# IV

## Lining the All-American Canal: Its Impact on Aquifer Water Quality and Crop Yield in Mexicali Valley

*Gerardo García Saillé, Ángel López López, and*

*J. A. Navarro Urbina*

### INTRODUCTION

One of the main problems facing irrigated, arid areas is the availability of water for crops, and high salinity in the supply that is available aggravates this problem. The Mexicali Valley has two water sources to serve domestic, urban, industrial, and agricultural users in Baja California and part of Sonora, the greatest volume of which comes from the United States, whose source is the runoff into the Colorado River watershed.

The 1944 Water Treaty allocates 1.5 million acre-feet (AF) (1.85 billion cubic meters [$m^3$]) of water per year to Mexico. In addition, it takes 567,500 AF per year [AF/y] (700 million $m^3$) from an aquifer for irrigation and 159,711 AF/y (197 million $m^3$) for urban and industrial uses in the border cities of San Luis Río Colorado, Mexicali, Tecate, Tijuana, and Ensenada, as well as the rural population of the Mexicali Valley. The salinity from these sources has increased over time. Surface waters delivered to Mexico have steadily deteriorated, as suggested in studies by Comisión Nacional del Agua (CNA, in English National Water Commission), Universidad Autónoma de Baja California, and El Colegio de la Frontera Norte (COLEF).

Annual recharge of groundwater totals 567,500 AF. Of this volume, 81,000 AF seeps from the unlined All-American Canal (AAC). Some 16,216 AF of this is captured by the surface drainage system and is currently used in the irrigation of approximately 1,000 hectares (ha) (2,471 acres) of farmland. The remaining 74,864 AF are a recharge source for the aquifer.

The recharge from the AAC, in addition to being 14% of the volume extracted from the aquifer for irrigation, helps dilute the soluble salts in the aquifer. Approximately 70% of the recharge comes from over-irrigation (additional water applied to soil to avoid the accumulation of dissolved salts from the irrigation water itself) of Mexicali Valley crops with high-salinity water. The actual average of soluble salts in the aquifer is 1.8 grams per liter (g/L), and this increases by 20.6 milligrams per liter per year (mg/L/y). In contrast, the water incorporated into the aquifer from the AAC has a soluble salt concentration of 0.85 g/L and much lower annual increases than those in the Mexicali Valley aquifer.

The anticipated lining of the AAC will likely have two effects:

- A 14% reduction of the total available water in the Mexicali Valley, and a commensurate lowering of the static level
- An increase in the concentration of dissolved salts in the aquifer

Under these conditions, production of crops intolerant of salt will decrease, salts will accumulate in the soil, and a commensurate loss of productivity will result. Thus, growers will be forced to use more expensive technology or greater volumes of water to maintain production levels, either of which would result in a reduction of income per surface unit. Therefore, it is important to perform a quantitative and qualitative evaluation of the impact of lining the AAC on the water quality of the Mexicali Valley aquifer, the impact of this deterioration on crop production, and the loss of soil productivity due to its progressive salinization.

# BACKGROUND

In irrigated, arid areas, two of the main problems facing agricultural production are the availability and quality of water. The Mexicali Valley, located in the northwest corner of the country, is no exception. Agriculture has developed here only because of water from the Colorado River, although this has been controlled by a system of dams in the United States. The water treaty negotiated between the United States and Mexico in 1944 allocated to Mexico an annual volume of 1.5 million AF (1.85 billion $m^3$) from the Colorado River.

Various geohydrological studies have been carried out in this aquifer and suggest a median annual recharge of 567,500 AF/y, of which 405,403 AF are a result of over-irrigation during the crop-planting and harvesting process. Some 162,161 AF come from the periphery of the Mexicali Valley, 81,080 AF of this originates in the AAC at the northeast end of the valley.

The United States government intends to line the AAC with concrete to increase its conveyance efficiency and recover the volume lost to seepage in an approximately 53 kilometer (km) stretch starting at Pilot Knob. This chapter presents a general overview of the negative effects of this project on agricultural production.

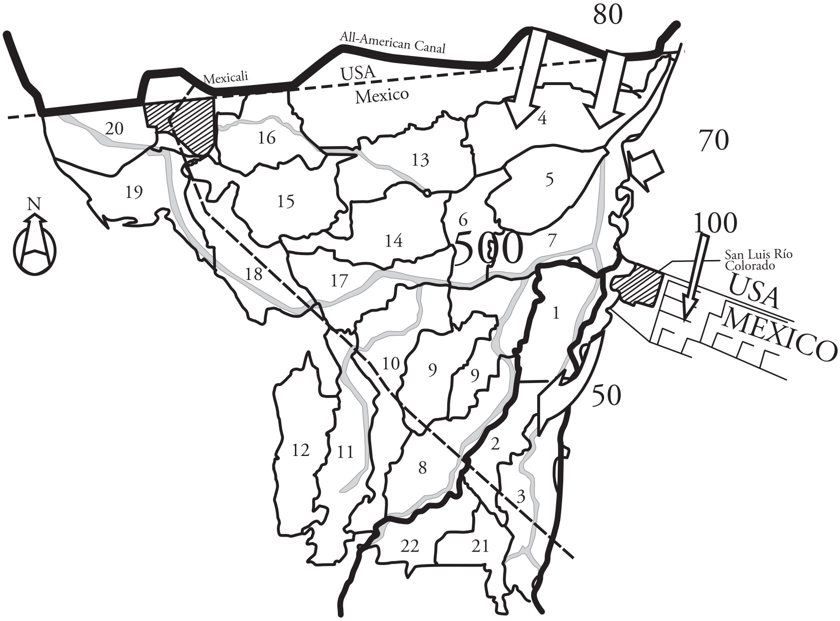
The salt accumulation in the soil and the ensuing effect on crop yield are influenced not only by the volume and quality of irrigation water, but by weather, ground formation processes, stratification, and management, among other factors. These factors working alone or together could accelerate the loss of productive agricultural capacity. The following section describes the characteristics of the area where the most severe affects will occur as a result of reduced aquifer volume stemming from lining the AAC.

# AREA CHARACTERISTICS

## *Geographic Location of the Area*

The area expected to be most affected is the northeast section of the Mexicali Valley in the so-called first irrigation unit. It is physically occupied by irrigation modules 5 and 6 and bordered in the north by Mesa de Andrade, in the south by Federal Highway 2, in the east by the Colorado River, and in the west the agricultural area of irrigation module 13, which is incorporated into irrigation module 16. The largest towns located within this area are Vicente Guerrero, Los Algodones, and Ciudad Morelos "Cuervos." The Mesa Drain is located between the Mesa de Andrade and the agricultural area. The drain directly captures a significant proportion of the volume that seeps from the AAC, estimated at nearly 20,270 AF/y (Figure 1).

Figure 1. Location of the Possibly Affected Area in Irrigation District 014, Colorado River



## *Topography*

This area is nearly flat, with slight undulations and slopes of 2 centimeters (cm) to 3 cm per thousand centimeters with a generally northeast-southwest orientation. Maximum altitudes are approximately 40 m above sea level in the vicinity of Ejido Culiacán and minimum altitudes are 22 m above sea level in the western part near irrigation module 13. In the north-south orientation, altitudes measure between 32 m and 22 m above sea level.

## *Climate*

The area's climate, according to the criteria established by García (1980), is classified as very dry and hot, with a median annual temperature of 22.3°C and extreme minimum temperatures of -7.7°C. Median annual precipitation measures 57 millimeters (mm) and potential evaporation is 247 cm. Under these conditions, salt accumulation processes in the soil are commonly present in the absence of irrigation, which is why permanent irrigation agriculture must be practiced.

## *Soil*

The distribution of the different types of soil in the region, according to their mechanical composition, is presented in Table 1. Considering the characteristics of the series of soils, and grouping them according to similar characteristics in terms of ease of water handling and movement through them, it is clear that coarse soils occupy a surface area of 10,671.0 hectares (ha) (26,368.73 acres), sandy textures occupy a surface area of 7,468.6 ha (18,455.40 acres), and those with a clay texture 138.9 ha (343.27 acres). Coarse, sandy soil texture occupies 98.47% of the region's surface, which is an advantage for agricultural practices and the adequate development of crops. More than 95% of the soil is classified agriculturally as first- or second-class.

## Table 1. Soil Distribution by Textures in the Affected Area

| Series | Texture | Surface (hectares) | % |
|---|---|---:|---:|
| Gila light hase | Sandy loam | 5,554.87 | 30.39 |
| Gila heavy hase | Clay-lime loam | 12,444.07 | 68.08 |
| Imperial | Clay-lime loam | 89.57 | 0.49 |
| Holtville | Clayey loam | 194.14 | 1.04 |
| Total |  | 18,262.65 | 100.00 |

## *Soil Salinity*

Table 2 shows the soil classification distribution in terms of salinity and sodium parameters as outlined in a study of soil salinity carried out in 1995 by the office of Ingeniería de Riego y Drenaje (Irrigation and Drainage Engineering) of CNA. The table shows that soil salinity is not currently a serious problem for the development of agriculture in the area because just slightly more than 5% of the physical surface area with irrigation rights—some 1,007 ha (2,488 acres)—has moderately soluble salt accumulation problems. This contrasts with the general salinity conditions in the irrigation district soils that present soluble salt accumulation problems—nearly 50% of these soils range from slight to severe.

## *Water Availability*

In the affected area, the main source of irrigation water is the aquifer. The non-profit Asociaciones Civiles, made up of the local irrigation modules, has the permission of the federal government to use 155,494 AF/y on a surface of 18,278.6 ha (45,167.41 acres). The irrigated area that uses gravity to bring water from the Morelos Dam is 277.9 ha (686.94 acres) and has an allocation of 2,792.42 AF. This provides a total surface area of 18,556.6 ha (45,854.35 acres) with an allocated volume of 158,286 AF/y, which means more than 98% of the water used in crop irrigation in the area comes from the aquifer. And in this area, seepage from the AAC is the most important contribution to the recharge of the aquifer.

## Table 2. Surface Soil Classification in the Areas Affected by Salt Accumulations

| Classification | Parameters | | Surface | |
|---|---|---|---|---|
| | Electrical Conductivity | Percentage of Interchangeable Sodium | Hectares | % |
| 1st Class | 0-4 | 0-15 | 13,120.39 | 71.78 |
| 2nd Class | 4-8 | 15-20 | 4,151.07 | 22.71 |
| 3rd Class | 8-12 | 20-30 | 740.28 | 4.05 |
| 4th Class | 12-20 | 30-40 | 266.86 | 1.46 |
| Total | | | 18,278.60 | 100.00 |

## *Current Irrigation Water Use*

During the last few years the types of irrigated crops in the area have not varied, with the exception of the sesame seed crop, which was wiped out by a white fly infestation. In general, the crop surface tends to contract by always remaining above allocated rights. Table 3 shows the pattern of planted surfaces in the area from 1997 to date and Table 4 shows the gross water volumes (the total water extracted from the aquifer) per crop.

The information in Tables 3 and 4 establishes that the planted surface in the area has been greater than the surface with assigned irrigation rights and that the volumes used surpass the volumes assigned to the Asociaciones Civiles. This is due partly to the use of excess volumes for double crop planting, as well as to the acquisition of volumes from other *asociaciones* through irrigation permit transfers.

## *Evolution of Irrigation Water Quality*

To evaluate the quality and degree of annual use of the aquifer, in the month of February wells are shut down for three days. Officials take readings on the third day for the static level of the aquifer and take samples for analysis of soluble salts and other parameters of agricultural importance, such as pH and electrical conductivity

## Table 3. Planted Surface Pattern by Crop in the Area (acres)

| Crop by Seasonal Type | 1997-1998 | 1998-1999 | 1999-2000 | 2000-2001 |
|---|---:|---:|---:|---:|
| Fall-Winter | | | | |
| Safflower | 54.73 | 2,007.96 | 398.11 | 0 |
| Barley | 80.67 | 3.24 | 31.62 | 0 |
| Green onion | 2085.47 | 2,359.52 | 1,206.48 | 880.54 |
| Rye-grass | 298.78 | 330.81 | 143.51 | 250.54 |
| Wheat | 62,965.77 | 52,128.28 | 85,900.07 | 67,060.18 |
| Various winter | 6,108.13 | 10,985.45 | 4,085.65 | 3,548.08 |
| Subtotal | 71,593.64 | 67,813.66 | 93,387.06 | 71,739.34 |
| Spring-Summer | | | | |
| Cotton | 152,566.44 | 95,954.07 | 48,996.23 | 71,320.15 |
| Sorghum early grain | 31.62 | 1,696.29 | 780.81 | 114.31 |
| Sorghum late grain | 413.02 | 1,362.23 | 977.83 | 510.81 |
| Sorghum early forage | 1,363.78 | 3,527.49 | 5,115.38 | 2,571.87 |
| Sorghum late forage | 430.29 | 379.46 | 44.59 | 32.43 |
| Early corn | 168.97 | 466.29 | 2,139.73 | 676.21 |
| Late corn | 312.89 | 540.08 | 1,261.62 | 488.92 |
| Various summer | 129.73 | 690.16 | 658.37 | 318.65 |
| Subtotal | 154,605.94 | 104,616.08 | 59,974.54 | 76309.05 |
| Perennials | | | | |
| Alfalfa | 42,298.23 | 36,535.99 | 26,145.26 | 25,696.08 |
| Asparagus | 8,607.12 | 8,961.84 | 9,827.78 | 9,917.78 |
| Vine | 1,678.61 | 1,118.91 | 1,065.40 | 745.13 |
| Fruitages | 639.65 | 414.48 | 377.84 | 287.84 |
| Bermuda | 0 | 0 | 0 | 0 |
| Other perennials | 0 | 0 | 0 | 0 |
| Subtotal | 53,223.61 | 47,031.22 | 37416.28 | 36,646.83 |

## Table 3. continued

| Crop by Seasonal Type | 1997-1998 | 1998-1999 | 1999-2000 | 2000-2001 |
|---|---:|---:|---:|---:|
| 2nd Crops | | | | |
| Sorghum grain | 2,288.18 | 1,955.26 | 1,372.69 | 747.56 |
| Sorghum forage | 0 | 0 | 128.11 | 101.35 |
| Corn | 779.42 | 785.75 | 653.51 | 349.46 |
| Various | 184.22 | 41.35 | 9.73 | 0 |
| Subtotal | 3,251.82 | 2,782.36 | 2,164.04 | 1,198.37 |
| Total | 282,675.01 | 222,243.34 | 235,963 | 185,893.59 |

(EC). Some investigators, such as López L. (1991), using the information generated by CNA from these samplings as a baseline, have analyzed the behavior of soluble salt concentrations in the Mexicali Valley aquifer over time and distance. Among other things, these studies have determined that for each year of aquifer use, there is an average increase of soluble salts in the irrigation water of 21.8 mg/L. The foregoing is similar to the findings of a 1994 CNA study evaluating the years from 1961 to 1992; the study developed the following model:

$Y = 1,130 + 20.623\ (X)$

$R^2 = 0.993$

where,

Y = Concentration of soluble salts expected in the aquifer

X = Years, starting in 1961

$R^2$ = Determination coefficient

## Table 4. Volumes Used by Crop in the Affected Area (acre/feet)

| Crop | 1997-1998 | 1998-1999 | 1999-2000 | 2000-2001 |
|---|---|---|---|---|
| Fall-Winter | | | | |
| Safflower | 54.73 | 2,007.96 | 398.11 | 0 |
| Barley | 80.67 | 3.24 | 31.62 | 0 |
| Green onion | 2085.47 | 2,359.52 | 1,206.48 | 880.54 |
| Rye-grass | 298.78 | 330.81 | 143.51 | 250.54 |
| Wheat | 62,965.77 | 52,128.28 | 85,900.07 | 67,060.18 |
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| Cotton | 152,566.44 | 95,954.07 | 48,996.23 | 71,320.15 |
| Sorghum early grain | 31.62 | 1,696.29 | 780.81 | 114.31 |
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| Sorghum early forage | 1,363.78 | 3,527.49 | 5,115.38 | 2,571.87 |
| Sorghum late forage | 430.29 | 379.46 | 44.59 | 32.43 |
| Early corn | 168.97 | 466.29 | 2,139.73 | 676.21 |
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| Perennials | | | | |
| Alfalfa | 42,298.23 | 36,535.99 | 26,145.26 | 25,696.08 |
| Asparagus | 8,607.12 | 8,961.84 | 9,827.78 | 9,917.78 |
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| Fruitages | 639.65 | 414.48 | 377.84 | 287.84 |
| Bermuda | 0 | 0 | 0 | 0 |
| Other perennials | 0 | 0 | 0 | 0 |
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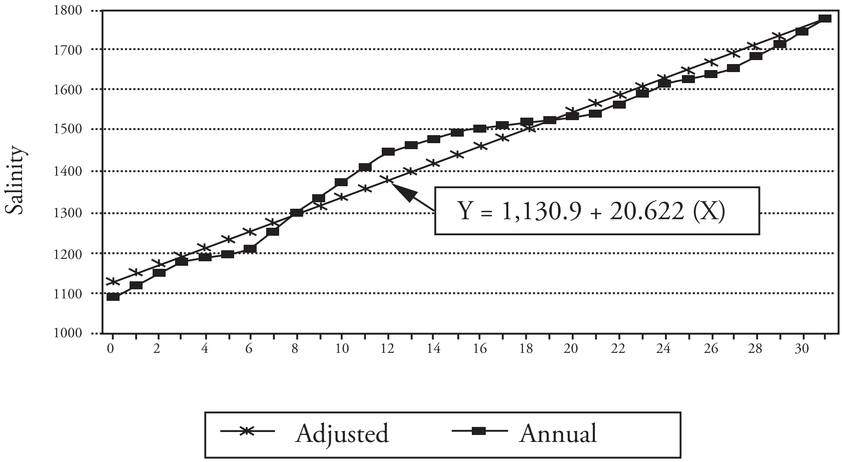
| Subtotal | 3,251.82 | 2,782.36 | 2,164.04 | 1,198.37 |
| Total | 282,675.01 | 222,243.34 | 235,963 | 185,893.59 |

Note: Data are from the agricultural statistics office of CNA's irrigation district 014.

Figure 2. Deterioration of Water Quality in Wells



In contrast, Navarro (1998) analyzed the evolution of soluble salt concentrations only for water extracted from wells in the affected area. Navarro used similar methodology as López L. and CNA and arrived at the following model for aquifer water quality evolution in the area:

$Y = 1{,}179.84 + 21.929\ (X)$

$R^2 = 0.981$

where,

$Y$ = Concentration of soluble salts expected in the aquifer

$X$ = Years, starting in 1962

$R^2$ = Determination coefficient

These studies are summarized in Table 5. Note that the three studies carried out differ by less than 2 mg/L/y in terms of variations in the increase in soluble salt concentrations in the aquifer under current operating conditions.

## Table 5. Relationship of Salt Increases Determined by Studies Conducted on the Aquifer

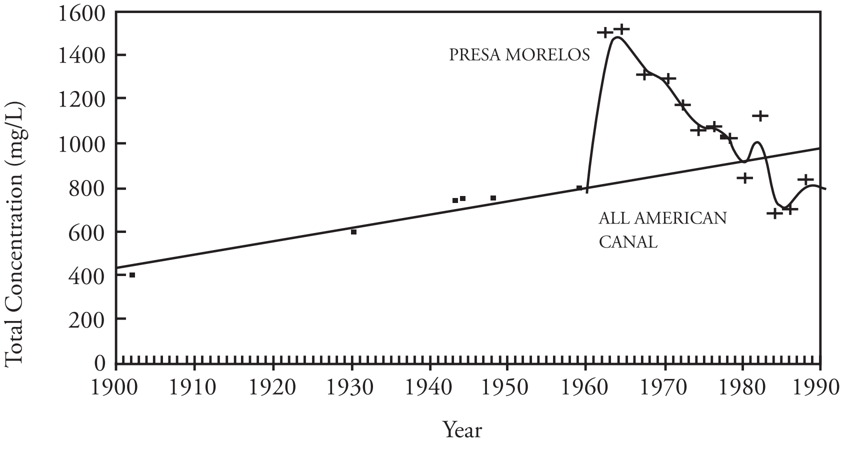
| Author | Year | Model | $R^2$ | Salt Increases (mg/y) |
|---|---|---|---|---|
| López | 1991 | No Model | - | 21.8 |
| CNA | 1994 | $Y = 1{,}130 + 20.623\ (X)$ | 0.993 | 20.623 |
| Navarro | 1998 | $Y = 1{,}179.84 + 21.929\ (X)$ | 0.981 | 21.929 |

The largest proportion of water entering the aquifer—405,400 AF/y—comes from over-irrigation, that is, additional water that must be applied to the soil to avoid the accumulation of dissolved salts in the irrigation water itself. Both CNA, through its Office of Irrigation and Drainage Engineering, and COLEF (Cervantes and Bernal 1990) have studied the evolution of Colorado River water quality entering Mexico via the Morelos Dam. Both determined that soluble salt concentrations have increased at a rate of approximately 6 mg/L/y since the turn of the 20th century. In other words, the concentration of soluble salts in Colorado River water has increased from just more than 400 mg/L at the turn of the century to more than 900 mg/L at present. This evolution is presented in Figure 3.

The marked differences from the early 1960s to the late 1970s are due to the fact that Welton-Mohawk Irrigation and Drainage District sewage was incorporated into the Colorado River current. This sewage brought with it dissolved salt concentrations of up to 15,000 mg/L. It was mixed into the river's water before its arrival at Morelos Dam, and despite dilution in the river current, salt concentrations in water delivered to Mexico in that period for crop irrigation in the Mexicali Valley reached 2,500 mg/L.

The problems generated by the incorporation of sewage with high concentrations of soluble salts during this period were partially solved by both the United States and Mexico signing the International Boundary and Water Commission's (IBWC) Minute 242, but this did not address the effects this crop irrigation water had on the soil of the Mexicali Valley. The quality analysis of the water conveyed in the AAC and the volumes delivered to Mexico from 1990 to date are shown in Table 6.

Figure 3. Evolutionary Trend of Water Quality in the Colorado River and the All-American Canal from 1900 to 1990



Source: Cervantes and Bernal 1990

### Table 6. Annual Average Concentration of Soluble Salts in Water Conveyed in the All-American Canal and Delivered to Mexico at Morelos Dam (mg/L)

| Year | Morelos Dam | All-American Canal | Difference |
|---|---|---|---|
| 1990 | 910 | 775 | 135 |
| 1991 | 931 | 802 | 129 |
| 1992 | 965 | 836 | 129 |
| 1993 | 834 | 821 | 13 |
| 1994 | 965 | 872 | 93 |
| 1995 | 978 | 862 | 116 |
| 1996 | 982 | 834 | 148 |
| 1997 | 870 | 778 | 92 |
| 1998 | 785 | 714 | 71 |
| 1999 | 840 | 734 | 106 |
| 2000 | 850 | 726 | 124 |
| 2001 | 921 | 760 | 161 |
| Averages | 902.58 | 792.83 | 109.74 |

Thus, it can be concluded that the seepage from the AAC into the Mexicali Valley aquifer, and particularly into the area affected by the lining, contributes to the dilution of soluble salts in the aquifer.

## *Effects of AAC Lining on Water Quality*

To generate a model that predicts future soluble salt concentrations in the Mexicali Valley aquifer, Navarro (1998) relies on the following assumptions:

- The Mexicali Valley aquifer has a total annual recharge of 567,500 AF/y, as determined in the Mexicali Valley geohydrologic study undertaken by the Secretaría de Recursos Hidráulicos (SRH, in English Secretariat of Hydraulic Resources) in 1972

- Of the total recharge volume, 64,860 AF/y is supplied by AAC seepage; this equals 31% of the total water used in the impact area, which has an allotted volume of 206,755 AF/y
- The remaining recharge in the area is composed of over-irrigation water, which totals 141,891 AF/y, or 69%, of the water used in this area
- The distribution of the 64,860 AF/y will be uniform in the affected area the first year after lining the canal, and the total aquifer recharge will be 503,000 AF/y

Given these considerations and performing the corresponding calculations, the anticipated concentrations of soluble salts in the aquifer were determined as shown in Table 7. This analysis establishes that, upon not receiving the 64,860 AF/y of seepage from the AAC, the concentration of soluble salts in the aquifer will increase from 1,879 mg/L to 2,004 mg/L, a difference of 125 mg/L, or more than five times what can be expected under current conditions. In subsequent years the concentration of soluble salts will increase by 23.5 mg/L.

### Table 7. Evolution of the Concentration of Soluble Salts in the Affected Area After Canal Lining for 1-, 6-, 10-, and 20-Year Periods

| Years After Lining | Model | Expected Concentration of Soluble Salts (mg/L) |
|---|---|---|
| 1 | C = 0.72 * 1873.29 + 0.28 * 2340.42 | 2,004 |
| 6 | C = 0.72 * 1976.40 + 0.28 * 2489.65 | 2,120 |
| 10 | C = 0.72 * 2058.89 + 0.28 * 2609.20 | 2,213 |
| 20 | C = 0.72 * 2265.11 + 0.28 * 2908.07 | 2,445 |

Source: Adapted from Navarro 1998

## EFFECT OF THE CHANGES IN WATER QUALITY ON CROP YIELD

The effect of salt concentrations on crops has been widely studied and described by many investigators, including Aceves 1979; Ayers and Westcott 1985; Fulton, Geattan, and Hanson 1993; U.S. Geological Survey 1985; Kaddah and Rhoades 1976; Kovda 1973; Mass and Hoffman 1976; Oster 1999; Rhoades 1990; Richards 1954; Shainberg and Oster 1978; and Wilcox and Durum 1974, among others. These teams investigated the relative tolerance of crops to soluble salt concentrations in irrigation water. At the same time, they have tried to relate the different levels of crop tolerance to crop yield under different salinity conditions and ionic ratios in the soil.

Investigations related to this same issue, but under local conditions, have been carried out by Cervantes 1983; Duarte, Rivera, and Russell 1987; Cisneros 1990; Cisneros 1993; Ruíz 1995; Palacios, Escamilla and Reyes 1978; García 1999; and Orozco 2001. These studies have demonstrated that a proportional response in yield reduction of different crop species exists when soluble salt concentrations in irrigation water occur.

Other authors have investigated the processes by which salts accumulate in the soil, including Jurinak and Suarez 1990, Kovda 1973 and 1980, Fetter 1988, Cervantes 1983, Svinarev and Bortsev 1962, Thornton 1981, Tanji 1990, Mendel and Shiftan 1981, and Voloubuyeb 1963. These projects establish methods that can be used to resolve salt accumulation problems in irrigated soil, in addition to the noted processes.

The impacts on water quality and availability in the Mexicali Valley as a consequence of the deterioration, both natural and induced, of aquifer water quality have been analyzed. Among these studies are Román 1991 and 1998, Cervantes and Bernal 1990, López 1991, CNA 1990 and 1995, and Navarro 1998. These analyze the impact of a degradation of surface and groundwater quality upon crop yield in the Mexicali Valley, whether by natural or induced causes.

Thus, to quantitatively evaluate the loss of this volume and the foreseeable increase in the concentration of soluble salts in the water, the decrease in crop yield in the area can be calculated by applying Mass and Hoffman's (1976) equations, which point out that salt tolerance is a relative value based on climactic and cultural conditions under which the crop is developed. Absolute tolerances that might predict the physiological responses inherent in the plants cannot be determined because there are many interactions between plants, soil, water, and environmental factors. These, in turn, influence the plants and their capacity to tolerate the presence of salts. The relative values that express the reduction in yield due to the effect of salts in the soil are described by the following equation:
$Y = 100 - B(CEe - A)$

where,
Y = Relative yield (%)
CEe = Average of soil salinity, expressed in EC of the soil saturation extract (deci Siemens per meter [dS/m])
A = Value of the conductivity where relative yield begins to decrease (dS/m)
B = Percentage of yield that diminishes per unit of increase in salt concentration

Under this model, one must first calculate the expected values of the EC of the soil saturation sample and then calculate the reduction in yield. These values are shown in Table 8.

Applying the relative yield equations for each crop, Navarro (1998) calculated the yield loss for the area's crops. These are presented in Table 9.

## Table 8. Electrical Conductivity Values of Soil Saturation Extract Anticipated as an Effect of Lining the AAC

| Year | Expected Concentration of Salts (mg/L) | CEa (dS/m) | CEe (dS/m) |
|---|---|---|---|
| 1 | 2,004 | 2,592 | 3.9 |
| 6 | 2,120 | 2,742 | 4.1 |
| 10 | 2,213 | 2,862 | 4.3 |
| 20 | 2,445 | 3,162 | 4.7 |

Notes: CEa is EC of irrigation water; CEe is EC of the soil saturation extract
Source: Adapted from Navarro 1998

## Table 9. Expected Relative Yield for Main Crops in the Area

| Crop | % of Expected Production for Each Period (years) | | | |
|---|---|---|---|---|
| | 1 | 6 | 10 | 20 |
| Wheat | 100.0 | 100.0 | 100.0 | 100.0 |
| Barley | 100.0 | 100.0 | 100.0 | 100.0 |
| Rye-grass | 100.0 | 100.0 | 100.0 | 100.0 |
| Green onions | 55.7 | 52.5 | 49.2 | 42.6 |
| Various (veg.) | 91.5 | 89.9 | 88.4 | 85.3 |
| Alfalfa | 86.4 | 85.0 | 83.2 | 80.7 |
| Asparagus | 86.4 | 85.0 | 83.5 | 80.7 |
| Vine | 76.8 | 74.8 | 72.9 | 69.0 |
| Fruitages | 66.2 | 63.0 | 59.8 | 53.3 |
| Cotton | 100.0 | 100.0 | 100.0 | 100.0 |
| Sorghum G.T. | 100.0 | 100.0 | 100.0 | 100.0 |
| Various (summer veg.) | 86.0 | 84.0 | 82.0 | 78.1 |

Table 9 suggests that the more tolerant crops—those with a better capacity for adaptation to higher concentrations of soluble salts in the soil—will not see their potential yield affected. However, more sensitive crops will suffer a considerable decrease in their total yield. One of the more notable cases is the crop yield reduction of green onions, which falls up to 58% over a 20-year period. For this crop in particular, a detailed analysis of the effects of AAC lining should be performed because the yield reduction will not only reduce the volume produced, and consequently the profit margin of the farmers, but it could have the collateral effect of increasing unemployment in the neighboring communities. This crop generates the largest need for labor in the area, providing employment for the day workers (jornaleros) who live in neighboring communities.

## ADDITIONAL EFFECTS

To have access to these waters and maintain harmony in society, current legislation establishes "water right concessions." But, given the high demand for water in the region, nothing can be allocated in this manner. Likewise, the fact that lining the AAC will negatively affect the availability, quality, and pumping levels of groundwater, as well as the regional economy in one of the most productive areas of the irrigation district, it will result in reduced water supply for individual agricultural users.

An analysis of water rights revealed that currently, an irrigation volume of 115.2 cm is assigned to each hectare with recognized rights and is made up of 88.2 cm of Colorado River water and 27.0 cm of federal well water. To maintain balance in the aquifer recharge, lining the AAC would mean extracting 64,860 AF/y less, because federal well water availability would be reduced, given that in the affected area only 200 ha (494.2 acres) are irrigated with private wells. This means this volume reduction will be distributed equitably so that the total irrigation sheet will be 110.87 cm, composed of 88.19 cm from Colorado River water and 22.68 cm from federal well water.

The foregoing means an average reduction in the irrigation sheet per hectare of 4.29 cm for all the district's users. Approximately 6,943.85 ha (17,158.62 acres)—the surface area of one irrigation module—could be irrigated with that amount of water.

In terms of volume endowment and the water marketplace, which exists to balance the water rights with the actual consumption of the farmlands, users who have made technological improvements in their parcels will find their benefit annulled. Users farming high-consumption crops, upon having their allotment reduced, will need a higher volume of water.

## CONCLUSION

Some conclusions can be reached based on this review of the available information. Under the established theoretical foundations with which the processes of conveyance and accumulation of soluble salts in the soil were studied, and given the effects of these accumulated salts on the growth and development of the crops (be it directly by the water itself, by the effect of individual ions in the internal metabolic processes of the plants, or by the deterioration of the soil's productive capacity), the processes of conveyance and accumulation of soluble salts in Colorado River water and the Mexicali Valley aquifer have suffered over time. A deterioration in quality has manifested in a steady concentration of soluble salts in the water. AAC seepage is useful not only for the volume of water supplied to the aquifer, but also because of the diluting effect on the concentration of soluble salts. Therefore, lining the AAC, or building a parallel lined canal, will have the immediate consequence of reducing the volume of water for the region as well as an immediate and medium-term increase of the concentration of soluble salts. This increase in soluble salts will result in a loss of 9% of the area's production and an increase of 13% in energy costs, which in turn constitute 25% of the operational and maintenance costs of the hydro-agricultural infrastructure of Irrigation District 014.

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