Salinity - an environmental constraint on crop productivity

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Introduction

Until recent time, emphasis in agricultural research was focused on feeding today's hungry world and tomorrow's expanding population. Land available for new farming ventures was seen to be minimal and many reports pointed out the fact that agricultural land was shrinking rather than expanding. Still, on a world-wide basis, agricultural yields soared. Two primary factors which contributed to the great increases in agricultural output were the Green Revolution and the expansion of irrigated agriculture. Irrigated agriculture is not a new science; it is over 5000 years old. But it has increased by over 22 percent within the last 20 years (Table 1). Along with the benefits of irrigation come the problems of salinity; the two are inseparable. The Green revolution provided new high-yielding crop varieties; whereas, improvements in irrigated agriculture made multiple cropping systems a profitable reality and made many semi-arid lands highly productive.

Agriculture requires the input of materials and labor that eventually must be deducted from the proceeds of the sale of the crop to determine the net productivity. Productivity is a ratio of inputs and outputs; marketable yield as a function of invested resources. Usually money is the common denominator. Because of the costs of obtaining and moving water, irrigation problems associated with the control salinity, have key roles in the productivity formula. However, the true cost of growing an

irrigated crop is sometimes difficult to assess. Often unrecoverable imputs are made by the society and have obscure effects on the formula. Although sociology and economics are concerns of other authors in this issue, irrigation and salinity effects on future agricultural production are not independent of these other two topics.

There is no way to foresee the many things that may come into play to affect the future role of irrigation and salinity on agricultural productivity. This would require a fortune teller or prophet. An adequate prediction of the future influences of salinity requires not only a scientific knowledge of the water and salinity problems that now face Australia and the rest of the world, but also a knowledge of the sociological pressures that influence future policies and decisions that deal with the

problem. One would also need to predict any technological innovations that might contribute to the solution. On the other hand, it is said that history repeats itself; that civilizations go through cyclic changes. If this is true, perhaps the best way to predict the future might be to review the past.

Table 1. Changes in irrigated agriculture in the principal irrigation areas of the world from 1961 to 1981 (1,2).

Country	1961 (ha x 1000)	1981 (ha x 1000)	Percent Change
China	74 060	76 500	+ 3.3
India	23 475	38 970	+ 66.0
U.S.A.	15 260	21 490	+ 40.8
Pakistan	11 090	12 400	+ 11.8
Russia	7 205	11 500	+ 59.6
Indonesia	6 990	6 800	- 2.7
Iran	4 695	3 500	- 25.5
Mexico	4 050	4 200	+ 3.7
Iraq	3 685	4 000	+ 8.5
Japan	3 400	2 626	- 22.8
Egypt	2 470	2 852	+ 15.5
Turkey	1 985	1 724	- 13.2
Spain	1 865	2 435	+ 30.6
Thialand	1 660	3 170	+ 91.0
Argentina	1 500	1 555	+ 3.7
Chile	1 420	1 500	+ 5.6
Peru	1 220	1 116	- 9.5
Korea	1 215	1 070	- 11.9
Australia	850	1 581	+ 86.0
Philippines	810	1 090	+ 34.6
Sudan	805	2 520	+313.0
Vietnam	610	3 040	+498.4
South Africa	605	856	+ 41.5
Syria	570	600	+ 5.3
Morocco	530	680	+ 28.3
Columbia	490	226	- 53.9
Afganistan	---	2 900	---
TOTALS	172 515	210 901	+ 22.3

Salinity in the Ancient World

The advent of civilization has progressed in hand with agricultural development throughout the world (3). In early civilizations in both hemispheres, agricultural and irrigation technology has provided for population expansion and development

that would not have been possible otherwise (4). The most notable of ancient irrigation developments were those of Egypt, China, Iraq, Iran, Peru and Mexico. Numerous references exist in ancient histories to irrigation systems involving wells,

tanks, and canals. For example, there is evidence of the existence of a large dam and basin irrigation in Egypt over 5000 years ago. In Iran, a system of tunnels which transport water from the surrounding mountains is over 2500 years old. There are over 2000 of these ancient wells in the Arabian desert that still function today. Some are 200 m deep. In the Tigris and Euphrates valleys are remains of two large irrigation canals, one of which is 9 to 14 m deep and 112 m wide (4).

In Latin America intensive irrigated agriculture supported dense populations and provided the economic basis upon which the complex civilizations of the Aztecs and Incas were built. There is strong evidence that plant domestication evolved in that area 7000 years ago (4). By the time of the Spanish Conquest, agricultural technology in arid regions of Central America and Peru involved terracing and elaborate systems of irrigation canals which drew water from several kilometers upriver.

Several historians believe that salinity problems in some of the most advanced of the ancient civilizations may have played an important role in their decline and fall. A specific example of this scenario occurred in Khuzistan, a province situated along the southern edge of Mesopotamia at the foot of the Zagros

Mountains and on the shores of the Persian Gulf (5). The sequence of development and decline in this area began along the upper valley of the Tigris-Euphrates Rivers in 5000 BC and lasted 2300 years. Extensive irrigation networks were the result of the technological and administrative accomplishments of the Khuzistan civilization and were an integral part of their economic and social development. Eventually, salinization, silting of canals and administrative neglect were contributing causes for reduced agricultural production. Such problems adversely affected the economic resources of the nation and helped to erode the foundations of the society.

Between Baghdad and the Zagros Mountains are the Diyala Plains, which, like Khuzistan, were irrigated for thousands of years (5). The area is known to have undergone three periods of salinization, the earliest of which occurred between 2400 and 1200 B.C. Agricultural production during this period shifted from an economy based on wheat production, to one dependent upon more salt-tolerant barley. As wheat production disappeared and barley yields declined, the rural population in the plains dwindled; and urban centers were reduced to villages.

The Viru Valley in Peru is an example taken from the Western Hemisphere. Civilization evolved there between 900 and 400 B.C. and included the development of villages built around pyramid mounds (6). These villages and walled fortifications were central to an elaborate system of irrigation canals. Amaranth, maize, beans and squash were major food crops in the area; and hybrid maize varieties were grown in irrigated fields. Between A.D. 1200 and the Spanish Colonial Period, inadequate drainage and salinization contributed to a gradual decline in both population and culture.

In North America, the most extensive ancient irrigation works were attributed to a culture that flourished in the Gila and Salt River drainages of Southern Arizona between A.D. 500 and 600 (4). Intervillage cooperation and control permitted the creation of more than 300 km of ditches and canals. The name of the people was "Hohokam", a Pima indian word meaning "those who have vanished". It is interesting to note that each of the areas that have been used as examples are now deserts.

Not all of the successes and failures in irrigated agriculure's long conflict with salinity are confined to ancient history. The same problems are present today throughout the world. Salinity and irrigation problems in California are typical of those facing many nations.

Salinity in California

Salinity affects 1.7 million ha in California, 1.2 million of which lie in the irrigated regions (Table 2). No less than six ofthe nation's top ten agricultural counties are included in these areas (7). Since irrigation was introduced in California in the late 19th century, it has led to worsening salinity problems in two of California's major agricultural areas, the San Joaquin Valley and the Imperial Valley. The histories of the problems and attempts at their solutions have parallels with similar areas in other parts of the world.

Table 2. Salinity and drainage problems in major irrigated areas in California (in hectares).

Valley	Total Irrigated Area	Saline /Sodic	High Water Table	Poor Water Quality
San Joaquin	2 266 000	890 000	607 000	931 000
Sacramento	850 000	81 000	162 000	121 000
Imperial	202 000	81 000	202 000	202 000
Other Areas	769 000	121 000	121 000	121 000
Total	4 087 000	1 173 000	1 092 000	1 375 000

Adpated from (7).

The Imperial Valley, in the Colorado Desert in Southeastern California has been one of the most productive agricultural areas in the U.S. since 1901, when water from the Colorado River became available to that area. Salinity in the Colorado River at that time was about 700 mg/L. By 1918, agriculture in the valley had expanded to 146,000 ha (8). Because the valley was an ancient sea bed, about half of the irrigated area was non-productive or salinity damaged. The Imperial Irrigation District (IID) devoted SUS 2.5M to an open-ditch drainage system in the 1920's. Fortunately, a convenient drain had been provided by the creation of the Salton Sea during a river flood and levee break in 1905. This scheme failed to control the salinity problem because of the heavy soils in the area, increasing salinity of the river water and poor management. In 1940, the U. S. Soil Conservation Service and IID jointly sponsored the design and installation of subsurface tile drainage systems that were tailored to individual farm needs. Federally-sponsored construction of the Imperial Dam and the All-American Canal was completed during this same period. These improvements provided IID with a seasonally consistent water supply for an area of over 200,000 ha. The Salton Sea at that time covered 1300 square km and drained an area of 21,000 square km (9). By 1949, over 40,000 ha were tile-drained and salt balance in the valley was achieved. Continuing efforts were made to improve the situation by promoting improved irrigation management through the use of better field leveling techniques and the adjustment of canal grade and depth to reduce seepage.

The cost of these programs was $US 40.5M for tile drainage and $US 26.2M for concrete linings for canals and laterals (8). On-farm costs for leveling, more sophisticated irrigation systems and improved soil management techniques are not included in these costs.

Today, over 45,000 km of tile and tube drains have been installed over an area of 186,000 ha in the Imperial Valley (8). This is equivalent to drains spaced 38 m apart throughout the area. About one-third of this area is double-cropped. Unfortunately, salinity is still a prominent problem in the region. By 1979 salt concentration in the river had reached 810 mg/L due to increased water use and saline return flows. It is predicted that concentrations will reach almost 1300 mg/L by the year 2000. Moreover, the Salton Sea is suffering from the over-abundant flow of drainage water. Drainage from the Imperial Valley and another 25,000 ha being irrigated just north of the Salton Sea, in the Coachella Valley, contributes 5M tons of salt annually to the salinity of the sea. Salt concentrations in the sea exceed 40,000 mg/L, well above that of the ocean. The amount of water in the sea is also increasing. Water levels raised from -68 m below sea level in 1941 to -64 m in 1981 (9). Many seaside residences and businesses are now flooded. Recently, marginally toxic selenium concentrations have been found in the sea.

Salinity and drainage problems in the San Joaquin Valley are the most extensive in the state (Table 3). The San Joaquin is located in California's Great Central Valley and is an area 75 km wide by 370 km long. The area is an ancient sea bed and is underlaid with a water table containing from 3000 to 25,000 mg/L salt (10). Between 1870 and 1915, rapid growth in irrigated area was paralleled by increasing problems with salinity and drainage. In 1915 there were 810,000 ha of irrigated land in the valley (8). Fresno County, alone, had 324,000 ha underlaid with subsurface water less than 2 m deep.

The University of California Agricultural Extension Service and the federal Bureau of Soils established demonstration farms at Tulare and Fresno. Work on these farms led to recommendations that more salt-tolerant crops be grown in the area, that less water be used for irrigation (i.e. greater water-use efficiency), and that drainage be provided. The only natural drain in the area was the San Joaquin River, which flows north to San Francisco Bay. In the 1920's deep well pumping was used to lower water tables and to prevent salt accumulation on the soil surface. Between 1915 and 1950 drainage strategies became community issues and hundreds of kilometers of tile and ditches were installed. Construction of the Delta-Mendota canal in the 1950's and the California Aquaduct in the 1960's brought a full water supply to the valley. Although the salt content of the imported water is only 230 mg/L, the total salt imported annually amounts to 300,000 tons (11). Without a proper disposal site for saline drainage and pumped ground water, efforts to prevent salt accumulation in the valley or to lower the water tables to safe levels were insufficient.

Continued agricultural expansion into the west side of the valley has resulted in more demands on fresh water supplies and has increased saline return flows. It has also produced legal and political conflicts which have opposed necessary solutions. In fact, political and sociological issues have influenced decision-making processes concerning water availability in both of California's agricultural valleys. Certain parallels with Australia's Murray-Darling situation are evident.

Political and Social Issues

The Colorado River Basin ranks among the largest in the world.

Table 3. Comparisons of flow and drainage statistics of various river systems of the world.

River	Length km	Basin Area sq km	Ave. Annual Flow GL
Danube	2850	833 000	282 000
Indus	3180	937 000	109 000
Colorado	2330	847 000	17 000
Murray	3750	1 050 000	15 000

The Colorado River provides irrigation to 600,000 ha and 17 million people within a seven-state area in the U.S.A., and another 240,000 ha and 0.5 million people in Mexico (12). An international treaty guarantees 2500 GL/year of water to Mexico. Another treaty assures that this water will not exceed 145 mg/L. The annual flow of the Colorado is 17,400 GL. By legislation, Southern California receives 6320 GL/year; whereas, the other six states receive 6600 GL/year. It has been argued that the Colorado River is the most litigated, regulated and argued-over major river in the world (Table 4),(12). Most Australians would probably challenge that statement.

Legislation concerning the Colorado River has resulted in specific allotments for its use amounting to almost 90 percent of its annual harvestable flow. Cooperative state agreements now restrict salinity levels below Hoover Dam to below 723 mg/L salt and below Imperial Dam to below 879 mg/L salt. However, United States federal requirements for water delivery to Mexico are set at a maximum of 145 mg/L salt. This had resulted in the funding of a multi-million dollar desalinization and power plant complex. Meanwhile, many hectares of crop land have been taken out of production in order to reduce saline return flows. Future pressures will be made to improve irrigation efficiency in both the Imperial and Coachella Valleys in order to reduce the quantity of drainage effluent into the Salton Sea.

Table 4. Some of the water and salinity control actions associated with the Imperial Valley and Colorado River.

Part of the LAW OF THE RIVER:

Year	Legislation	Proposed Action
1902	Reclamation Act	Federal involvment in hydrologic development
1911	Formation of Imperial Irrigation District	Control and legislate water Improve irrigation effic.
1922	Colorado River Compact	Water rights established among seven western states
1928	Boulder Canyon Project Act	Approval of Hoover Dam and All-American Canal
1930	Imperial Dam authorized	Control flooding Provide water
1972	US Bureau of Reclamation Investigation	Identified 16 salinity control projects
1972	Clean Water Act	Established salinity standards for river water
1973	Colorado River Basin Salinity Control Forum	Provide basin-wide salt control plan/ Authorize 12 projects for control
1974	Colorado River Basin Salinity Control Act	Reduce upstream return flow/ Improve irrigation efficiency/ Authorize desalting plant contruct.
1981	Legal action against IID by Salton Sea shoreline property owners	Reduce volume of waste water, claim damages
1985	Central Arizona Project	Increases water needs in Arizona
	Paradox Valley Control Unit	Deep well injections of highly saline brines
	Grand Valley Unit	Reduce salt returns from leaks over saline areas

Several attempts to solve the drainage problems in the San Joaquin Valley have resulted already in failure. The San Luis Authorizing Act of 1960 attempted to provide a $US 86M master drain jointly supported by federal and state funding. The 450 km drain was to run from Bakersfield, California to the San Francisco Bay. California backed-out of the deal when water-users failed to agree on a plan to reimburse state expeditures for the plan (8). Subsequently, the federal government began construction of the northern 300 km section of the drain at a projected cost of $US 60M. After 130 km of the drain was completed, further construction was halted by arguments over the location of the drain outlet. Environmentalists and San Francisco Bay civic leaders have filed court actions over concerns about pollution from agricultural waste water. In the interim, drainage water flowing through the completed portion of the drain has been discharged into Kesterson reservoir, a 500 ha evaporation basin and salt marsh located north of Los Banos.

Dead and deformed birds and contaminated fish were found in the Kesterson Wildlife Refuge in 1983. The source of the problem was high levels of selenium, a mineral of geologic origin which had been concentrated in the drainage water. The state has directed the federal government to decontaminate the site by July 1988. Decontamination of the area will cost $US 24.6M. Meanwhile, over 4000 ha of land will be unproductive because of the lack of drainage.

California is not unique in its struggle with salinity problems. Nor are the sociological and political problems any more complex than in other areas of the world.

Salinity in Egypt and Israel

In Egypt, since the building of the Aswan Dam, salinity has become a serious problem, foreshadowed only by a rapidly swelling population and a limited water supply. The waters of the Nile are very good by Australian standards. But, salinity in the Nile increases from about 400 mg/L at Cairo to as high as 10,000 mg/L in northern regions of the Delta. Intensive irrigation and poor drainage are causing serious problems. Several programs are underway to drain water-logged lands, to produce salt-tolerant species and to expand agriculture in a more water-efficientmanner. In the western desert, near Sadat City, drip and sprinkle irrigation is being used to bring more land into production with the limited water resources. Egyptian scientists have been developing salt-tolerant cultivars of rice, wheat, barley, and several vegetable crops adapted to the local climate. For example, scientists at Ein-Shaimes University are studying the development of agriculture on the coastal areas. Here farmers grow vegetable crops on sand dunes using drainage water taken from shallow wells. One locally-adapted tomato variety, 'Edkawry', has reported high salt tolerance. Farming is conducted by transplanting tomato or melon seedlings on raised beds to avoid salt intrusion from the shallow ground water. Shallow wells are dug to intercept subsurface drainage water flowing toward the sea; and the water, containing 4000 mg/L salt, is hand-carried to the plants. High yields of fine quality vegetable crops are reported. This type of farming is extremely labor-intensive. Dunes are periodically removed and replaced to reduce the salt load of the sand. In a country where lines of children walk endlessly across fields to hand-pick insects from the leaves of crops, this type of labor intensive effort probably makes sense. In Egypt, the cost of hand labor can only be calculated by Egyptian standards. Technological luxuries are replaced by necessary innovations. Drought-sensitive sunflowers replace glass and plastic tensiometers as irrigation sensors. This is the way of many third-world countries.

Farming practices in Israel are similar to those in the U.S.A. and Australia. But land and water resources are much more dear than in either country. Water use and re-use is imperative to the survival of Israel. The use of saline ground water is a major research interest. Water with 3000 mg/L salt is used to irrigate crops in the Beissan Valley. Near the Dead Sea, at N'eot Ha'kikar, water containing 4000 mg/L salt is used to grow crops (13). The economic emphasis in Israel has been on producing vegetable crops for the European winter market. Higher labor costs and increased competition from the southern Mediterranean countries have forced Israel to make quality an important focal point in marketing. The use of saline water to improve the sugar content of melons, tomatoes and other vegetables has become a viable research option.

Summary

All of the successes and failures in irrigated agriculture in its long conflict with salinity are not confined to ancient or recent history. The same problems are present today, throughout the world. Although we would like to believe that we understand the problem more fully and have more sophisticated means to prevent such disasters as have occurred in the past, it would be easy to under-estimate the situation, and thus court similar disasters. The major difference between then and now is magnitude. It is true that we have more knowledge now. It is also true that we have bigger irrigation systems, dams, canals, irrigation areas and populations.

It is almost certain that future increases in agricultural production depends upon increases in irrigated agriculture and further improvements in plant breeding, particularly, in the development of salt-tolerant plants. History has shown that irrigation systems must be maintained and improved for the benefit of the society as a whole. The development of adequate drainage is an essential element in the scheme. It will also be one of the most expensive elements. Although the grower benefits most directly from improvements in irrigation and drainage, it may not be fair that he pay the cost. Society benefits from immensely from the creation and establishment of agronomy-related jobs and industry. Increased agricultural production generally lowers food costs and provides an export commodity. These benefits are important for a healthy society.

Additional productivity in irrigated agriculture can be achieved through improvements in water-use efficiency and the development of salt-tolerant crops. In order to do this, a total water management system would be required. Water applications would have to be minimal for crop use and leaching requirements, thus conserving water resources and reducing drain volume. Slightly saline ground waters and drain waters would have to be used to irrigate salt-tolerant crops or be applied to moderately-tolerant crops during growth stages so as not to reduce crop yield. Such strategies would conserve fresh water needed for continued agricultural expansion and would reduce the size of conveyance and storage facilities needed for their eventual disposal.

Salt-tolerant cultivars are essential for agricultural diversity in this system. high cash values cannot be maintained if everyone is forced into the production of a few salt-tolerant species such as sugar beet, cotton, barley and wheatgrass. Salt tolerant cultivars of high-yielding grains, forages, fruits and vegetables will be needed to maintain balanced diets and balanced trade. Fundamentally, this may be one of our greatest research needs.

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