# *"A Never-Ending Source of Water": Agriculture, Society, and Aquifer Depletion on the Coast of Hermosillo, Sonora*

José Luis Moreno

## Introduction

This article analyzes the evolution of irrigation and water use in the region of the Hermosillo Coast, in the Mexican state of Sonora. Over the last 60 years water use in this region has supported an agricultural development model the principal characteristic of which has been inequality: in the access to that resource; in the distribution of economic benefits; and in the distribution of social and environmental costs. Repeated legal and political efforts to limit subsoil water extraction have failed for the most part, and the depletion of the aquifer has led to saltwater intrusion from the Gulf of California, soaring energy costs for deep wells, and immanent water shortages.

The history of the Hermosillo Coast region shows that this kind of development is unsustainable over the long term because it favors narrowly conceived economic objectives at the expense of social and environmental objectives. It has, moreover, favored a small group of people. In physical, environmental terms the development model has, from its inception, depended on the extraction of subsoil water far beyond the ability of natural recharge to replenish the source, thus threatening the future existence of agriculture and urban centers in the region. In economic terms, the unsustainability of the development model can be seen in subsidies to electricity, water, and crop prices that have promoted the wasteful use of aquifer water. In social terms, aquifer-fed agricultural

José Luis Moreno is professor and researcher at the Colegio de Sonora, in Hermosillo.
Translated and edited by Casey Walsh, associate professor in the anthropology department, University of California, Santa Barbara.

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development in this region has proven unsustainable because it has produced the intrusion of seawater into the aquifer in the coastal zone inhabited by small-scale farmers known as colonos. While efforts to relocate the colonos did not succeed, this in turn meant that these small producers continued to farm with substandard water, negatively affecting their businesses and accelerating the process of land and water concentration in the hands of a few wealthy families. By the late 1990s, 70 percent of the small colono producers who had settled during the golden age of agriculture in the 1940s had been forced to sell or rent their lands.The state has played a crucial role in securing the interests of regional elites and transferring the costs of this development model to other social groups as well as the environment. Examples of this include the relocation of wells, subsidies, and "special water concessions" that are given to certain producers to take advantage of market conjunctures. Because of its role in the development model, the state is unable to carry out its own declared intentions of regulating and reducing water extraction.

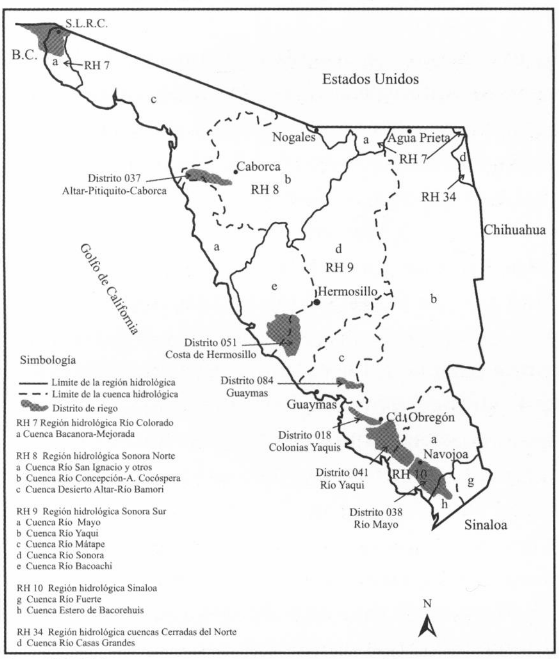
## Geography and Early History

The deep-well irrigation district of the Hermosillo Coast is located on the central coastal plain of the state of Sonora. It forms part of the large geographic region known as the Pacific Coastal Plain, which is sandwiched between the Sierra Madre Occidental mountain chain on the east and the Gulf of California to the west. In general it is a flat area that slowly descends from the city of Hermosillo, at 200 meters above sea level, to Kino Bay (Bahía Kino), about 100 kilometers away. The soils are made up of alluvial sands and silts deposited by watercourses over thousands and millions of years. This soil composition together with the topography favored the filtration of surface water and the formation of rich aquifers. The climate is very dry and hot during the summer with occasional rains, and the temperature can fall to freezing in the winter.

The zone is considered semiarid because it receives only between 75 and 200 millimeters of rainfall annually. These scarce rains are also erratic, and can fall in late winter as well as in mid-summer, a pattern typical of the border region. The summer rains result from tropical weather systems and are usually intense and localized downpours that create great torrents in the watercourses of the region. The winter rains are those that sweep down from the northern Pacific, and are usually lighter and longer lasting.

Due to intense heat and dryness in the region, annually three times more water evaporates than falls as rain. The native vegetation in the region is composed of the xerophytic species typical of the semidesert: mesquite, palo verde and palo blanco, various cacti, and an array of hardy shrubs. This native vegetation largely disappeared with the creation and colonization of the irrigation district in the late 1940s, but has reestablished itself with the abandonment of agricultural lands due to salinity and other factors. The irrigation district at its present size is surrounded by a wide variety of land-cover types that include these native species as well as dryland agriculture and even pasture.

The district falls within the lower reaches of the Sonora and Bacoachi Rivers, whose watersheds are characterized by intermittent surface streamflow (figure 1). The Sonora River arises near the town of Cananea and the border with Arizona, and runs 300 kilometers before filling the Abelardo Rodríguez Reservoir near Hermosillo. Since the construction of this dam and the capture of the floods that characterized the summer rainy period, the river has meandered and shifted on its way downstream, and now filters into the sandy delta soils without reaching the Gulf of California.



Fuente: INEGI (1993).

*Figure 1. Irrigation districts and hydrologic regions.*

Until 1945, the only subsoil water extracted came from the top 100 meters of the upper aquifer. The original inhabitants of the region, the nomadic Seris, used water from water holes and springs. Spanish and Mexican colonists sunk shallow wells, until the late 19th century when they made use of steam engines to extract greater quantities of water from deeper wells. The steam engine was accompanied by derivation dams and canals that shunted surface water from the rivers and transported it large distances to agricultural fields. These two new technologies eclipsed an earlier system of irrigation in which fields were watered by the natural flood stages of the river or by water taken from shallow wells. The San Fernando hacienda, property of Alfredo Noriega, employed this new technology in the late 19th century. The hacienda used two steam engines imported from the United States to lift water from the aquifer via a 50-meter-deep wellshaft that measured 3.5 meters in diameter. Known throughout the region as "Noriega's machine," this steam engine was used to irrigate fruit orchards. The machine was accompanied by the "Noriega floodgate," which channeled water from a branch of the Rio Bacoachi through a 25-kilometer-long irrigation ditch onto fields of grains. Dozens of men and mules contributed to the building of this infrastructure.

In 1920, the use of surface water from the Rio Sonora began to increase, due to the extensification of agriculture in the region. European colonists—in this case Italians—were largely responsible for this change, but surprisingly they were not settled in the region as a result of any of the government programs to colonize and develop the scarcely populated borderlands of northern Mexico, promoted by figures such as Roberto Gayol (1994). Arriving on their own account, these Italians quickly changed production methods and infrastructure in the region, converting large expanses of land to agricultural use. To irrigate the Santa Teresa de la Concordia hacienda, for example, they built a 20-kilometer canal to take water from the Arroyo La Poza through the Giottonini floodgate. This work required dynamiting part of El Gorguz Hill, a local landmark. These new agricultural enterprises also used tractors for the first time in the region, and introduced the "bolseo" system of water storage, in which four hectare-wide, meter-deep lagoons were built that enabled the production of up to three metric tons of wheat a year.

Despite the important innovations implemented by these colonists, they were, in general, people of scarce resources. Most were originally from northern Italy, but a few came from the mining zone of Santa

Rosalia in Baja California Sur, or from other countries such as Argentina. The Italians had labored previously in the agricultural fields of California, and a good number of them continued to work for North Americans who owned land in the Sonoran coastal plain. The Giottonini brothers, for example, had the job of initiating agricultural activities on the lands of their boss Charles Wyland, a resident of San Francisco.

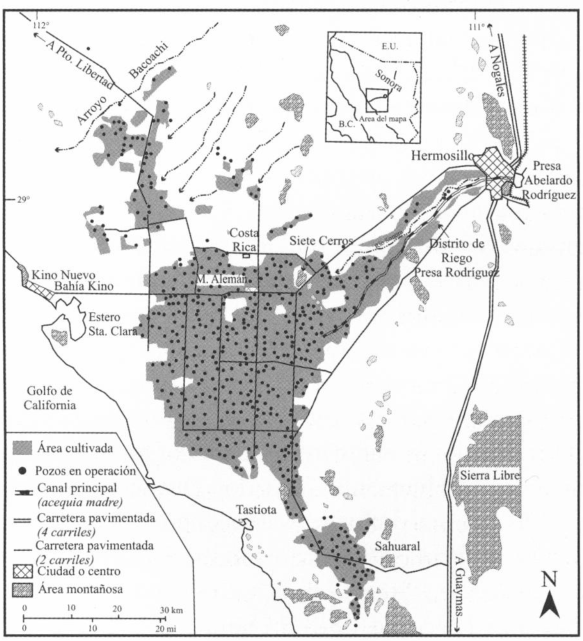
Collective farms (*ejidos*) began to appear in 1930, as a result of government land reforms. Contrary to other regions in Mexico, however, these *ejidos* were not the result of popular mobilizations, did not have irrigation, were farmed in an individual rather than collective manner, and did not receive the support of government agencies such as the agrarian banks. A good example is the first *ejido* constituted in the region of the Hermosillo Coast: El Triunfo. It was founded in 1931 by ex-miners from the local mountains, and by Mexicans repatriated from the United States. Two years later the *ejido* was recognized by the federal government and awarded 2,250 hectares of unimproved land expropriated from the San Carlos property. The *ejido* began cultivation without irrigation infrastructure, depending instead on rainfall and the occasional floods of the Sonora River.

## The Technological and Productive Divide

In the 1940s, a series of factors combined to drive agricultural development in the region near the city and coast of Hermosillo. These included technological advances in dam building and the digging of wells, the opening of new areas to cultivation, and the politics of supporting private property owners (rather than the public *ejido* sector) through irrigation. This boom in development was shown especially in two agricultural zones (figure 2). In the region of the Coast of Hermosillo, in the lower Sonora and Bacoachi river drainages, the irrigation district grew through the extraction of subsoil water from depths of more than 100 meters. At the same time, the Hermosillo Irrigation District located in the middle part of the Rio Sonora drainage was opened to irrigated agriculture through the use of surface water stored in the Rodríguez Reservoir, near the city of Hermosillo. The well field was opened in 1945, and the dam was built between 1944 and 1948. In both cases irrigated development was guided by plans that had been originally drafted in the late 19th and early 20th centuries.

Former president Abelardo Rodríguez began to organize the construction of the dam in 1943 and seven months later construction started. According to Rodríguez, the work "was needed in order to stop the damaging floods and to use water that would otherwise end up in the sea" (Rodríguez 1962). Engineers that considered dam projects in this site had declared them impossible, but Rodríguez hired experts from the Ambursen Construction Company of New York, who had experience building dams all over the world. The principal engineer from the Ambursen Company was Spencer Stewart, who had worked previously with Rodríguez in the construction of a dam in Baja California. He studied the place where Rodríguez proposed the dam be built and recommended a "floating type" of dam that was appropriate for sandy soils.

The Rodríguez Dam had an immediate negative impact on producers downstream, because it eliminated the streamflow that they had used for their crops. According to regional historians, these producers, who included the Italian colonists and the *ejidatarios* of El Triunfo, turned to subsurface water instead. In 1944, five Italians and a Mexican, who had been farming since the 1920s using the waters of the now-dry Rio




Fuente: West (1993).

*Figure 2. Hermosillo Coast and Abelardo L. Rodríguez Reservoir Irrigation Districts.*

Sonora, formed a business partnership to drill a well. Using a Pomona Pumps turbine and Fairbanks Morse diesel engine, both of U.S. origin, they pumped a constant stream of water from a 10-inch pipe onto their fields. Thus began 20 years of unregulated extraction of water (referred to as "free pumping") from the upper aquifer at depths greater than 100 meters. The business of pumps and turbines was already booming when Arnoldo F. Moreno, the local distributor of Pomona and Fairbanks products, invited Fairbanks Morse engineer Ray Cooper to visit the region in 1945 and install the first really large diesel motor for pumping. Meanwhile, the first studies of the aquifer's characteristics were not conducted until around 1950, and the first estimate of the aquifer's recharge rate was not made until almost 1960. The advent of unregulated deep-well pumping resulted in the concentration of land and water in the hands of a relatively small number of local elites. An example was the Mazón family, originally involved in commerce and retail, which accumulated 5,000 hectares and six deep wells as they entered into agriculture.

Social inequality, seen in the concentration of land and water in few hands, was present at the creation of the irrigation district, and was built upon previous patterns of land and water concentration in the hands of what scholars have referred to as "regional notables" (Balmori, Voss, and Wortman 1990; Voss 1982). On Christmas Eve of 1949, the Secretary of Agriculture and Livestock published a Decree of Colonization for the Hermosillo Coast. The decree allowed for 200,000 hectares of public and private land to be put up for colonization in parcels of 200 hectares, for production using subsurface water. The decree stated that 60 or 70 pumps were already "working at full capacity without using up the water," reflecting the idea that the water was limitless. The 200-hectare parcels of the new district could either be held by individual property owners or be conceded to colonists organized into societies of ten people with the same maximum limits to water and land. Notable families often held various 200-hectare parcels, each in the name of a different family member. Fifty important people and their families owned almost half of the wells in the region, which they used to cultivate almost half the area of the irrigation district: 38,000 hectares. Adolfo Orive Alba (1960), the principal federal authority on water issues, recognized the irregularity of this situation on the Hermosillo Coast, but reached the ambiguous conclusion that it "may or may not fall within the constitutional definition of small property." While private "small" property flourished in the region, the state sector of agricultural *colonias* and *ejidos* had much less access to land and especially water. The *colonias* possessed 69 wells and the only *ejido* to appear on the federal registry of water users was El Triunfo, with just two wells. *Ejidos* in this district constituted about 1 percent of the irrigated land.

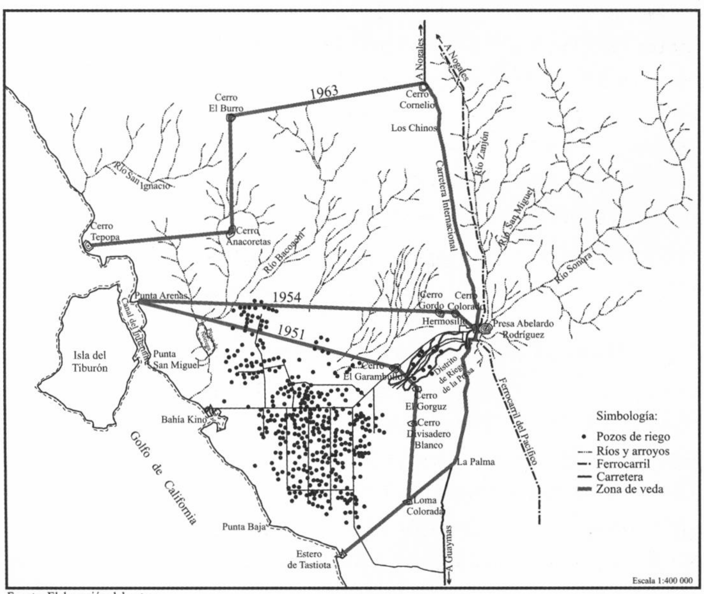
The dam has never fulfilled expectations that it would water 20,000 hectares of land. Originally it irrigated 10,000 hectares, but strong demographic growth over the last 60 years has resulted in a transfer of water from agriculture to urban use. In 1940 the city of Hermosillo had 18,000 inhabitants; by 1950 it had 43,000, and by 1980 the number had grown to 297,000. So while in 1960 about 80 percent of the dam's water was earmarked for agricultural uses, in the mid-1980s the Secretary of Agriculture reserved virtually all the water from the dam for the city, especially for domestic uses. Silting has also reduced the dam's total capacity, making surplus water for agriculture even harder to come by. Given this situation, the farmers in this irrigation district have shifted their production from crops to livestock.

## Free Pumping of Water

As soon as the 1949 Colonization Decree was published the extensification of irrigated agriculture boomed on the Hermosillo Coast. The excessive extraction of subsoil water was immediately noted to be a problem. Water was pumped at an alarming rate to produce high-value commercial crops such as wheat and cotton, but despite a series of legal limits and moratoriums on the expansion of subsoil water use, the pumping continued largely unabated in the years that followed. This dynamic of overextraction linked to commodity production, repeated formal restrictions on water use, and their poor enforcement has characterized water use in the region since the middle of the 20th century.

Between the Colonization Decree of 1949 and the first moratorium (*veda*) on new subsoil wells declared in 1951, the number of wells grew 50 percent, cultivated area grew 60 percent, and the volume of water extracted from the aquifers grew 70 percent. In 1951 the region's wells pumped 386,000 cubic meters ($m^3$) of water, exceeding the recharge rate for the first time. The *veda* was also the first of its kind in the state of Sonora, and would constitute one of the seven most important legal cases mentioned by Mexico's first National Subsoil Water Regulation, published in 1956.

Despite the restrictions called for by the 1951 *veda*, between that year and formal creation of the 051 Irrigation District in 1953 the number of wells increased from 308 to 409, cultivated area increased from 41,000 to 63,000 hectares, and the volume of water extracted rose from 386,000 to 767,000 $m^3$. By contrast, the limits of the irrigation district were expanded from 200,000 to 500,000 hectares. With the creation of the irrigation district another set of measures designed to limit water use was adopted, yet at the same time the surface area of the irrigation district was expanded even further, to 630,000 hectares. In 1954 the surface area governed by the 1951 *veda* was increased to include the entire 051 Irrigation District. This "second *veda*" was based on the recognition that in order to protect the existing wells and their aquifers, new wells had to be restricted in the entire region that depended on the aquifers, including the urban areas of Hermosillo. Regardless of the declared intention of restricting subsoil water use, between 1953 and 1955 the number of wells increased from 409 to 473, a total that has remained more or less steady until the present day. By 1963 the amount of water extracted from the aquifer had risen to almost 1,000,000 $m^3$, which resulted in an abatement of the water level in the aquifer to 20 meters below sea level, and a serious problem of seawater intrusion (figure 3).



Fuente: Elaboración del autor.

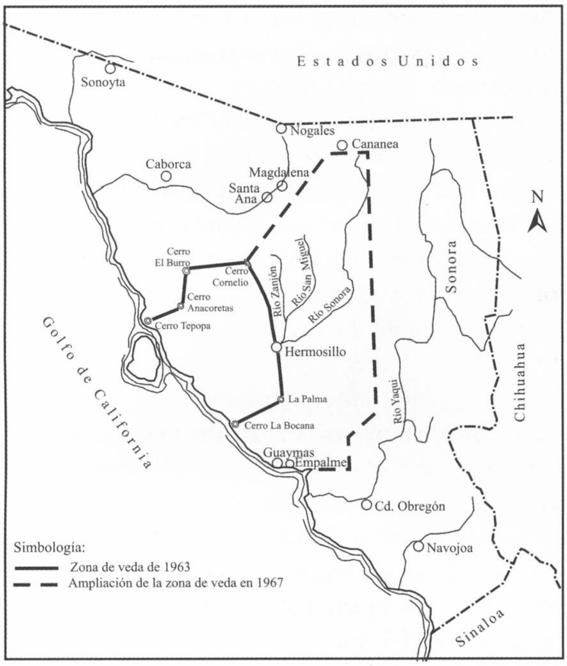
*Figure 3. Areas under the groundwater pumping bans: 1951, 1954, and 1963.*

The dynamic of expansion of water and land use together with unenforced limits placed on this expansion was clearly linked to the production of high-value crops. Wheat and cotton accounted for 95 percent of the surface area cultivated annually. Wheat production increased steadily, while the production figures for cotton responded to varying climatic conditions and to those of the international market. The 051 Irrigation District provided 23 percent of the nation's area dedicated to wheat, and 2 percent of that planted in cotton. These figures exceeded those of regions with more streamflow, such as the Mayo River Valley and San Luis Rio Colorado, in the Colorado River delta, which highlights the importance of subsoil water.

Hewitt (1978) shows how the expansion of commercial agriculture and increased crop yields were enabled by the generalization of a green revolution technological "packet" that included seeds, agrochemicals, and new cultivation practices that included water use. Newly built infrastructures such as roads and electricity cut costs of transportation and pumping. These changes are also reflected in trade statistics: While in 1940 to 1955 Mexico imported about 200,000 to 300,000 tons of wheat annually, between 1955 and 1959 this number fell to 25,000, and in 1964 to 1965 600,000 tons of surplus wheat were actually exported. Cotton production also soared, especially around 1950, when the Korean War drove prices for the fiber up. High prices enabled farmers to afford the subsoil water and green revolution technology needed to turn thousands of hectares of the Sonoran Desert into cotton fields in places such as Guaymas and Caborca (Dunbier 1968). Despite the importance of scientific and technological advances to this growth in commercial agriculture, there was at the time still almost no information concerning aquifers in Mexico.

## Regulation of Water Extraction

In the 1963–1964 period three important events happened. The first was the publication of a regulatory framework that decreed the reduction of subsoil water extraction by deep wells, formally ending the 20-year "free pumping" period. Second, the surface area of the 051 Irrigation District was expanded, bringing with it an expansion of the surface area covered by the second *veda* to include unregulated well fields. This was known as the third *veda*. However, the ineffectiveness of these measures




Fuente: Larios (1968).

*Figure 4. Area under groundwater pumping ban: 1967.*

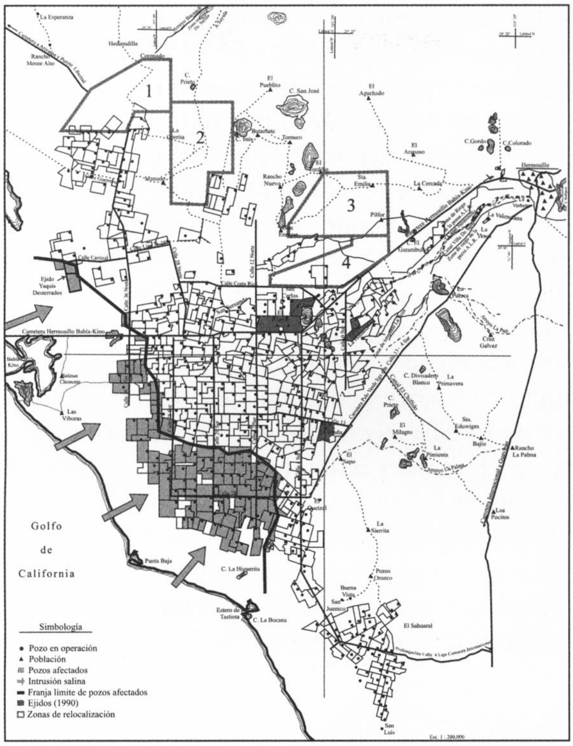
was made clear by the third event, for in the same years subsoil water was pumped from the aquifer at a historic high—1,136,000 $m^3$. During this and the following agricultural cycles, cultivated area in the irrigation district reached historic highs of around 85,000 hectares, stimulated by tax reductions and a special plan by the Secretary of Hydraulic Resources to save the faltering cotton industry by actually *increasing* water allocations for the crop, despite the limits established at the same time by the new regulatory framework and the third *veda*. The various measures adopted around 1963 were formalized in the Operational Rules of the 051 Irrigation District, published in late 1966. Contained within these rules were stipulations concerning water use that selectively and discretionally favored some producers—property owners—over others. This was to be the document that governed water use until 1993.

In mid-1967 a fourth veda was declared in the Hermosillo Coast Irrigation District (figure 4). This was another geographical extension of the previous moratoriums so that it would encompass almost all of the watersheds of the Sonora and Bacoachi Rivers, an area almost six times larger than that covered by the veda of 1951. At the time of the fourth veda, more than 20 years of intensive subsoil water use on the Hermosillo Coast had turned that corner of the Sonoran Desert into an agricultural emporium. In fact, the 051 Irrigation District comprised 53 percent of the Sonoran Desert converted to that use in Mexico, and 22 percent of that found in the greater binational region. The negative impacts of this growth on the region's aquifers were now clearly visible. The water table had fallen to 30 meters below sea level, and all the wells near the Gulf of Mexico were contaminated with salt water.

## Studies of the Aquifer

With the exception of the early study made by De la O Carreño (1960), which put the recharge rate at 324,000 $m^3$, estimates of the recharge rate of the aquifer declined steadily over the years. In 1968 Ariel Construction Company completed a detailed study of subsoil resources in the Coast of Hermosillo region that confirmed a 1967 estimate of a recharge rate of 350,000 $m^3$. This number continues to be the one accepted by the government agencies charged with regulating water use. A more important aspect of this 1968 study was the discovery of a second aquifer underlying the first. Farmers who had been told between 1964 and 1968 to reduce their water use by 24 percent greeted the new water source with euphoria. José Hernández Terán, the Secretary of Hydraulic Resources, told the press that this discovery, along with similar discoveries in Caborca and Guaymas, signaled the end of the "moratorium on drilling new wells across much of Sonora" (*El Imparcial*, April 9, 1968).

Nevertheless, the 1968 study pointed out that the only solution to the problem of salinity in the groundwater was to reduce extraction to the recharge rate of 350,000 $m^3$, which meant a 75 percent reduction in the number of wells every four years. While in 1960 De la O Carreño warned of the immanent salinization of the groundwater through overextraction, the problem gained recognition a decade later with the 1968 study and another conducted by Leopoldo Castillo (1971). According to Jiménez (1971), 32 percent of the wells sampled along the coast extracted "useless or doubtful" water, and 85 percent were "high" or "very high" in salts. No well was recorded to have "very good" water. The proposed solution was to relocate these wells farther from




Fuente: Elaboración del autor.

*Figure 5. Volume of water extraction at the Hermosillo Coast (upper line) and the 1968 accepted recharge rate of the aquifer (lower line), in 1,000s of m*$^3$.

the coast. Special mention must be made of the study carried out by Matlock, Fogel, and Busch (1966), because it is the only one at the time that attempted an estimate of the total quantity of water available in the Hermosillo Coast aquifer (100,000 m$^3$), and because it was commissioned by the AOANS, the region's most important farmer organization, founded in 1963. It was carried out by a consulting group from the United States, and a principal conclusion of the study was that the aquifer could be used for 100 years if saltwater intrusion was limited.

By the end of the 1960s, then, three important aspects of the groundwater were understood. First, the recharge rate was finally confirmed to be around 350,000 m$^3$, many years after the first well was drilled and a whole series of legal and political measures were adopted to regulate subsoil water use. The second important piece of information about subsoil water was the existence of a second, deeper aquifer. As a result of this knowledge, between 1968 and 1977 the extractions of water increased once again, to a yearly volume of between 800,000 and 900,000 $m^3$ (figure 5). The third aspect of subsoil water that was commonly recognized was that salt water had intruded into the aquifer in a wide strip of land along the Gulf of California, and that this was the principal problem facing agriculture in the region. Future efforts to limit groundwater use would be directed at halting or mediating saline intrusion by balancing extraction and recharge along the coast, rather than the conservation of the aquifer throughout the region.

Despite the warning of saline intrusion, the subsoil resources of the region continued to be viewed as limitless, especially considering the newfound existence of a second aquifer. The studies made at this time were cited by both farmers asking for greater extractions of water and the state authorities who approved them. Even without official approval, and even while recognizing problems associated with overextraction, increased water extraction proceeded apace, supported by the popular conception, expressed repeatedly in interviews conducted with farmers in the region, that the aquifer formed a "never-ending source of water."

## Programs to Reduce the Extraction of Subsoil Water

On October 6, 1977, the Leadership Council of the Coast of Hermosillo Irrigation District approved an important plan, the goal of which was a 50 percent reduction in subsoil water extractions over the following 13 years. According to this plan, water extraction would be reduced to 402,000 $m^3$ by the 1989–1990 agricultural cycle, and surface area cultivated would also be halved. During the first five years of the plan only a 5 percent reduction was achieved, but by the 1982–1983 cycle water use fell to 638,000 $m^3$. Thirsty perennial crops (grapes, citrus, pecans) replaced cotton, spelling trouble for plans to reduce water extraction by phasing out the cultivation of the equally thirsty fiber.

While government-led plans usually did not have a great effect, in 1981 and 1982 an economic crisis rocked Mexico, resulting in the reduction of subsidies to electricity used to power water pumps. Water use dropped as higher costs forced farmers to take land out of production or switch to dryland agriculture. In 1987 and 1988 water use again dropped as low wheat prices forced another reduction in lands irrigated. The reduction plan concluded in 1989–1990 without having reached its objective: Water extraction was at 448,000 $m^3$, not the 402,000 $m^3$ proposed 13 years earlier. Even with the reductions that were achieved, extraction was far superior to recharge, and aquifer abatement continued, now at 1 meter per year rather than 2 meters per year. It was not until 2000 that extraction was balanced with recharge at 350,000 $m^3$, and by that time the water level was 60 meters below sea level and salt water had invaded 10 to 15 kilometers inland from the Gulf of California (Comisión Nacional del Agua 1999).

In early 1980 another important decree was published which ratified the reduction plan initiated in 1977 and mandated the rehabilitation of the irrigation district through the relocation of salty wells. A series of obstacles prevented the plan from reaching a successful conclusion. First, the relocation of wells was to affect *colonos* much more than wealthier private property owners, and the *colonos* protested loudly that they would have to abandon the infrastructure they had built. The second obstacle was the opposition raised by the ranchers whose lands were to be expropriated in order to accommodate the relocated farmers. A third and decisive obstacle arose from the economic crisis of 1981, which made the relocation of 105 deep wells prohibitively expensive. By 1990 only 32 wells had been relocated (Comisión Nacional del Agua 1994). While *colonos* may have resisted relocation, the fact that they were not relocated resulted in their suffering from productive and economic problems related to water salinity.

Social stratification together with land and water concentration, present at the creation of the irrigation district, continued to characterize the region. According to Martínez (1998), this was an unequal process of accumulation that favored the private sector over the social (*ejido* and *colonia*) sector, and was accompanied by an increase in the importance of the government apparatus. Water in particular fell under the control of a few powerful families. A comparison of the lists of water users from 1958 and 1972 shows that while in the first year six families (Ciscomani, Valenzuela, Peralta, Mazón, Tapia, and Astiazarán) possessed a total of 45 wells, 14 years later they increased this number to 75 wells. By expanding the list, we see that in 1972, 49 families controlled 52 percent of the wells in the region. Data from 1991 show that, in general, private property owners who constituted 58 percent of the users controlled 75 percent of the wells and 70 percent of the volume extracted. In reality, the property owners control much more land and water through rental and sale agreements with small social-sector farmers unable or unwilling to continue producing.

## Transferring the Irrigation District to Water Users

The new National Water Law (*Ley Nacional de Aguas*) of 1992 marked the biggest change in the legal framework governing land and water since the 1980 decree. Particularly important was the transfer of the irrigation districts, which shifted the responsibility for the "operation, conservation and maintenance of hydraulic works" from the federal water bureaucracy to the users themselves, who in turn were expected to be "financially autonomous and administratively independent" (Comisión Nacional del Agua 1994).

The transfer of the irrigation districts to the users presented a number of new challenges and problems. To begin with, the concession given by the National Water Commission (CNA for its Spanish initials) to the association of users was for 409,000 $m^3$, which was to be gradually reduced to the 350,000 $m^3$ recharge rate. However, no operational regulations have been written or ratified to achieve this goal. A second problem is that according to data on piezometric levels gathered in the wells, water extraction in the region is actually double that of the official figures—some 650,000 $m^3$ a year—which signals a high level of corruption in the district (José Arreguín, interview with the author, 1999). A third problem is the unwillingness of the users themselves to abide by plans to reduce subsoil water use. Among the arguments they mention are: (a) There is no current and trustworthy study of recharge rates; (b) such a reduction can only be achieved through a presidential decree; (c) the users must agree to it by consensus; and (d) the CNA has approved of water uses upstream that negatively affect the aquifer. The proliferation of upstream water uses is a particularly important issue, for it shows, first, that there is little enforcement of existing regulations such as the *vedas* that prohibit new wells throughout much of Sonora and, second, that much of the upstream areas are not regulated and operate according to the old concept of "free pumping."

The transfer of the irrigation districts was expected to reduce distortions in the agricultural economy by making each district financially self-sufficient, and thus promote efficiency. However, subsidies, particularly subsidies for electricity, have not been eliminated and continue to contribute to a serious undervaluation of water and subsequently the easy overextraction of the aquifer (Téllez 1994). At the same time, a surging world market for high-value crops such as table grapes induced even more aquifer depletion. By the end of the 1990s Sonora produced 62 percent of industrial grapes (used in wine, alcohol, vinegar) in Mexico, 70 percent of table grapes, and 90 percent of raisins. Sonora was also the fifth-most-important producer of oranges. All this fruit was irrigated with water from aquifers.

## Water for the City

By the end of the 20th century the two major hydraulic systems in the lower Sonora River—the Abelardo Rodríguez Dam and the deep wells of the Hermosillo Coast—showed unmistakable symptoms of decline. In 1999, for the first time in history, the dam's reservoir dried up when it did not receive enough stream water, and the well field of the coast was proposed as the source for Hermosillo's urban and domestic water needs. This solution became even easier to consider due to the establishment in 1992 of a legal framework in Mexico for the sale and rent of water rights. Sale of water to the city looked increasingly attractive to agricultural producers suffering through chronic difficulties. For the city, it would be much less costly to bring water from the Hermosillo Coast than from distant dams on the Yaqui River.

Opposition to the plan was raised by the Users Association of the 051 Irrigation District, who complained that taking their water would have an enormous economic and social impact on the region. They added that a comprehensive plan for the management of water resources throughout the watershed was needed, rather than an easy fix through the appropriation of the subsoil water of the Hermosillo Coast. Nevertheless, on May 19, 2005, the Users Association unanimously approved a plan to sell 20,000 $m^3$ of aquifer water to the city of Hermosillo. The agreement stipulates that for every two wells the city purchases it acquires the right to shut down a third well, thus also helping reduce overuse of the aquifer.

## Recent Studies (2000–2005)

As debate raged concerning the best way to provide water for the city of Hermosillo, scientists returned to the geohydrological issues surrounding subsoil water. Samani (2000) estimated that the Coast of Hermosillo aquifer recharged at only 160,000 $m^3$, including both fresh and salt water. Rangel-Medina (2000) showed that what had been thought of as two distinct aquifers was really one that had two semiconfined areas within. This meant that farmers, pumping water from deep levels to avoid draining what they thought was a distinct upper aquifer, had indeed been extracting indirectly from the unified aquifer by removing ancient "trapped" water from the lower portion.

The CNA commissioned a new definitive study of the recharge rate of the aquifer of the Coast of Hermosillo, for which the 1968 estimate of 350,000 $m^3$ per year was still the accepted number. The results of the study were clear: The annual recharge was only 250,000 $m^3$, of which almost 100,000 $m^3$ were salt water intruding from the Gulf of California (Monreal et al. 2002). In effect, the recharge rate of fresh water to the aquifer was found to be less than half of the amount that had guided water extraction since 1968. At the same time, satellite images were used by researchers to estimate the true levels of water extraction in the region. While the irrigation district claimed that 400,000 $m^3$ were taken each year, Palacios (1999) argued that this figure was more likely to oscillate between 500,000 and 600,000 $m^3$. This new information helped explain why the area of the aquifer contaminated by saltwater intrusion had reached 17 kilometers inland in a 65-kilometer stretch along the coast (Castillo 2000).

The concentration of land and water in few hands, present since the birth of the irrigation district, continued to increase in recent years. A 2002 study of fruit production made by Martínez and Reed showed that only 16 families controlled 30 percent of the surface area planted in crops such as table grapes, industrial grapes, citrus, and pecans. The comparison of data from 1993 and 2003 shows that water has also accumulated in the hands of fewer producers. The number of private property owners fell in those ten years from 1,331 to 1,060, at the same time that the volume of water they received rose from 69 percent to 81 percent of the total. The share of well water received by small *ejidatarios* fell from 4 percent to 1 percent, and that of *colonos* from 26 percent to 16 percent.

## Conclusions and Recommendations

The research presented here indicates that sustainability on the Hermosillo Coast is a still-distant goal. Basic information concerning the dynamics of the aquifer is lacking, as are reliable data on all the hydrological variables that come together to determine the availability of water in the Sonora and Bacoachi river basins. We still know little about saline intrusion and processes related to the management and use of water in the upper river basins. Balancing extraction with recharge is not enough to ensure sustainability. Without measures to ensure equitable distribution of water, such as consensus-based decision making and equitable state spending, there is risk that the discourse of sustainability will be used as a mechanism for the exclusion of disadvantaged social groups, the destruction of the environment, and the continued concentration of land, water, and the benefits of development among the local elite.

There is, furthermore, a real need to reconceptualize the idea of natural resources. As of now, farmers, politicians, and the region's public consider the "extractable reserves" held by the aquifer to stand at 30,000 $m^3$ and that the "mining" of the resource can continue at the current rate for another 70 years. The magnitude of these numbers and the expectations generated by them explain to a degree the failure to preserve the aquifer and secure a long-term sustainable use of the resource. Instead, technological innovations such as desalinization and the purchase of water rights by the urban areas are considered the means by which to solve what is a fundamentally social and political problem: namely, the overdraw of aquifer water. Changing the cultural attitudes and behaviors is rarely seen as important. "Water scarcity," held by most people to be a natural phenomenon with a technological solution, is really a social and cultural issue: There is water, but it is overconcessioned, badly managed, contaminated, and poorly regulated. "Scarcity" thus becomes a concept that justifies measures that reproduce social inequality and environmental degradation. What is required to begin dealing in a serious way with environmental problems in the region is a vision that contemplates a regime of water use that is compatible with natural reproductive cycles, and whose benefits are distributed more equally among the greatest number of people.

Currently there are various efforts to remedy the situation. The creation of River Basin Councils (*Consejos de Cuenca*) and Subsoil Water Technical Committees (*Comités Técnicos de Aguas Subterráneas*), postulated by the National Water Law of 1992 as a way to improve the political management, use, and administration of the resource, has also failed to produce the desired results. The Sonora River Basin Council was created in 1999 with representatives from the different stakeholders in the resource, but has shown few advances. The Hermosillo Coast Subsoil Water Technical Council, a similar grouping of stakeholders, has not yet been constituted, despite the fact that sixty of Mexico's aquifers have such organizations, and three of these are located in the middle portion of the Sonora River.

Regulated water markets have also been proposed as a mechanism to make the management of the resource more efficient and transparent. Such a market could be constituted in the form of a trust (*fideicomiso*) that involved key actors such as the Federal Electricity Commission and the Secretary of Agriculture, or a "water bank" that managed the transactions of water. These institutions could reorient and restructure subsidies and prices to achieve a more sustainable use of the aquifer, as well as generate and disseminate information about the quality and availability of water and the environmental problems associated with its irrational use.

Another suggestion is to reduce the volume of water apportioned to agricultural users, through mechanisms such as penalties to users who extract amounts of water that are not justified in terms of profitability, support to users who wish to change to more profitable (and less water-intensive) crops and technology in exchange for cession of part of their assigned water, and the cancellation of concessions to those users who repeatedly fail to comply with the management plans and laws. Such a "rescue" of water rights, including the cancellation and sealing of deep wells to preserve the aquifer, has been carried out in the area of Caborca, Sonora.

A complementary action would be to promote the efficient use of water through infrastructural modernization, including improvements in distribution networks, measurement technology, and plants for treating and reusing residual water, as well as innovative projects involving rainwater capture and aquifer recharge. Permanent programs to promote a "water culture" through environmental education are indispensable. All of these recommendations can only be carried out through the involvement of the greatest number of stakeholders possible. This is no longer a problem that can be solved among a small group of producers and federal officials, but must also include state and municipal authorities and a wide range of users from within the region as well as other agricultural regions upstream, and of course those from the urban area of Hermosillo. Greater social participation should be supported through existing institutions such as the River Basin Councils and Subsoil Water Technical Committees, as well as councils associated with municipal and state-level water service providers. ✥

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