that generally do not provide any treatment), contribute substantially to the pollution of groundwater.

Groundwater management is a classic "common pool resource" problem: a) the (physical and institutional) costs of exclusion are high; and b) the use of the resource by one user has an adverse "subtractability" effect on the use by others. The result—everywhere—is that people follow their own short-term interests to produce outcomes that are not in the wider population's long-term interest. Mexico's problem is thus similar to, and can be informed by, similar problems faced elsewhere. It is in reference to these two challenges that the effectiveness of institutional arrangements needs to be judged.

On the **i**nstitutional side, a number of changes have recently taken place. CNA has been involved in the creation of Technical Committees for Groundwater (Comités Técnicos de Agua Subterranea – COTAS), which bring together the users and authorities in different aquifers for joint management. The creation of the COTAS is a clear step in the right direction to decentralize water management, bringing it to an appropriate level while forging a new partnership between users and government.

There are, however, two competing visions of what aquifer management and the COTAS mean. One is that the COTAS are committees of users to be consulted with (*consulta y concertación*) by those who actually make the decisions (namely the CNA). From discussions with users groups in a number of aquifers it is clear that such COTAS will simply not work. The users are deeply skeptical of the CNA and have no interest in participating if it is only in a *consulta y concertación* role.

The other vision of aquifer management sees a partnership between government and the users in a COTAS with real powers - a legal personality. To a substantial degree, Hermosillo has achieved this "by accident," as the statutes of the Irrigation District which give it a legal personality have been used to manage the aquifer. In Hermosillo, the Regional Office of the CNA has demonstrated how to legitimize the users' role in managing the aquifer, how to provide technical support for both hydrogeological issues, and in monitoring and accounting for the water. It is also this second vision of COTAS,

with real power and real resources, that is supported by virtually all users, and the State of Guanajuato. Guanajuato is the only state in the country that has taken a lead in promoting COTAS, in parallel with CNA's efforts at the federal level.

COTAS in which users have real powers provide incentives for actors to take responsibility for the management of their own aquifer while bringing different actors from the various sub-sectors together, thus permitting a more integrated approach. However, even the COTAS in Guanajuato have no specifically defined roles or legal capacity concerning aquifer management, and additionally lack of a financial structure and strategy.

In addition to the COTAS, institutional change is also needed in the urban water and sanitation subsector. There is lack of clarity in the institutional roles and responsibilities between the federal, state and municipal governments, public and private water users, and final water consumers. For example, in the state of Querétaro, the state runs the water supply company, but is simultaneously supposed to be the regulator. On the COTAS board, therefore, the state has a disproportionate weight, which does not lend itself to equal negotiations with the other stakeholders. In general, the unclear situation regarding urban utilities is expressed in the fact that they generally do not pay their *derechos de agua*, although they would only have to pay a fraction of what industries are charged. Thus, the groundwater sector cannot be regarded in an isolated manner, but needs to be seen in light of the institutional arrangements in the other sub-sectors such as water supply and sanitation, and irrigation.

Finally, with regard to **i**nformation, the picture has been improving over the past years. For many of the over-exploited aquifers in Mexico, sufficient data exists to make confident statements about their conditions and necessary management measures. In addition, many actors have information about how to better conserve their water resources, be it through technical improvements in the irrigation sector, demand management measures in the urban sector, or recycling and waste treatment in the industrial sector. The challenge lies in linking this knowledge back to the incentive structures so that stakeholders will act on the information they have and put it to its best use.

Overall, the changes described here are moving in the right direction. The National Water Law of 1992 provides an excellent legal basis for these changes, with its emphasis on user participation and tradable water rights. The Law incorporates the most up-to-date principles of water resources management which are also advocated by the World Bank in its Water Resources Policy Paper of 1993, and expressed in the Dublin Principles of 1992. Changes such as the introduction of water rights, decentralization of decision making, and recognition of water as an economic good are key issues that have already been established in Mexico. The important challenge now is to recognize the irreversibility of these changes, to move ahead in consolidating achievements, and to advance into the second round of water reform.

IV. Recommendations

The results of the present study lead to a number of recommendations to achieve the move towards stabilization and the sustainable and productive management of Mexico's aquifers.

First of all, the development and articulation of a Government strategy at federal and state levels with regard to aquifer management is needed to provide clear guidelines for the stakeholders at different levels, ensuring their full participation and transparency in decision making while providing them with political legitimacy and funds for concrete actions. In particular, such a strategy should include:

- Communication and interaction with water users to create a "water culture" and public conscience regarding groundwater problems and management;
- Enforcement and revision of the legal and institutional framework regarding COTAS and the role of the states and municipalities, with a view to strengthening the COTAS by providing them with legal personality, decision making and sanctioning power over the aquifers' management, a financing mechanism to render them self-sufficient and—in the long term—independent from government handouts;
- True stakeholder participation in actions related to the constitution, regulations, and organization of any aquifer program (including federal investment programs intended to improve water use efficiency);
- Promotion and channeling of current and future water efficiency programs towards the over-exploited aquifers;
- Strengthening and development of groundwater information systems (including the water rights registry—REPDA);
- Improvement of public access to groundwater related information systems;
- Intensified implementation of groundwater monitoring networks, as well as increasing the number of aquifer and geohydrological systems studies;
- Review of the rural energy subsidy (tarifa 09) to turn it from a distortionary subsidy into a direct, targeted subsidy benefiting the poor (this could be constructed similar to, or integrated into, the PROCAMPO subsidy);
- Restructuring of the water supply and sanitation sector with a view to making utilities act as responsible stakeholders in aquifer management, including by enforcing their water concessions and payments of *derechos de agua* to be on an equal footing with industries; and
- Review of farmers'exemption from payments of *derechos de agua*.

V. Further Bank Involvement

The Bank has played an active role in Mexico's water sector for several decades, in irrigation, water supply and sanitation, and water resources management. Since 1994, the Bank has been financing the Mexico Water Resources Management Project (PROMMA) which has as its main objective the nationwide improvement of water resources management, including groundwater.

As an outcome of this study, the Bank is preparing an Aquifer Management Pilot Project to be folded into the PROMMA. It would be implemented in five aquifers over a four-year period and focus on strengthening stakeholder participation through support to the COTAS, awareness campaigns for water users, training of CNA personnel, implementing adequate groundwater monitoring systems (including technical), modeling and alternative studies for the pilot aquifers, introducing demand management at the aquifer level, and elaborating investment plans.

Due to the multi-sectoral aspects of groundwater management, this pilot project should be linked to other on-going projects in Mexico, such as PRODEP, the Irrigation and Drainage Sector Project (Timeslice), which target improvement in irrigation efficiency, the Agricultural Productivity Project, and sanitation sector investment initiatives that would improve the efficiency of water utilities. [The findings of this study coincide with those of a water and sanitation sector study currently being carried out by LCSFP.] For further synergy effects, the pilot could also be coordinated with other GOM initiatives or external agencies that are active in the different water sub-sectors in Mexico.

An important issue to be addressed by the Bank and by the GOM is the poverty implication of groundwater over-exploitation. The modernization changes are almost all positive for both economic growth and the environment. But they also put a premium on knowledge and mean that the historic Mexican approach of land-based solutions to rural poverty alleviation are not working. There are some positive aspects—for instance employment generation per cubic meter of water is substantially better for high-value crops than traditional ones. There is, however, an economic polarization in rural areas which is particularly pronounced in the over-exploited aquifers. A systematic focus on these issues is therefore essential—including by the World Bank—both to address the poverty issues and to ensure that this does not reverse the progress being made in efficient and environmentally-friendly resource use.

Overall, the Bank should actively support the larger policy issues on the Mexican agenda, such as reform of the electricity and water and sanitation sectors, decentralization (not only of water resources management), and economic liberalization, which all directly or indirectly affect groundwater management.

1. Introduction

1.1 Background

1 The impetus for this study is the alarming deterioration of the condition of a large number of Mexico's most important aquifers, and the associated deterioration of the vital services these aquifers provide to people, industry, agriculture and environmental quality.

2 Mexico has a population of approximately 98 million inhabitants, of whom about 80 million (50 million urban and up to 30 million rural) are supplied with groundwater for domestic purposes. Of Mexico's 6 million irrigated hectares, 2 million depend on groundwater. In addition, industrial growth poles are mainly located in the central and northern areas, which have scarce water resources.

3 On top of these demands for groundwater, 100 out of the country's 647 aquifers are over-exploited, with annual withdrawals significantly exceeding natural recharge. Many of these aquifers provide services to highly productive agricultural, urban and industrial areas, and withdrawals from them account for about one-half of the country's total groundwater extractions. Groundwater levels are continuously falling, rendering pumping increasingly expensive and making groundwater use progressively less economically viable. Other detrimental effects include land subsidence with concomitant damage of infrastructure, and pollution due to intrusions of untreated wastewater or salt water in coastal aquifers. Thus, the current situation of continuously increasing over-exploitation of groundwater resources is of major concern not only to a few isolated areas, but to a major part of the country's population and its economic and environmentally sustainable development.

1.2 Objective of the study and analytical approach

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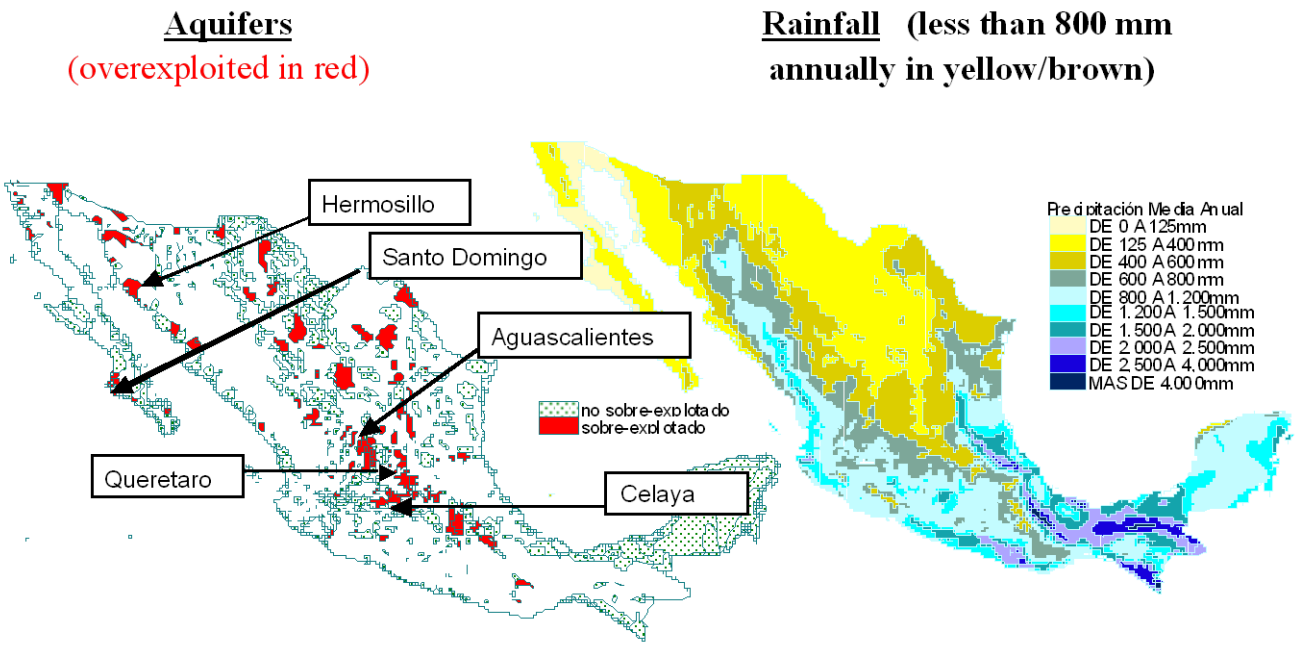

Map 1: **The Five Study Aquifers**

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associations—behave the way they do, and how they might behave differently. This was done by consistently observing the incentives facing the actors, the information available to them, and the institutional framework (legal, regulatory, as well as informal and cultural) under which they operate. The same "three I's"— Incentives, Institutions and Information—are used to explore options for changing behavior, and ensure that the invaluable groundwater resources of Mexico are exploited in a sustainable and productive manner.

2. What is the problem and why does it matter?

9 A broad picture of the state of Mexico's approximately 600 aquifers shows that "in aggregate" extractions amount to only about one third of total recharge (Figure 1). A closer look, however, reveals a much more disturbing picture. About 100 of these aquifers are over-exploited - i.e. withdrawals by water users exceed the annual natural recharge and thus lead to a continuing lowering of the water tables - with the number rising by approximately 30 every decade (Figure 2). For these over-exploited aquifers the picture is quite different—on average extractions exceed recharge by about 30 percent (Figure 2a). These over-exploited aquifers are located in the drier areas of the country (Figure 3), and provide water to many of the most important and productive agricultural areas, as well as areas of high industrial and urban productivity.

Figure 1: **Overall status of Mexico's 647 aquifers: Annual withdrawals and recharge (billion cubic meters)over time**

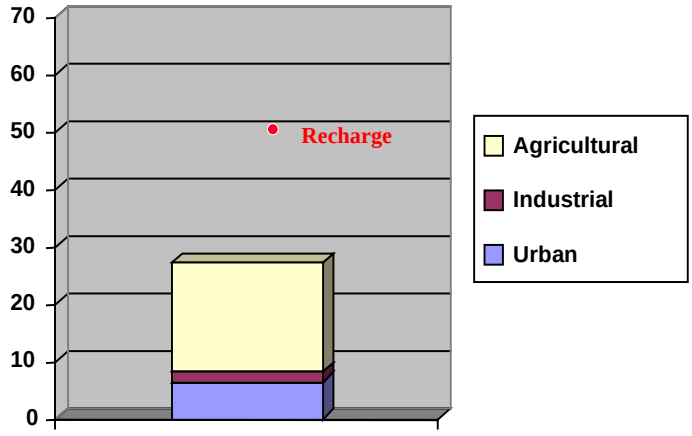


Figure 2: **Number of over-exploited aquifers**

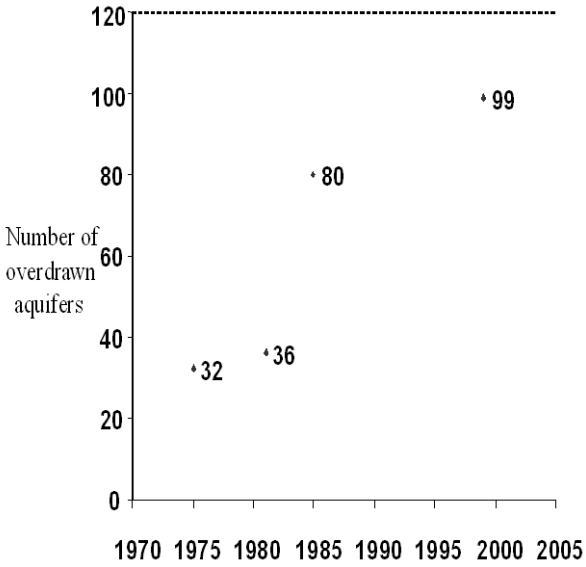
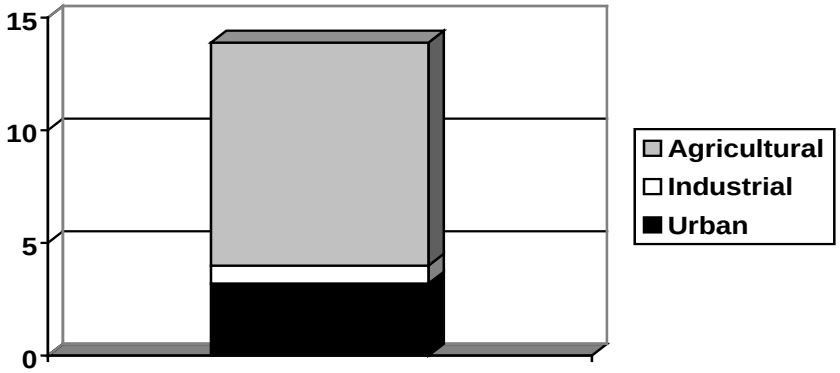


Figure 2a: **Status of Mexico's 99 over-exploited Aquifers: Annual withdrawals and recharge**



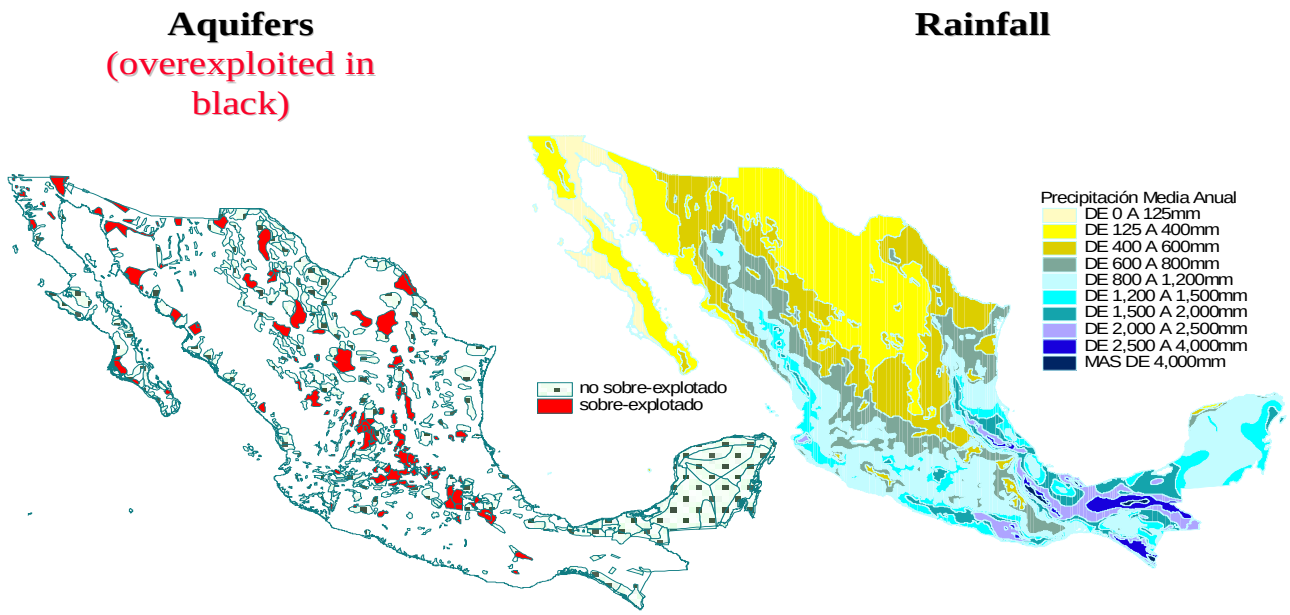


Figure 3: **Location of Mexico's over-exploited aquifers compared with precipitation patterns**

10 Overexploitation is caused by both "natural" drivers (most importantly the skewed geographical distribution of rainfall), and "institutional" drivers. With respect to the latter, the analysis shows that irrigated agriculture accounts for about two-thirds of the water abstracted from the over-exploited aquifers. While agriculture accounts for only 9 percent of GDP, irrigation remains enormously important for Mexico. Irrigated lands account for about 15 percent of all employment, over half of all agricultural production, and two thirds of agricultural exports. Areas irrigated with groundwater are amongst the most productive, and account for just under half of the total irrigated area (Figure 4). But the fastest growing demand comes from urban and industrial uses, which already constitute about a quarter of all demand from groundwater (Figure 5).

Figure 4: **The stress from irrigation—surface and groundwater**

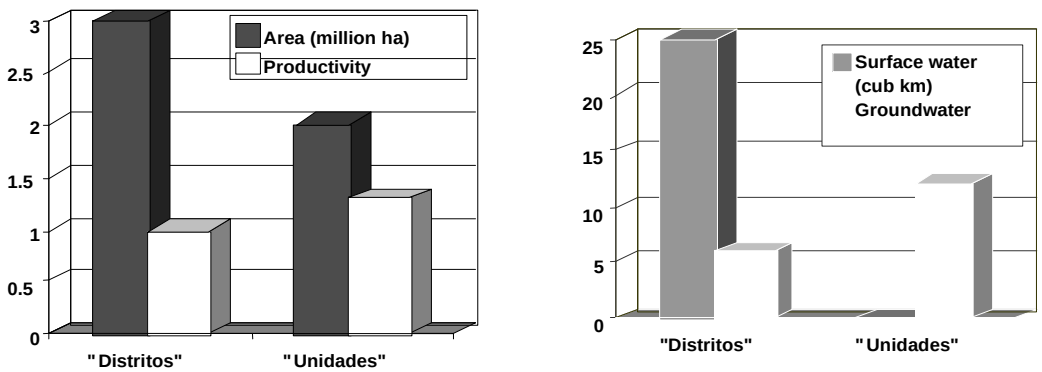
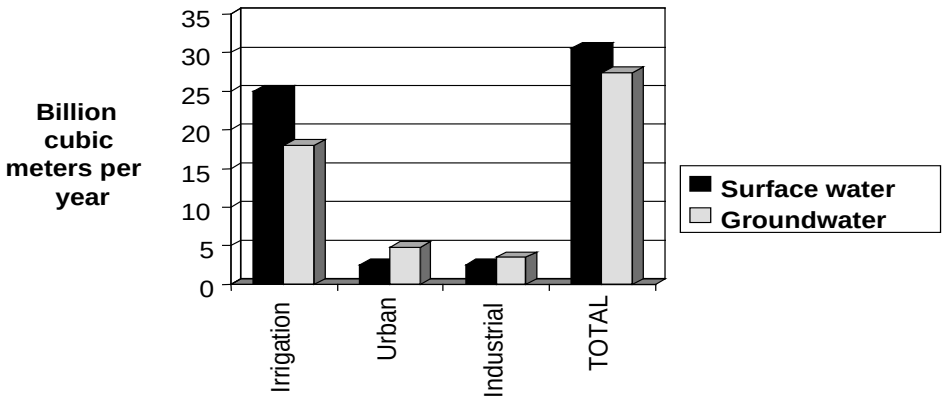
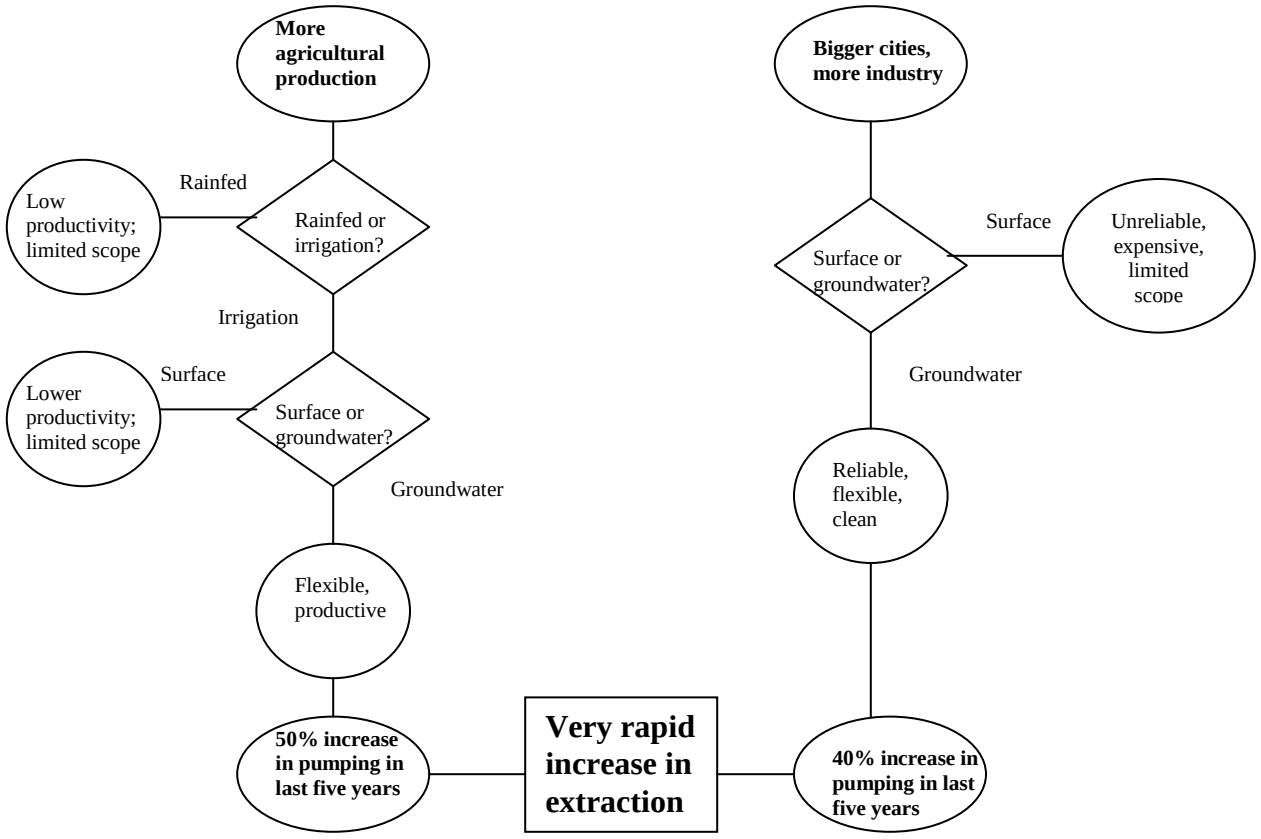


Figure 5: **Agriculture dominates, but other uses are more dependant on groundwater**



11 Both the growing urban and industrial demands, and the growing demand for reliable irrigation water have led to a spiraling demand for groundwater (Figure 6), with aggregate demand increasing by almost 50 percent over the last five years.

Figure 6: **The forces acting on Mexico's aquifers**



12 From the above it becomes clear that current trends are not sustainable and will be detrimental to Mexico's development in the medium to long term if not properly addressed. The following sections will explore the reasons for the current situation and analyze the incentives stakeholders face to over-exploit. The study results show that the underlying reasons are of an institutional rather than a technical nature, meaning technological solutions in and of themselves will not resolve the situation. The results of the study point to a general adverse incentive framework that affects aquifers countrywide and can be explained by underlying water resources management, energy, and agricultural policies over the past decades.

3. Why are conditions as they are?

13 Groundwater management is a classic "common pool resource" problem: the (physical and institutional) costs of exclusion are high, and the use of the resource by one user has an adverse "subtractability" effect on the use by others. The result—everywhere—is that people follow their own short-term interests to produce outcomes that are not in the greater population's long-term interest. Mexico's problem is thus similar to (and can be informed by) similar problems faced elsewhere. The two principal challenges are restricting access and giving users incentives for conservation. It is with reference to these two challenges that the effectiveness of institutional arrangements needs to be judged.

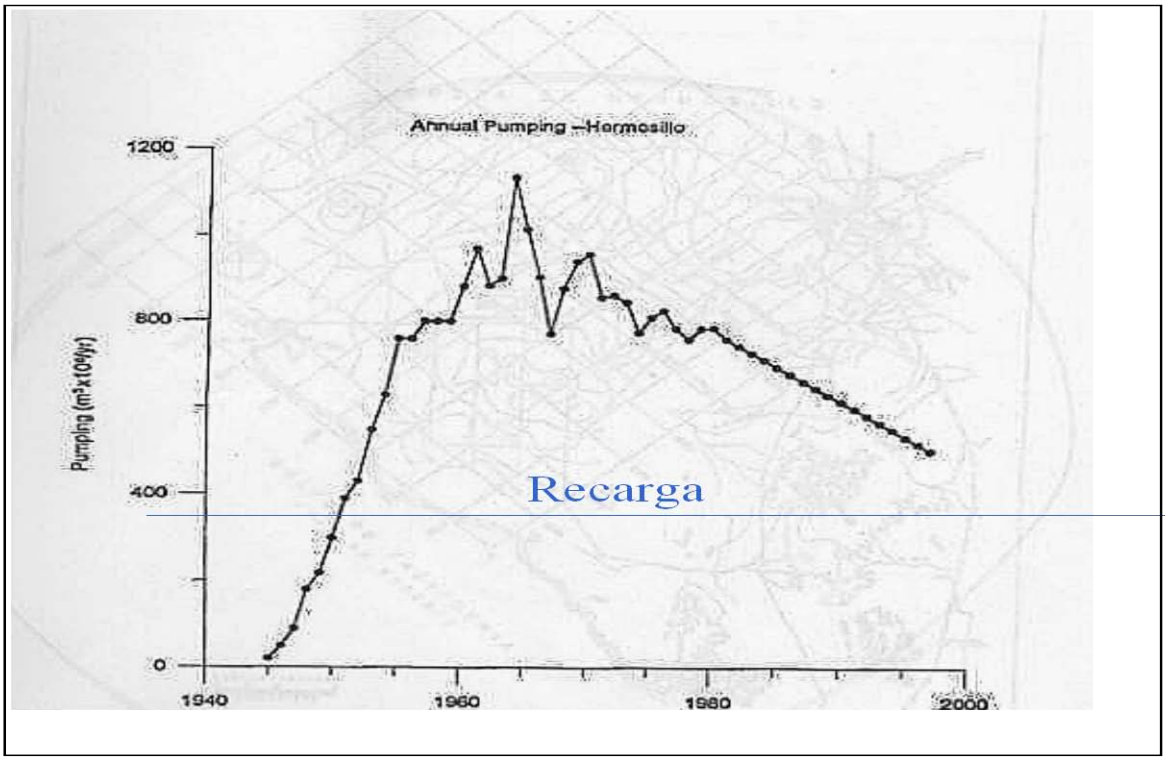
14 In the following, two of the cases examined for this study will be described in detail, namely the coastal aquifer in Hermosillo, which is dominated by agriculture, and the continental aquifer in Aguascalientes, dominated by increasing urban use. The two aquifers stand for many others in the country. While their hydrology or the magnitude of the problems may vary (cf. for instance the Valle de México), national policies towards aquifer management are the same all over the country, leading to the same diagnosis.[1]

3.1 Where irrigation is dominant -- the case of Hermosillo

15 The dynamic of unsustainable groundwater management is examined first by focusing on a case where irrigation is dominant, namely the coastal aquifer of Hermosillo in the arid state of Sonora. Groundwater extraction in this aquifer started in earnest after World War II (Figure 7). Within a period of just 20 years, extraction was exceeding sustainable yield by a factor of three.

[1] This study does not specifically address issues related to transboundary groundwaters, e.g. at the border between Mexico and the United States. While a number of these aquifers are subject to over-exploitation and pollution, the institutional and policy mechanisms used to deal with the problems differ from those applied to national aquifers (see Volume II, Chapter 1 - Annex 1).

Figure 7: **Pumping trends in the Hermosillo aquifer**



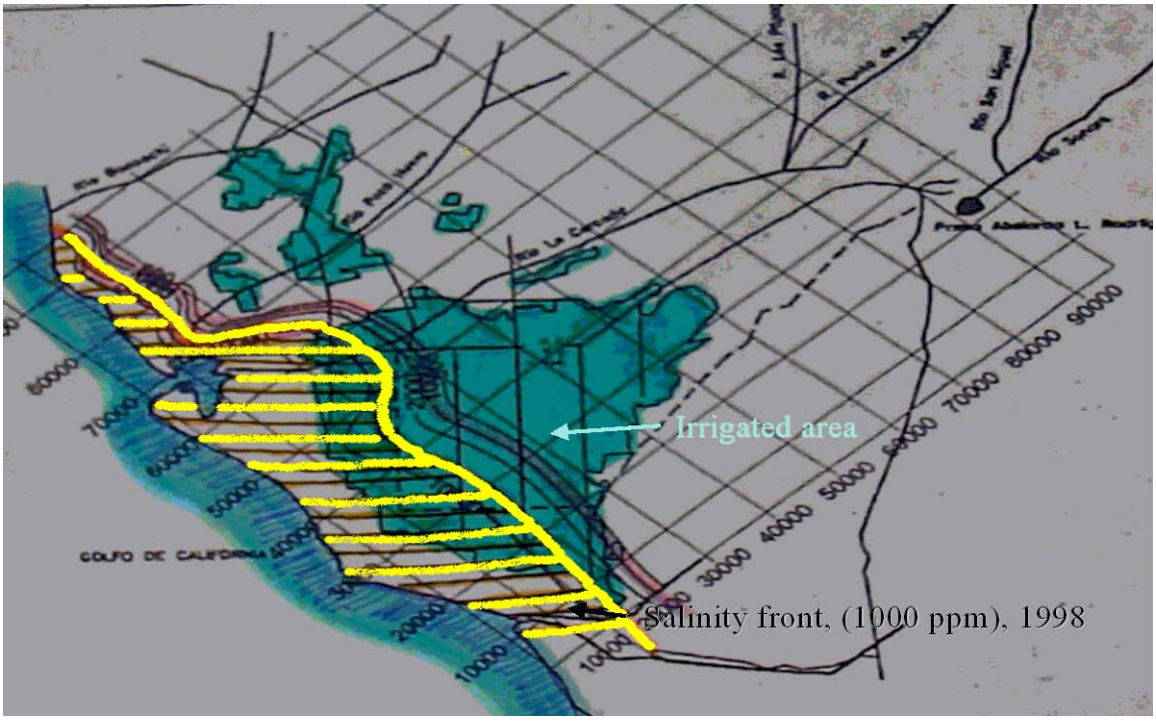
16 The driving forces behind this phenomenon are examined in terms of "the three I's:" Incentives, Institutions, and Information. With respect to Incentives, the overall macro environment was a fundamental factor leading to overexploitation of the aquifer. In the Mexican economy during the post-World War II period, crop prices were artificially high (due to a combination of output subsidies and import tariffs), and costs were artificially low (due to subsidies on virtually all inputs). In the early 1990s these subsidies accounted for 30 percent of the total value added in agriculture. The implicit incentive to overproduce (and overuse water and other inputs) was accentuated by poorly defined water rights, which gave users no motive to consider the long-term value of the resource.

17 With respect to Institutions, the government's main concern was production and the stimulation thereof. Little effort was made to address the underlying institutional problems inherent in a common pool resource.

18 With respect to Information, with some important exceptions, sustainability issues were not dominant, and environmental costs were given little attention.

19 The results were predictable. The groundwater table in the coastal aquifer of Hermosillo sank rapidly to its current level of about 90 meters, which is about 50 meters below sea level. This has resulted in a massive intrusion of seawater from the Gulf of California, with about a 20 percent loss of the irrigated area due to salinity (Figure 8).

Figure 8: **Saline intrusion in the Hermosillo aquifer**



20 In recent years, a new water economy has come into play in Hermosillo. At the macro level, Mexican agricultural policy has changed dramatically. Output and input subsidies (which accounted for about 30 percent of value in the early 1990s) have largely been replaced by non-distortionary direct payments to farmers (Figures 9 and 10).

Figure 9: **Incentives—The economic environment has changed dramatically**

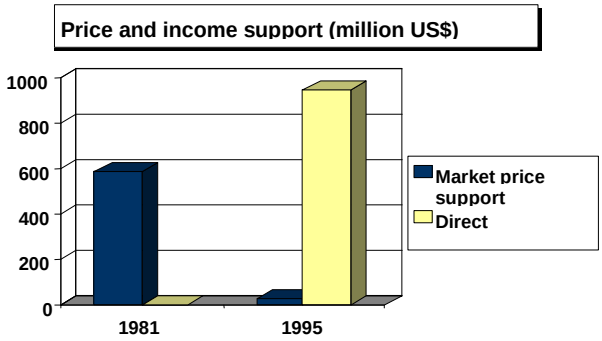
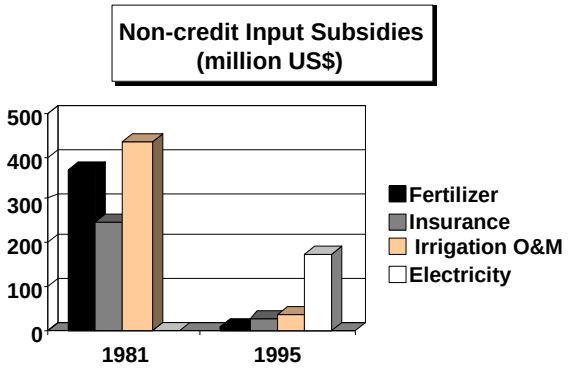


Figure 10: **Distortionary subsidies on inputs—electricity subsidy as an anomaly**



21 The one major exception, which continues to this day, is the subsidy of electricity to farmers, who pay only one third the cost. Even with this huge distorting subsidy, which amounts to an annual US$ 300 million countrywide, most traditional field crops are no longer economically viable in Hermosillo (Figure 11), whereas high-value vegetable and perennial crops are less susceptible to such changes (Figures 12 and 13).

Figure 11: **Price which is necessary for traditional crops to be viable, with and without electricity subsidy**

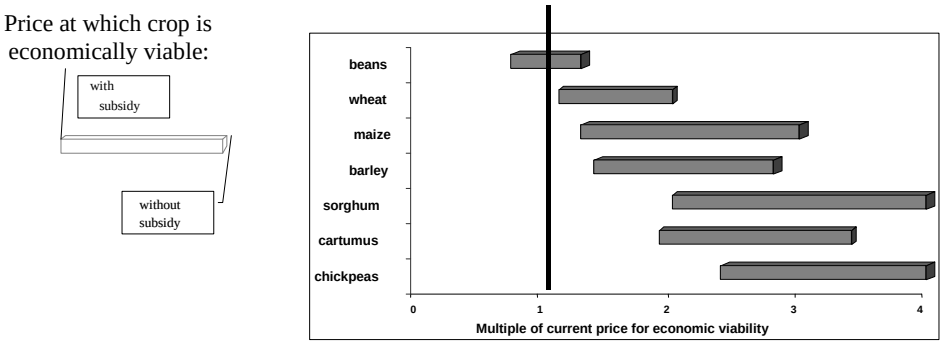
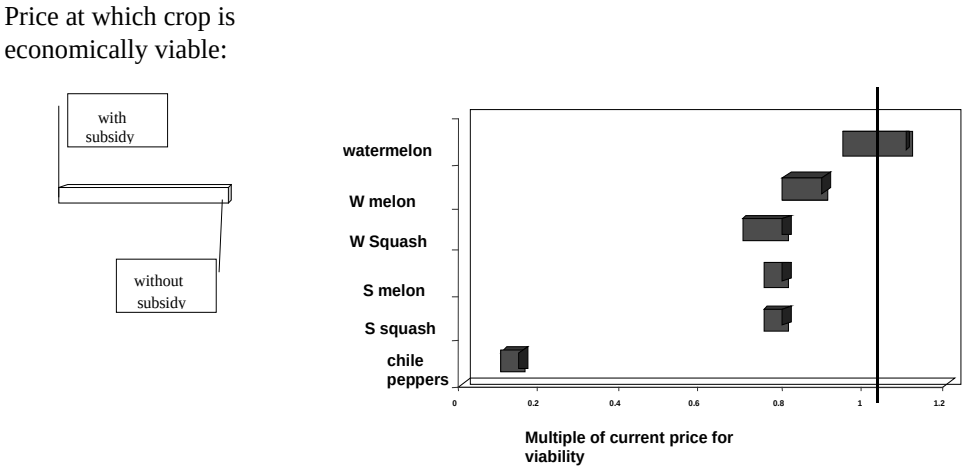


Figure 12: **Price which is necessary for vegetable crops to be viable, with and without electricity subsidy**



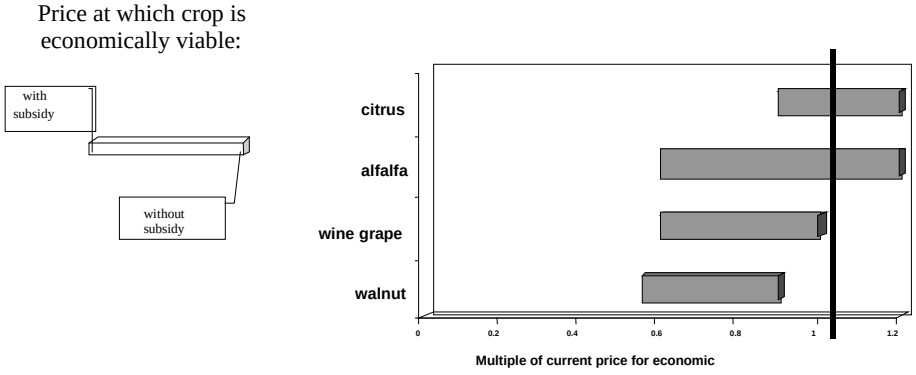
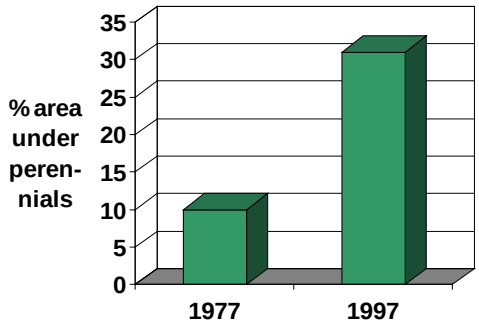


Figure 14: **Net changes in cropping patterns in Hermosillo**

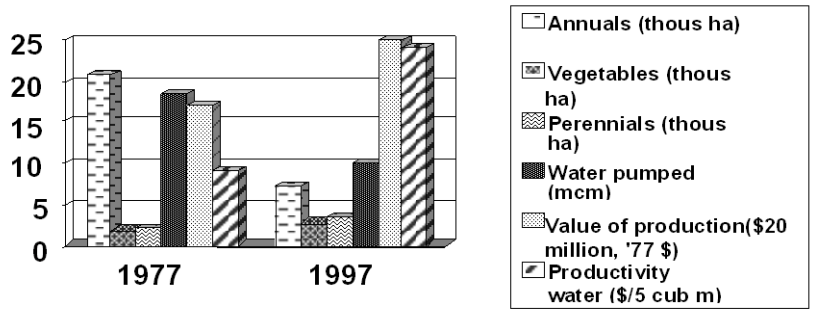


22 The electricity subsidy notwithstanding, the net result of the overall economic changes has been a sharp contraction in the total area planted, and a drastic change in cropping patterns, away from low-value traditional crops to high-value fruits and vegetables. (Figure 14).

23 This has been coupled with some remarkable institutional reforms subsequent to the passage of Mexico's world-renowned 1992 National Water Law (Lei de Aguas Nacionales - LAN). A new partnership has formed between the CNA and the Asociación de Usuarios of Hermosillo. Since 1992, the Asociación de Usuarios of the Distrito de Riego (in Hermosillo) has legal personality (personalidad jurídica), with administrative and financial autonomy to manage the concessioned irrigation water from the aquifer. The Users' Association now limits withdrawals to approximately the sustainable yield (defined by the CNA), and uses pricing and a form of inter-year "water banking" to a previously-unimaginable discipline. Especially since the 1997 regulation—which separated water and land rights—water transfers have become brisk, with water moving away from the saline coastal areas further inland, primarily for irrigation of high-value table grapes. The CNA has played a fundamental and progressive role in Hermosillo, by legitimizing the Users' Association, and by providing critical technical support, including aquifer modeling and water budgeting and metering.

24 There have, of course, been profound economic and social effects from this "revolution" in Hermosillo. Most of these effects are positive. Many of the farmers of the area are well educated, well informed of technological and institutional possibilities (both at the farm and aquifer levels) and have shown remarkable resilience. Over the last 20 years the productivity of water has risen about 3 fold (Figure 15 shows similar data for the area of Guaymas in Sonora), meaning that the 400 million cubic meters (mcm) a year which is now pumped in Hermosillo produces a greater economic return than the 1000 mcm pumped twenty years ago.

Figure 15: **Increase in productivity of water, 1977 to 1997**



25 Equally important is the fact that one hectare of a high-value crop uses approximately twice as much labor as one hectare of a traditional crop, once again muting the effect of the decline in total irrigated area (Figure 16) .

26 There are two dark clouds over the Hermosillo aquifer (and neither of them promises more precipitation!). The first is environmental. Even if no more water were to be pumped from the aquifer, the cone of depression already created would continue to "suck in" seawater, and the irrigated area lost by salinity would grow from 13 percent to 25 percent over the next 50 years (Figure 17).

Figure 16: **Where jobs are generated**

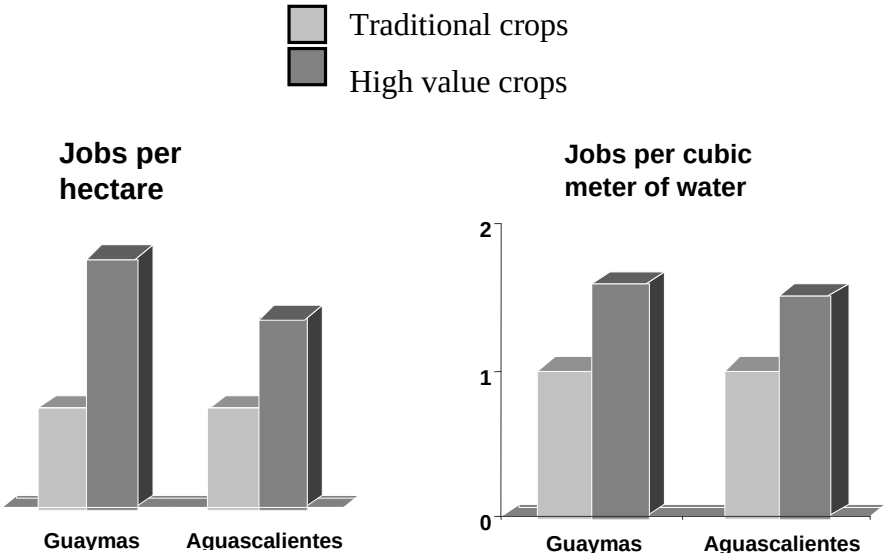
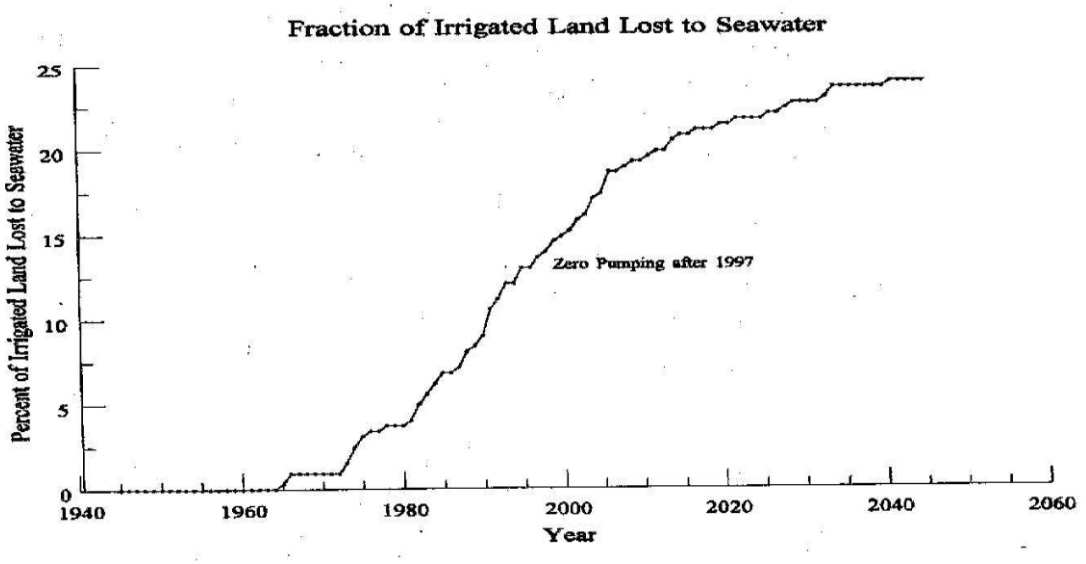
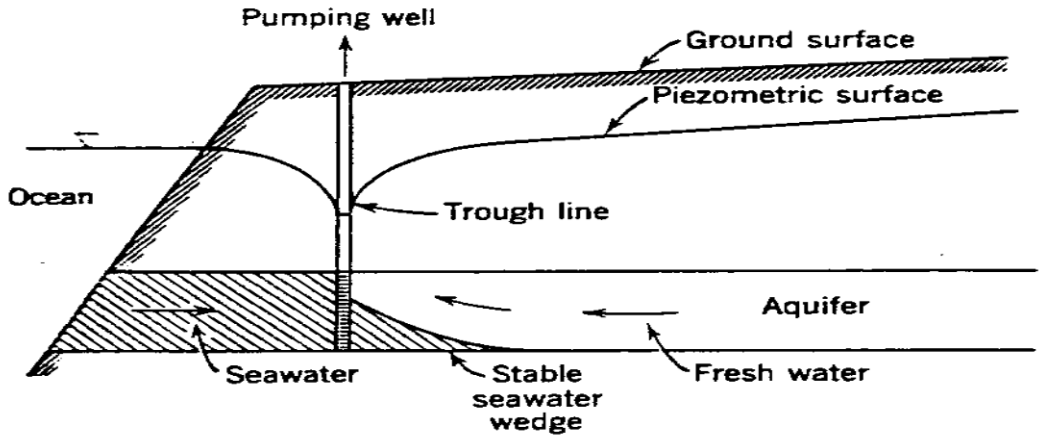


Figure 17: **The Hermosillo case**



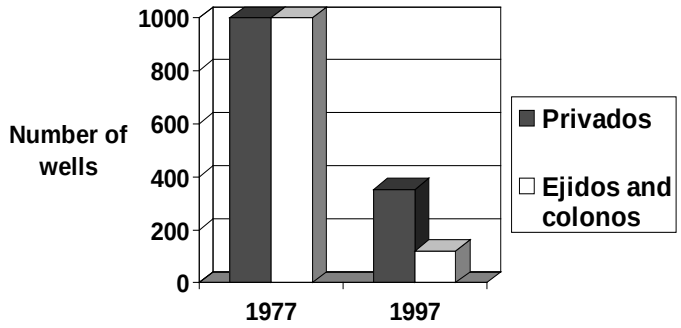
27 A number of technical solutions have been proposed to arrest the degradation of the Hermosillo aquifer. One is to treat and recycle the wastewater from Hermosillo City (about 100 mcm per year), but this is unlikely to have any real effect as most of the discharged wastewater—albeit untreated—already finds its way into the aquifer via the Sonora River. A second technical would be to install a battery of wells which would pump the saline groundwater back into the sea (Figure 18). Preliminary calculations show this to be prohibitively expensive, so it is therefore unlikely to be undertaken. What is likely is that a substantial ribbon along the coast will become permanently saline, with irrigation moving inland, as is already happening.

Figure 18: **Technical solutions for stopping the saline intrusion—Pumping wells near the coast to intercept seawater**?



28 The second "dark cloud" is social. Twenty years ago, poor farmers (ejidos and colonos) accounted for about one half of the water used from the Hermosillo aquifer. With few exceptions, these farmers have been unable to make the transition to a flexible, high-value agricultural regime. The number of such farmers has already been drastically reduced (Figure 19), and there is little prospect that this trend will change.

Figure 19: **Water ownership and how it is changing**



29 The ejiditarios themselves see little future as farmers, and their children seldom stay on the ejidos. This is a social phenomenon of historic importance and far-reaching consequences. What would appear to be required is a recognition that poverty-oriented programs need to focus more on the generation of employment opportunities for the poor of the Hermosillo coast, and less on attempting to address poverty through land-oriented programs.

30 An important feature of water management in Hermosillo is that the Irrigation District has not permitted the city of Hermosillo to draw water from the aquifer. In substantial part this exclusion is based on a (legitimate) fear that if the urban utility ("Organismo Operador") is permitted to take water from the aquifer it will not "play by the rules," but will assert a priority right (which does not exist in the law of 1992) to take water without compensation. This means that the utility has had to resort to high-cost and low-reliability surface supplies, which have complicated the operation of a utility which, like most others in Mexico, performs poorly in both technical and financial terms.

3.2 Where urban use is important -- the case of Aguascalientes

31 The critical issue of the co-existence of urban and irrigation demands on an aquifer is, accordingly, best examined where urban users constitute a significant fraction of overall use, and where there has been some effort at reforming the operation of the urban utility. Of the five aquifers which were studied in detail, Aguascalientes, in central Mexico, is the aquifer where urban uses loom largest (Figure 20).

32 Extractions from the Aguascalientes aquifer exceed recharge by a factor of about two, despite a reduction in extractions for irrigation over the last decade (Figure 21). Urban demands account for about one third of all water abstracted from the aquifer. Over the last 30 years the water table has dropped from about 40 meters to 90 meters (Figure 22).

Figure 20: **Water use characteristics of the five aquifer studies in detail**

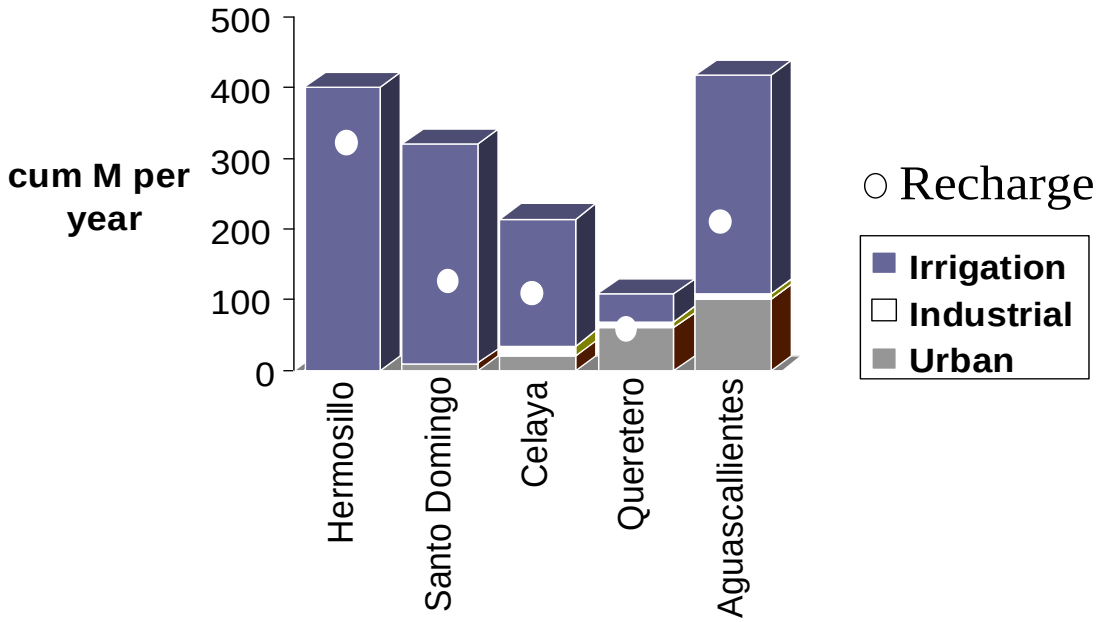


Figure 21: **Abstractions and recharge for Aguascalientes aquifer**

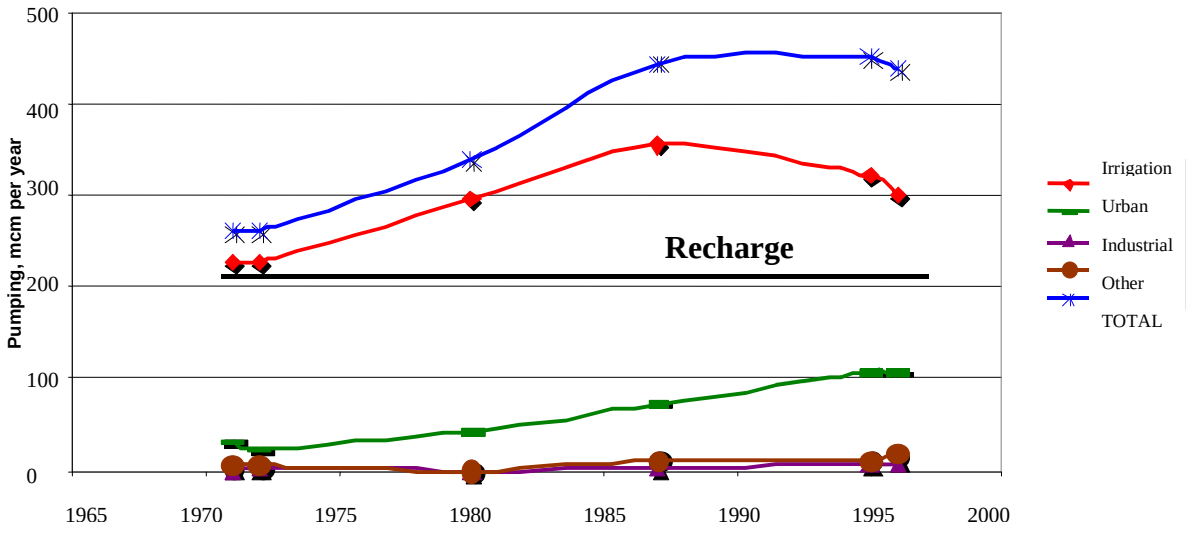
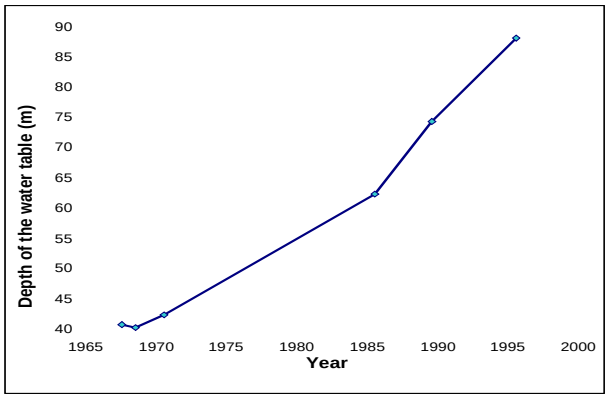
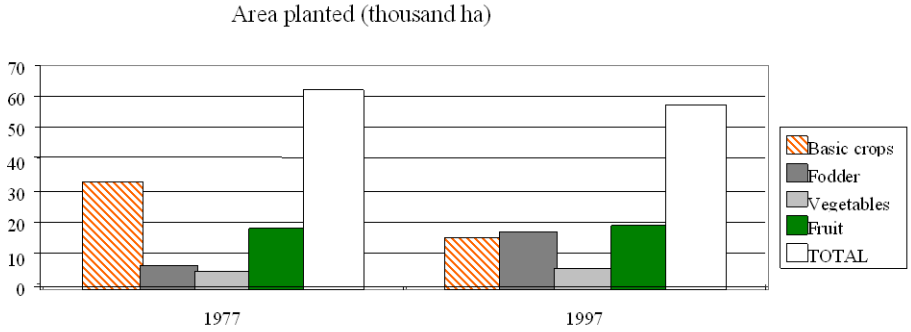


Figure 22: **The depth of the water table in Aguascalientes over a 30-year period**



33 The institutional changes in irrigated agriculture in Aguascalientes are not as dramatic as they are in Hermosillo. There are some important and serious anachronisms. For instance, some irrigation districts in Aguascalientes discriminate against high-tech irrigation, both in terms of governance and in terms of water allocation during droughts, when small (usually traditional, low-tech) farmers get their full water rights, while larger (usually high-tech) farmers face drastic reductions in allocations. These anomalies notwithstanding, there have also been significant changes in cropping patterns and irrigation technology in Aguascalientes (Figure 23). As in the West coast, farmers in the Bajío have shown that they can actually increase the value added to their crops while using less water (Figure 24).

Figure 23: **Agricultural responses in Aguscalientes — Changed cropping patterns**



34 An interesting by-product of intensive study by the CNA of the Aguascalientes aquifer is a comprehensive water balance which sheds light on the important issue of "real" and "paper" water savings from high technology. It is often claimed that losses at the field level are not real losses, because the water actually recharges the aquifer. Detailed investigations of the water balance of the aquifer (Figure 25) have shown, however, that only one quarter of the water lost at the field level actually finds its way back to the

aquifer, since the main component of infiltration is lateral, and evaporates from the soil directly or through evapotranspiration from weeds. In addition, of course, is the fact that the quarter which does return to the aquifer has to be pumped up 90 meters (for a second time) before it can be used. These investigations, which need to be repeated in other settings, provide compelling evidence that, in Aguascalientes at least, the case for more efficient irrigation technologies is compelling.

Figure 24: **Agricultural responses in Aguascalientes — Changed value of production**

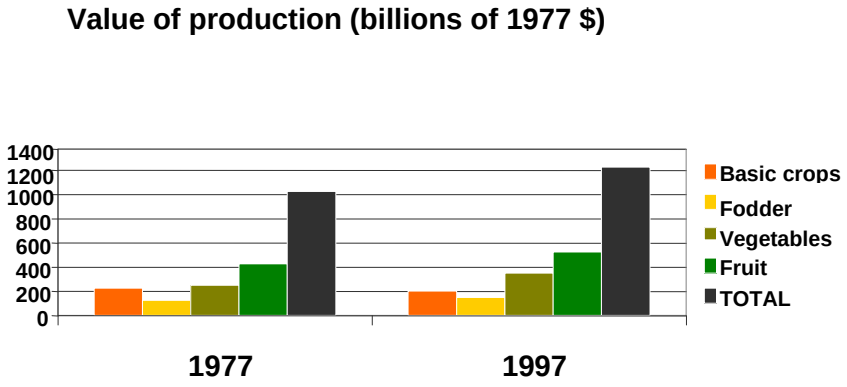
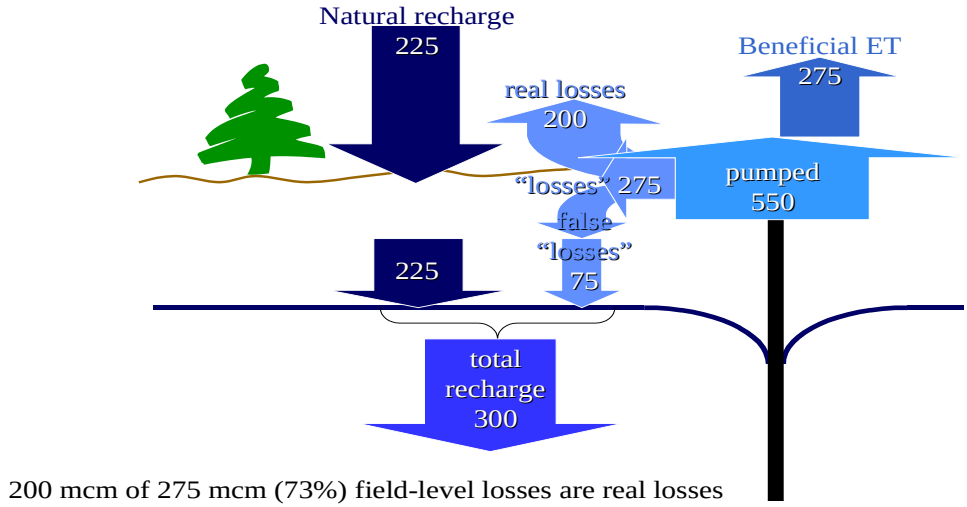


Figure 25: **Water balance in Aguascalientes Aquifer**



200 mcm of 275 mcm (73%) field-level losses are real losses

35 Aguascalientes also provides important insights into the ways in which urban utilities could behave in an overexploited aquifer. Since 1993 Aguascalientes has had a concession contract with a private concessionaire (CAASA) for investment in and operation of the urban utility. In terms of the "three I's", the situation is as follows.

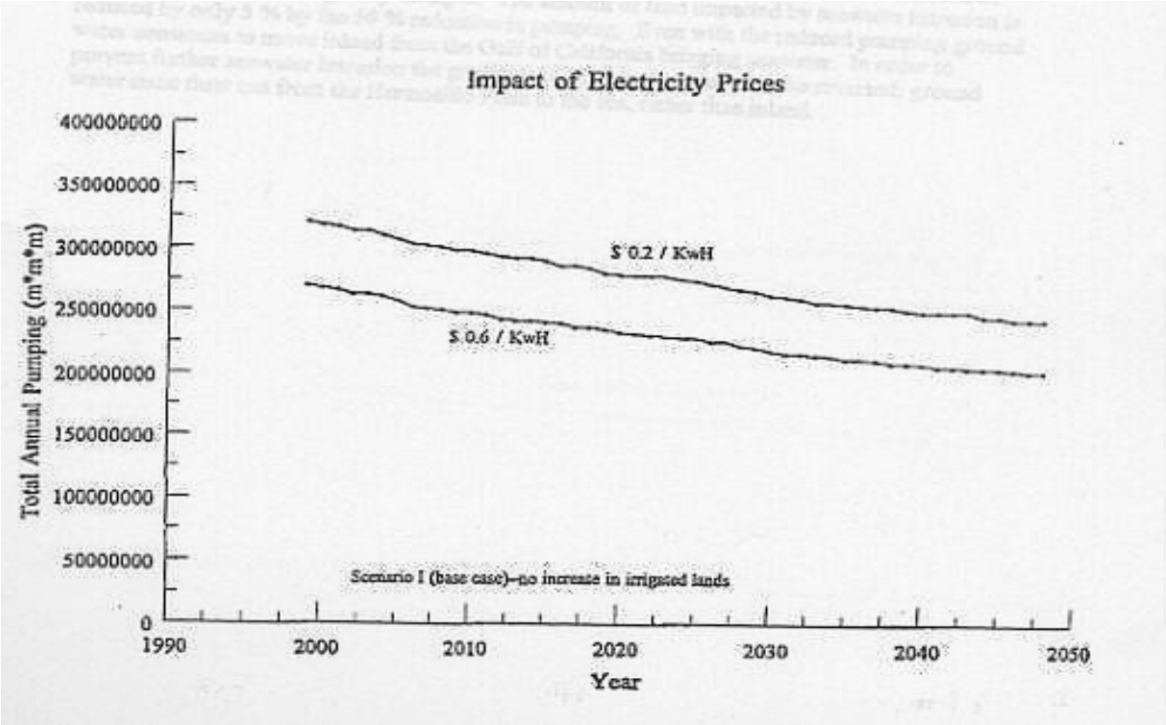
36 First, consider Incentives. As in any other concession contract, a fundamental element is that the basis of the contract is a negotiated tariff, which means that the concessionaire can turn a profit primarily as a result of efficient use of inputs (including raw water). In Aguascalientes, the costs for raw water loom particularly large, since they account for about 30 percent of the overall input costs of the utility. In addition, overpumping-induced subsidence destroys many water and sewer lines and thus imposes large costs on urban utilities in many cities in Mexico. [The most detailed studies of this have been done in the nearby city of Celaya, where subsidence-induced damage is estimated to be over $40 million.] CAASA thus has powerful incentives both to use water efficiently itself and to find ways of working with others to reduce further drawdown of the aquifer.

37 Second, consider Information. Shortly after winning the concession contract, CAASA initiated some state-of-the-art work on developing decision support systems for aquifer management in Aguascalientes.

38 Third, consider Institutions. The insertion of the private sector into urban utility management was an innovative and important step for Mexico. The reality is that, as in many other countries, state-owned utilities have performed poorly, been subject to small-minded political manipulation, served users inadequately, and not been financially viable. The result is a familiar vicious cycle of poor performance, low willingness to pay, poor financial condition, worse performance, etc. To take just one performance index, the level of unaccounted water in Mexican utilities is about four times that in well-run utilities elsewhere in Latin America.

39 The sad reality is that the Aguascalientes "test case" for private sector involvement in urban water supply in Mexico has become mired in a maze of inter-related institutional problems. At the "smallest" scale, shortly after the concession was awarded there was a political conflict with the changing of political parties at the municipal and local level. Claims and counterclaims were made about malfeasance in the awarding and terms of the concession. This, then, exposed the absence of a broadly-debated and broadly-accepted regulatory framework, which would have balanced the differing interests of the government, users, and the utility and shareholders. This breakdown has had serious consequences for, inter alia, the management of the Aguascalientes aquifer. Bad blood between the State and the concessionaire has reached the point where the State does not recognize the right of the concessionaire to even participate in the (embryonic) aquifer management committee (COTAS) or in the Lerma Chapala Basin Management Committee (into which Aguascalientes falls). The protracted struggle over finances means that CAASA no longer pays for the water it abstracts from the aquifer (thus behaving like virtually all the state-owned utilities in Mexico, who see raw water charges as having "the last call" on revenues). And CAASA has shelved its efforts to develop a decision support system for management of the aquifer.

Figure 26: **Eliminating the "09"electricity subsidy would reduce pumping by about 20% in Hermosillo**



4. How might the situation be different?

40 Implicit in the above descriptions are the broad outlines of how aquifers in Mexico might be managed differently (and better).

4.1 Irrigation

41 In terms of Information on more efficient use of water in irrigation, Mexico has an outstanding human resource in the cadre of farmers who are well-educated in efficient use of water at the farm and aquifer level. Many of them—and even more of their children—have degrees in agriculture, management and other relevant disciplines. Many have visited state-of-the-art farms and irrigation districts in the United States. They are closely tied into an impressive network of modern service providers of and marketers of high-value products. What this brings is a highly modern, efficient and flexible attitude to the business of irrigation and water management.

42 In terms of Institutional arrangements for effective aquifer management, the Hermosillo and Aguascalientes cases illustrate both what is possible and what opportunities are being missed, both at the farm level and the aquifer management level.

43 In terms of Incentives, the biggest change has been the liberalization of the Mexican agricultural economy, with the corresponding alignment of crop and input prices with world market prices. Equally important has been the recognition of legal and tradable rights, which have given farmers an incentive to conserve and invest in the resource. The Federal Government has been innovative and appropriate in moving away from the

distorting subsidies of the past (price supports, tariff barriers and input subsidies) to mostly non-distorting direct payments to farmers (figures 9 and 10 above), and also into appropriately targeted subsidies for water and energy efficient technologies.

44 The great incentive issue in irrigation is the "09 energy subsidy," whereby the Federal Electricity Commission charges farmers only one third of the cost of electricity. This subsidy is both an anomaly in a liberalized economic environment, and one which contributes in a major way to over-exploitation of groundwater. Based on experience from a temporary hike in energy prices in the early 1990ies, groundwater extractions would be reduced by about 20 percent if the energy subsidy were removed (figure 26).

45 It is obvious that the removal of the 09 subsidy would be opposed by farmers, as has been the case in the past. So a dialogue is also clearly needed between government and farmers, in which it is explained why the subsidy should not be continued, and in which agreement is sought on a compensating subsidy which would not have the deleterious impact of the energy subsidy. This is a process which has worked before in Mexico, when the much larger subsidies for credit, insurance and fertilizers were removed and replaced with direct payments in the PROCAMPO program.

46 It needs to be kept in mind that continued over-exploitation of the aquifers will adversely affect small, poor farmers in any case. The energy subsidy, which costs Mexico roughly $300 million per year for the 80,000 eligible users, is not sufficient for small farmers to cover their costs. Field surveys carried out for this study in the Santo Domingo aquifer showed that a significant number of farmers were with *carteras vencidas*, thus not eligible for credit. This explains why many farmers continue to grow non-profitable low-value crops, while not investing in the upkeep of their wells and equipment. Once the technical life of the wells ends, these farmers will be without a livelihood. At the same time, large farmers, who could afford to pay the full energy price, will continue to be subsidized. In this sense, the subsidy is doubly ineffective: it accelerates over-exploitation of groundwater resources and, with current trends, increasingly subsidizes the non-poor.

4.2 Urban water utilities

47 In most countries, urban utilities move to "modern practice" sooner and faster than farmers. The reverse is true in Mexico, where relatively little progress has been made in modernizing the financing and operation of urban utilities. This lack of progress is proving to be a serious hindrance to, among other things, improving aquifer management. Where the State or municipality runs the water utility, which is the case almost everywhere in Mexico, the state operates in its standard "I am the law and am therefore above it" mode. Among other things this means that it pays little respect to the rights of other users who naturally, as in the case of the farmers of Hermosillo, are wary about sharing their resource with an actor who will not "play by the same rules as others." In many other countries the entry of the private sector has been a catalytic factor in bringing the "gamekeeper-poacher" conflict of interest to the fore and in crystalizing the need for a more transparent and effective regulatory framework to balance the often-conflicting interests of utility customers, the utility and its shareholders, and the government (including the rights of other users and the environment).

48 The overwhelming need for the urban water sector in Mexico (again, for the aquifers, but also for many other purposes) is the development of a new and sounder institutional model. It is likely that such a model will include a major role for corporatized public sector utilities, who will keep private utilities honest, and for private utilities, who will compete with each other and with the corporatized public utilities, and who will keep the public utilities honest. It is also clear that this will require the Government (Federal, State and Municipal) to get out of the business of running utilities and into the business of even-handed regulation, almost certainly with a lot of attention going to the development of transparent, high-quality benchmarking data which can be used by all parties in assessing specific utilities against national and regional standards.

4.3 Industry

49 For the most part, industry plays a positive role in the modernization of aquifer management in Mexico. This is largely attributable to the fact that industry is unable, like the urban state-owned utilities, to skirt the rules with impunity. Industry uses just 10 percent of the water, yet pays almost all of the $300 million which the CNA collects annually in water charges. Industries are also strong supporters of water markets, which they use to voluntarily obtain the quantities of water they need. For these reasons they have a strong interest in more effective and equitable management arrangements, in which other users, too, will have to play by the same rules.

4.4 Aquifer management agencies

50 The cases examined in this study showed clearly what is needed in terms of aquifer management in Mexico. To a substantial degree Hermosillo has achieved this, in large part because the Irrigation District was able to use its *personalidad jurídica* powers to manage the aquifer.

51 There are two competing visions of what aquifer management and the COTAS (Technical Committees for Groundwater) mean. One vision is that these are committees of users to be consulted with (consultación y concertación) by those who make the decisions (namely the CNA). From discussions with users groups in a number of aquifers it is clear that this will simply not work. The users are deeply skeptical of the CNA and have no interest in participating if it is simply in a consultación y concertación mode.

52 The other vision of aquifer management is one that sees a partnership between government and the users in a COTAS with real powers (personalidad jurídica). To a substantial degree Hermosillo has achieved this "by accident," because the statutes of the Irrigation District, which gives it a legal personality, have been used to manage the aquifer. In Hermosillo the Regional Office of the CNA has shown the way to legitimize the users' role in managing the aquifer, and to provide technical support in both hydrogeological terms and in monitoring and accounting for the water. It is this second vision of COTAS—with real power and real resources—that is articulated by virtually all users and by the State of Guanajato.

5. The prospects for, and challenges of, the next round of water reform in Mexico

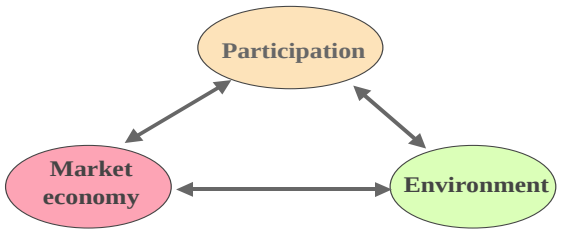
5.1 A panoramic view of water reform in Mexico

53 Over the last four or five decades, as in most other countries, the principal water resource challenge in Mexico was perceived to be increasing supplies for growing populations and economies. Some time ago a new generation of Mexican water leaders understood clearly that this "development era" would soon be coming to a close, and that the future would be much more focused on "managing the people" (demand management) than "managing the water" (supply management). A landmark in this transition was the Lei de Aguas Nacionales of 1992, a water law which is globally recognized as a model to be emulated. For the world at large, the LAN is a creative adaptation of the Dublin Principles of Water Management (defined in the process leading up to the Earth Summit in 1992, and around which a global consensus has emerged). The three Dublin Principles are:

- "the ecological principle", which states that water must be managed comprehensively (rather than sectorially) and that greater attention needs to be given to environmental impacts and uses;
- the "institutional principle," which builds on the subsidiarity principle (which requires that water be managed at the lowest appropriate level), and requires that all stakeholders participate in both policy formulation and resource management; and
- the "instrument principle" which states that water must be considered as an economic (as well as a social) good, with greater use of economic instruments such as tradable rights, and extraction and pollution fees.

54 A review of global experience shows that there are social and economic "pre-conditions" which underlie the adoption of these principles. In brief, adoption and implementation is likely where there is broad-based participation in decision-making, where the economy is run on market principles, and where environmental concerns are high on the national agenda (Figure 27).

Figure 27: **Global experience shows that water reform happens when the following, reinforcing, elements are strong:**



55 To a substantial and increasing degree, Mexico meets these three pre-conditions (Figures 28 and 29). Indeed, it is no coincidence that the passage of the LAN coincided with the liberalization of the Mexican economy.

Figure 28: **Economic liberalization and market reforms in Mexico?**

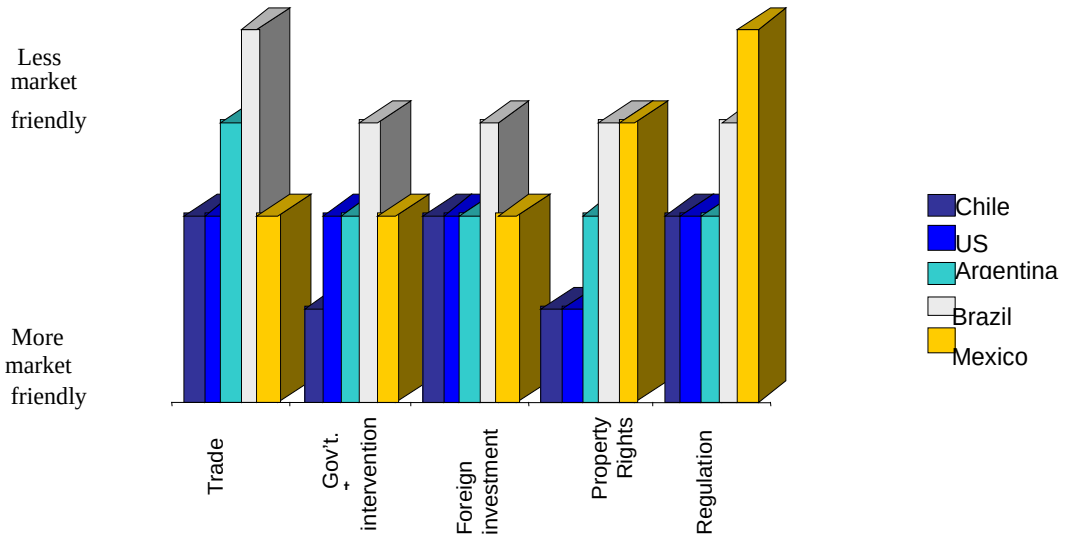
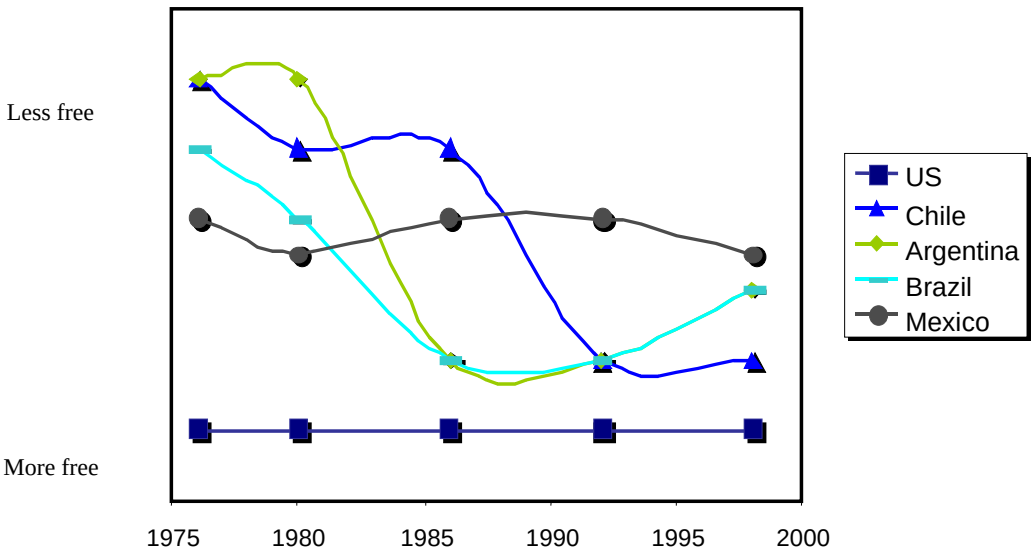


Figure 29: **Political Freedom in Mexico?**



56 Water reform is a process which is universally measured in decades, not years. In the eight years since passage of the LAN, Mexico has made remarkably fast—but inevitably mixed—progress. The most striking and best known success has been in the turnover of irrigation districts to Users' Associations. The results have been extraordinary, with farmers showing themselves capable of managing both the technical and financial aspects of their infrastructure and the CNA demonstrating what it means to be a good supporting partner to organized users. Mexico has justifiably become a world leader in the farmer-turnover business.

57 Institutional change is also happening at the resource management level, but at a slower pace. The flagship river basin agency in Mexico is the Lerma Chapala Basin Agency. A decade ago "participation" was primarily a matter of the Federal Government discussing issues with the State Governments. Over time the "participation clauses" of the LAN have provided a basis for far broader participation. Currently about half of the participants in the Lerma Chapala Basin are representatives of actual user groups.

58 A lot of progress has also been made in the definition and registration of water rights (a task which turned out to be much more demanding than was first thought). A major unresolved issue in the LAN was that of separation of water and land rights. The relatively slow development of water markets led the Government to pass a regulating decree in 1997 which separated water and land rights. This appears to have made a substantial difference in the vitality of the emerging groundwater markets. Field data from Santo Domingo in Baja California (collected for this study) showed that one third of operating farmers have purchased permanent water rights and a quarter have leased rights from others on a temporary basis.

59 The principle of "user pays" and "polluter pays" is a central part of the LAN. Again, as in all other countries, this is a huge cultural change which takes place only over time. From one perspective, Mexico does remarkably well—approximately US$1 billion is collected annually in user fees. There are several important points to note about this. First, this money is essentially all collected from extraction fees—very few pollution charges are levied or collected. Second, only one category of user—industry, which uses about 10 percent of the water—actually pays. Third, in line with the Ministry of Finance's policy of "no earmarked taxes," these revenues go directly to the Treasury (where they do, however, form an important, albeit informal, part of the discussions about the budget level of the CNA).

5.2 Groundwater management and the next steps in the Mexican Water Reforms

60 In this context, the challenges of the "next round" of water sector reforms in Mexico are clear. They are, in a word, to put the principles of the LAN into practice in groundwater management. A vision for this next round is not hard to construct. It is one in which the CNA concessions water to the COTAS (just as it does to the Users' Associations), and the COTAS become true aquifer management

agencies, with full powers to restrict access, charge users, and invest in priority infrastructure and software. Federal and State Governments have a vital role to play, which is quite different from their traditional role as the sole decision makers. In this next round, their principal function will change to that of supporter and facilitator of user-run COTAS. Government will support with legitimizing legislation and regulation, with information on aquifer conditions and best practices, with help in defining extraction limits and quality standards, and with stimulating technical and institutional innovation.

61 This process, like all other water reform processes, is not simple or friction-less, since there are many interests in continuing to conduct "business-as-usual." It will require leadership from the CNA, many of whose employees will see the inevitable reduction of its budget and power as a loss. And it will require that the CNA have an advocacy role vis-a-vis the Ministry of Finance regarding the need for a proportion of user and pollution fees to stay at the basin-of-origin or aquifer-of-origin. It will also require that the CNA invest much more in its capacity to provide users with information, decision-support systems, help in how to manage participation and institutional reform, and in providing assistance in understanding environmental issues (including water quality). This will inevitably be resisted by a supply-oriented agency dominated by engineers and other technicians.

62 This process is difficult, slow and complex in all countries. It is likely to be even more so in Mexico, given the long history of concentrated economic, political and informational power at the Federal level in Mexico, and the as-yet incipient nature of political and fiscal deconcentration. What is encouraging is the enormous will and capacity that exists amongst virtually all the users – farmers, industries and some local governments -- interviewed during the course of the work. There is little doubt that they are ready to take the reins; now what is needed is an unequivocal commitment from State and Federal Governments to support such a reform path.

6. Recommendations

63 The results of the present study lead to a number of recommendations to achieve the move towards stabilization and the sustainable and productive management of Mexico's aquifers.

64 First, the development and articulation of a Government strategy at federal and state levels with regard to aquifer management is needed to provide clear guidelines to the stakeholders at different levels, ensure their full participation and transparency in decision making, and provide them with political legitimacy and funds for concrete actions. In particular, such a strategy should include:

- Communication and interaction with water users to create a "water culture" and public conscience regarding groundwater problems and management;

- Enforcement and revision of the legal and institutional framework regarding COTAS and the role of the states and municipalities, with a view to strengthening the COTAS by providing them with legal personality, decision making and sanctioning power over the aquifers' management, a financing mechanism to render them self-sufficient and—in the long term—independent from government handouts;
- True stakeholder participation in actions related to the constitution, regulations, and organization of any aquifer program (including federal investment programs intended to improve water use efficiency);
- Promotion and channeling of current and future water efficiency programs towards the over-exploited aquifers;
- Strengthening and development of groundwater information systems (including the water rights registry—REPDA);
- Improvement of public access to groundwater related information systems;
- Intensified implementation of groundwater monitoring networks, as well as increasing the number of aquifer and geohydrological systems studies;
- Review of the rural energy subsidy (tarifa 09) to turn it from a distortionary subsidy into a direct, targeted subsidy benefiting the poor (this could be constructed similar to, or integrated into, the PROCAMPO subsidy);
- Restructuring of the water supply and sanitation sector with a view to making utilities act as responsible stakeholders in aquifer management, including by enforcing their water concessions and payments of *derechos de agua* to be on an equal footing with industries; and
- Review of farmers'exemption from payments of *derechos de agua*.

7. Further Bank Involvement

65 The Bank has played an active role in Mexico's water sector for several decades, both in irrigation, water supply and sanitation, and water resources management. Since 1994, the Bank has been financing the Mexico Water Resources Management Project (PROMMA) which has as its main objective to improve water resources management, including groundwater, nationwide.

66 As an outcome of this study, the Bank is preparing an Aquifer Management Pilot Project to be folded into the PROMMA. It would be implemented in five aquifers over a four-year period and focus on strengthening stakeholder participation through support to the COTAS, awareness campaigns for water users, training of CNA personnel, implementing adequate groundwater monitoring systems (including technical), modeling and alternative studies for the pilot aquifers, introducing demand management at the aquifer level, and elaborating investment plans.

67 Due to the multisectorial aspects of groundwater management, this pilot project should be linked to other on-going projects in Mexico, such as: the On-Farm and Minor Irrigation Networks Improvement Project (PRODEP), and the Irrigation and Drainage Sector Project (Timeslice), which target improvement in irrigation

efficiency; the Agricultural Productivity Project; and sanitation sector investment initiatives that would improve the efficiency of water utilities. [The findings of this study coincide with those of a water and sanitation sector study currently being carried out by LCSFP.] For further synergy effects, the pilot could also be coordinated with other GOM initiatives or external agencies that are active in the different water sub-sectors in Mexico.

68 An important issue to be addressed by the Bank and by the GOM is the poverty implication of groundwater over-exploitation. The modernization changes are almost all positive for both economic growth and the environment. But they put a premium on knowledge and mean that the historic Mexican approach of land-based solutions to rural poverty alleviation are not working. There are some positive aspects, for instance employment generation per cubic meter of water is substantially higher for high-value than traditional crops. There is, however, a polarization in rural areas which is particularly pronounced in the over-exploited aquifers. It is essential that there is a systematic focus on these issues—including by the Bank— both to address the poverty issues and to ensure that this does not reverse the progress being made in efficient and environmentally-friendly resource use.

Overall, the Bank should actively support the larger policy issues on the Mexican agenda, such as reform of the electricity and water and sanitation sectors, decentralization (not only of water resources management), and economic liberalization, which all directly or indirectly affect groundwater management.