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WORKING PAPER

TECHNOLOGY AND EMPLOYMENT PROGRAMME

The River as an International Environmental Resource — The Case of the Colorado

by

James E. Jonish

International
Labour
Office
Geneva

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WORLD EMPLOYMENT PROGRAMME RESEARCH

Working Paper

Technology and Employment Programme

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Working Papers are preliminary material circulated to stimulate discussion and critical comments.

January 1992

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Preface

The present Working Paper by Professor James Jonish, Deputy-Director of the International Center for Arid and Semi-arid Land Studies at Texas Tech University, fourth in a series devoted to environmental topics in the World Employment Programme, is concerned with the economic and environmental ramifications of an overallocation of water from the Colorado River. The problems addressed are not specific to the Colorado River. Similar difficulties, compounded by the involvement of different national jurisdictions, are experienced across continents. Accordingly, the findings of this study may share a wide interest.

Pressure on environmental resources is a common feature nearing the end of a century marked by global economic and demographic growth on an unprecedented scale. In the case of the Colorado, this pressure has come predominantly from irrigation-dependent agriculture on the demand side and, on the supply side, from an historical allocation of water which has proved rigid in the face of changing circumstances, notably unforeseen salination problems for downstream users. It has been suggested that rigidities could be relaxed by greater reliance on the pricing mechanism. Such a suggestion fits a general movement towards improved pricing of once abundant environmental resources. The suggestion, however, holds problems for agriculture. Should agriculturalists have to pay the full price for water - i.e., the non-subsidised price at which water authorities clear their allocations - they would find their livelihood and employment at risk in case farms are no longer economic.

If the assessment of uneconomic and environmentally damaging farming practices is correct, then to persist is not an attractive proposition. On the other hand, reform cannot ignore protective political realities towards the agricultural sector. For this reason the paper points to measures that will facilitate the structural adjustment that may follow a new approach to the allocation of water. It recommends a gradual approach and one which is clearly announced. Moreover, the paper recommends transitional assistance to offset loss of employment and capital value and to provide the basis for an alternative strategy of employment generation.

The issue of offsets has been important also between the U.S. and Mexico. An acceptable conclusion of negotiations has been difficult at each stage. Sovereign nations are not automatically disposed towards arrangements that make for efficient and equitable use of transboundary environmental resources. Indeed, the incidence of international disputes over the use of shared environmental resources (or over environmentally based trade distortions) is becoming more frequent. Accordingly, a greater need arises to find cooperative solutions concerning the use of shared environmental resources between nations, as it is within nations.

Content

1 Introduction

Multipurpose dams and large scale irrigation projects have long been viewed as important infrastructure investments in a society's economic development and industrialization, and income/employment generation prospects. Hydroelectricity, irrigation and flood control benefits were emphasized as important outcomes of such large scale investments. National and international funding provided the basis for these investments.

In recent years, more emphasis has been placed on the private and social costs of these investments. The problems represent a litany of socioeconomic and environmental issues. Once dams are completed, water is impounded behind the dam leading to problems of resettlement, and social and cultural destruction. With water impoundment completed, there are land and wildlife losses upstream and silt and fertility losses downstream. Sedimentation behind the dam itself may alter the long term expected benefits of any project. Perennial irrigation has effects on pest populations and diseases.

Other problems exist. The multiple objectives of multipurpose dams may be in conflict. Electricity production with peak power requirements may require water releases adverse to irrigation and recreation uses. Irrigation objectives require large filled reservoirs, yet this conflicts with flood control objectives of impounding unexpected stream flow adjustments.

Arid and semi-arid lands river basin development have additional problems: waterlogging of soils and salination. While irrigation water is critical to agriculture in these areas, predictable problems develop. Waterlogging of soils develops within several years of the operations of the irrigation system as drainage facilities are usually omitted. Once high cost drainage facilities are added, water and soil salinity problems develop, particularly for downstream users. Left untreated, saline soils lose productivity and are often abandoned.

Thus, there is concern about the sustainability of such agricultural practices, and the associated income and employment from these practices, in arid and semi-arid lands. In many instances, these social cost issues are aggravated by the fact that the costs and benefits of the projects are not equitably distributed and that the distribution of benefits and costs may differ significantly by political jurisdictions in river basin development.

The current case study traces the development of the allocation of water and its quality between two arid regions along the lower Colorado River basin: the southwestern U.S. and northwestern Mexico.

The Colorado River is critical to agriculture, industrial and municipal development in the Southwestern United States and the Mexican states of Baja California and Sonora. The Mexicali irrigation district in Mexico represents 529,000 acres of irrigated agriculture alone, while the Imperial Irrigation District in the U.S. represents 465,000 acres. Other U.S. irrigation districts receive water from the Lower Colorado River as well. Responsibility for improving water quality was placed with the U.S.

The case study describes the area of the Lower Colorado River and the infrastructure development in the U.S. and Mexico which led to expansions of production, income and employment on both sides of the border. The policy responses to salinity increases are documented as well as an estimate of the order of magnitude of the costs of compliance with the U.S.-Mexico agreement of 1973. The cost burden of compliance is placed on the U.S., following the polluter-pays-principle. The disparity between the two countries' ability to pay would also dictate that the cost of compliance be predominantly upon the U.S. within the U.S., almost exclusive reliance is placed upon the Federal government to meet compliance standards. Other more cost effective alternatives are examined here as well. They were rejected by policy makers, explicitly or implicitly, as inequitable, or of uncertain impact.

Two problems remain. First, it seems unlikely that a permanent solution to the salinity problem in the Lower Colorado River has been reached. Long-term salinity trends at the U.S. Imperial Dam are increasing, necessitating salinity control measures in the Upper Colorado basin. Second, the demand for water in the southwestern U.S. and northern Mexico is growing rapidly as industrialisation and urban growth proceed rapidly along the U.S.-Mexico border. Population within the border region has grown from 3 million in 1980 to 6 million in 1990, with 5 million concentrated in six principal sets of "sister cities". Municipal/industrial water pollution along the border has become a concern requiring U.S.-Mexican negotiations once again. The current rights to water use are predominantly agricultural in both the U.S. and Mexico. Water conservation or reallocation mechanisms will need to be developed if continued industrialisation and employment gains are to be realised.

Nevertheless, the solutions developed for the salinity question are important precedents to the co-operative resolution of the developing water quality and quantity issues along the border.

Chapter 2, following this Introduction, provides a broad overview of quantity and quality issues of irrigation in arid lands. These include market issues in water allocation and quality, water rights allocation in practice and salinity concerns. The socio-economics of irrigation water is also discussed.

Chapter 3 examines the Lower Colorado River and irrigated agriculture. The allocation of water between the various U.S. states and between Mexico and the U.S. are discussed.

Chapter 4 documents the policy responses to salinity and the cost of compliance. With the 1973 agreement it was agreed that the U.S. must provide Mexico with 1.5 MAF of "reasonable quality" water and that the cost burden of compliance was placed on the U.S. Alternative mechanisms and their costs to comply with the 1973 agreement are examined. Results of the agreement and remaining issues are discussed.

The concluding chapter, Chapter 5, summarizes the issues and costs of providing Mexico with water of a reasonable quality. The chapter concludes with a checklist or problem identification for arid lands river basin development projects. Of critical importance is the necessity that proponents of large scale irrigation projects include drainage facilities in the project costs, or else the anticipated benefits will not be sustained. The treatment of such drainage water for downstream users is an additional problem often unrecognized. It is the major focus of this case study.

2 Irrigation in Arid Lands: Quantity and Quality Issues

This section provides a broad overview of several issues in irrigated lands in arid and semiarid regions. They include the appropriation of the water for use (property rights), the degradation in the quality of the soil and water due to irrigation, and the socio-economics of irrigation water. While the focus here is on the arid western U.S. and Mexico, similar issues exist in other political jurisdictions.

2.1 Allocation of Water and Use

Surface water rights in the U.S. originate from two basic doctrines. In the humid eastern U.S. the riparian doctrine of water rights exists. This is based upon English common law and allows a landowner to the right to use the water that is on his land as long as the owner does not diminish the supply of water. In practice, this doctrine is interpreted so that the landowner may make "reasonable" withdrawals with respect to downstream landowner/uses. In essence, the riparian doctrine relies on large quantity of surface flows, high humidity (with low evapotranspiration) and large precipitation which yield large total supplies of water relative to total demands for water. Agriculture is generally non-irrigated.

In the arid western U.S., the riparian doctrine is inadequate in the case of rivers used for irrigation. Surface flows are small relative to potential demands, low humidity leads to high evapotranspiration and there is small precipitation. Instead the doctrine of prior appropriation has evolved; rights are obtained in chronological order ("first in time, first in right") to divert water and put it to beneficial consumptive use. Beneficial consumptive use was adopted as the standard for obtaining the water rights to encourage investment in irrigation and water use facilities and to discourage speculation by acquiring idle land and claiming water rights.

Within the doctrine of prior appropriation there are senior and junior rights to water. With stochastic river flows, junior appropriators experience a greater risk of water delivery reductions than do senior appropriators. However, in times of extreme drought, priorities are generally established in the following order: 1) municipal and domestic, 2) irrigation, and 3) commercial and industrial (Burgess and Quirk, 1978).

Under the prior appropriation doctrine, there is a difference between water diversion (water requirements or application) and beneficial consumptive use (actual consumption). This difference is return flow and return flows may be quite low; 5-10 per cent for evaporative cooling, or as high as 80-90 per cent for domestic and municipal use. The return flows generated are externalities which senior upstream appropriators create for downstream appropriators to capture. These externalities are positive with respect to the quantity of water created, they may be negative with respect to the quality of water created through salinity increase or other degradation.

The larger the return flow of water of good quality, the greater the number of junior appropriation rights can be accommodated under the system. Alternatively, the smaller the amount of water needed for beneficial consumptive use, the less water must be initially diverted for agricultural use and the greater the number of junior rights may be accommodated. Thus, reducing beneficial use by individual irrigators also creates positive downstream externalities. Technology options exist to improve on farm efficiency of irrigation practices, reducing beneficial consumptive use and for improving drainage and return flows of irrigation water.

2.2 Salinity and Quality Concerns

Sources of Salinity

Water and soil salinity are the result of natural and human induced sources. In a natural context, weathering takes place which allows mineral crystals in rock to oxidize. With rain or snow falls, excess water either evaporates from the surface of the soil, drains off the soil into return streams, or percolates into the ground to form a water table below the surface. This groundwater ultimately enters streams and rivers through seepage with further oxidized materials.

Water retained in the soil root zone but above the water table is utilized by plants in the process of osmosis. The water entering the roots is transpired through the leaves and passes to the atmosphere. This process of evaporation and transpiration or evapotranspiration distils pure water into the atmosphere leaving behind the salts in the remaining water. This saline water and residue is now concentrated in the soil, in the water table below the surface or in the rivers and streams as surface runoff or underground seepage. The natural sink for most dissolved salts in the surface water system is the ocean.

Irrigation, particularly in arid lands, can accelerate the process of soil and water salinity. Since there is substantially less natural leaching of soils in arid and semiarid regions than humid areas because there is less water available, arid land soils have on average greater salinity than do humidland soils. The application of irrigated water can cause more pronounced changes.

Once irrigation water is applied to the soil, evapotranspiration occurs and the total salts originally dissolved in the irrigation water are left behind. Thus any irrigation water left in the root zone will have a much higher salinity level than the original irrigation water. These mineral salts remain in the soil unless sufficient water is applied to leach out the salts and to carry them below the root zone and into the underlying water table (National Research Council, 1989).

However, without proper drainage - natural, lined tubes or drainage wells - leaching of the soil by applying excess water will raise the water table. The net result is that the root zone will end up waterlogged and saline. Leaching must be accompanied by an adequate drainage system to keep soil salinity down and to avoid waterlogging and resulting crop damages. Without leaching, the root zone of the soil becomes too saline and prevents crops from absorbing water.

While drainage systems reduce the local salinity problem, if the discharge or return flow of drainage water is returned to the original surface water source, it can create water quality problems for downstream users. For example, water received by the Imperial Valley in Southern California had an average salinity of 750-800 ppm in the 1960s. The discharged drainage water into the Salton Sea (a closed basin) contains about 3500 ppm

(Pillsbury, 1981).

New environmental concerns have developed with drainage systems besides salinity control. The residue of pesticides and fertilizers are raising health and ecological concerns for subsequent users. There are also concerns about the toxic effects of selected trace elements (like selenium) contributed by the local geology which are appearing in irrigation drainage systems (National Research council, 1989).

Economic Impact of Salinity

Salinity imposes costs on a number of users. The losses to agricultural irrigators include lower crop yields, higher leaching and drainage costs, and greater soil management costs. For municipal and industrial users, salinity costs include increased water treatment costs, accelerated appliance and pipeline deterioration and increased soap and detergent needs.

A report which provides estimates of economic impacts of the Lower Colorado River basin was prepared for the U.S. Bureau of Reclamation. Annual losses to excess salinity (over a baseline of 500 ppm) in the Colorado River are summarized in Table 2.2.1.

These results are based upon an area comprising 18 million people and 1 million acres of irrigated farmland in the U.S. For the total U.S., there are about 60 million irrigated acres; about 50 million are located in the 17 western states. It has been estimated that one-fourth and possibly one-third of the U.S. irrigated lands suffer some salinity damages. This places the order of magnitude of U.S. agricultural losses alone due to salinity at $1.4 to $1.8 billion per year.

Table 2.2.1
1986 - Annual Salinity Damages in Lower Colorado River[1]

Users	U.S. Dollars (millions)
Households	156
Agriculture	113
Industry/Utilities	9
Other	33
Total	$311

Source: U.S. Bureau of Reclamation, Estimating Economic Impacts of Salinity of the Colorado River (1988).
[1] Based on average (1976-85) of actual TDS in river and 500 mg/l base case (no damage).

2.3 Socio-economics of Irrigation Water

The U.S. Reclamation Act of 1902 established the Bureau of Reclamation to carry out the mandate to build large scale irrigation projects to provide inexpensive water in the 17 western U.S. states. This was the beginning of federal involvement in building and subsidizing irrigation projects in the west with the objective of having the west occupied and developed.

Today, irrigation consumes the majority of the west's water, some 85-90 per cent of the total, providing irrigation to 50 million acres. The U.S. Bureau of Reclamation provides water to more than 12 million acres (Bureau, 1986) including the largest projects. Irrigated farms in total contribute to one-fourth of total U.S. agricultural output by value, although they represent only one-seventh of agricultural lands (Frederich and Hanson, 1984).

Single or multipurpose irrigation projects are costly undertakings. The true costs of water provided by irrigation projects were often considered too high for farmers and their respective irrigation districts to pay. Subsidized prices are charged farmers with general federal revenues utilized to cover the full costs of water provision.

Project economics is also enhanced by a number of practices. One is to omit the costs and installation of a drainage system. Because drainage is not needed at the inception of irrigation operations, the cost of building them are delayed. Once waterlogging occurs, the supplemental request for drainage installations is necessitated. Overestimates of crop yields and/or prices and underestimating maintenance and operations costs reduce the apparent cost of irrigation projects. Ignoring environmental costs of projects also improves the financial feasibility of the project.

Even with these practices understating costs, western water was still relatively expensive. Further subsidies were utilized. These include eliminating interest payments in calculating repayment rates, or considering maintenance and operations expenses only in determining the price of water.

An analysis of these practices has indicated that the subsidies can be quite large. In a study of 18 irrigation districts provided water by the Bureau of Reclamation (U.S. Department of Interior, 1988), subsidized versus full cost prices of water were determined. The average subsidized price of water was 19 per cent of the full cost. This ranged from a low of 3.8 per cent (Grand Valley, Colorado) of full costs to a high of 53.7 per cent (Oroville, WA). The total annual subsidy was estimated at $534 million or an average of $54 per acre of irrigated land in the west.

Further aggravating this situation is that an average of 38 per cent of the subsidized water is used to grow crops which the Federal government considers surplus and in many cases is subject to commodity subsidy programs (National Research Council, 1989). Thus, many irrigated farmlands receive a double subsidy; both on the price of water and the price of crops.

These subsidized prices for water encourage excess consumptive use and discourages installing efficient on farm irrigation systems unless of course they are also subsidized. The burden of the subsidy must also be considered; the individual farmer in the rural West is being subsidized at the expense of the non-farming urban sectors. For the irrigation farm operator, dependent on the subsidized price of water, expectations of continued subsidies have been capitalized into the value of the farmland. Radical changes in terms and prices of water provided would result in considerable capital losses to these landowners.

Further complications to efficient use of irrigation water are restrictions on water transfers or marketing arrangements. These limitations exist at the Federal, interstate, intrastate and district levels. The Bureau of Reclamation controls are primarily concerned over the repayment schedules for the construction, maintenance and operations costs of the projects (Burgess and Quirk, 1978). Further, the Bureau does not allow carry over storage or credits on a year to year basis. Conservation is deterred since water saved would be lost if not used in the irrigation season (National Research Council, 1989).

State laws also exhibit considerable control over water allocations. No water transfer can occur within a state and between states unless it can be demonstrated that other water rights holders are not injured. Since water rights transfers of surface water (a Federal - irrigation district concern) might affect underground water users which are subject to state regulatory practices, the state can limit transfers.

The individual irrigation district may also restrict transfers. Water deliveries are usually contracted on a district wide basis. Individual farm conservation practices will result in water reallocated to other farms within the district with no compensation received by the conserving farm owner, except perhaps the small savings of subsidized water. For the district as a whole, the Bureau policy of not allowing carry over storage encourages the practice widely quoted in the west as "use or lose it."

2.4 System Inefficiencies

If the quantity and quality of water is considered as a desirable economic commodity, the water allocation and pricing system just described is inefficient in both static and dynamic terms.

Two of the most obvious sources of inefficiencies are the legal and institutional restrictions on water transfers and the subsidized price of irrigation water. The prior appropriation doctrine creates property rights in water and economic rents to those fortunate enough to obtain these rights. However, restrictions on transfers (lease or sale) prevents the trading of these rights from low value users to high value users so that the net benefits to water use would be equalized on the margin. For efficiency purposes, these transfers would occur not only intrastate but across state boundaries and also national boundaries.

With well developed market transfers of water, conservation would be enhanced by all appropriators. If quota allocations prevented transfers across national boundaries, transfers within national boundaries would improve efficiency on a local basis.

The subsidized price of water represents another inefficiency. As indicated, the average price of irrigation water to farmers in the U.S. is approximately 20 per cent of the full cost of water. Even this figure is understated since full cost refers to the financial cost of constructing dams, canals, diversion channels, structures, etc. It does not impute any value, or shadow price, to the water, and its quality.

Without realistic pricing of water, conservation is discouraged. As an illustration, in California today, farmers may pay as little as $2 per AF for water while Los Angeles water users pay $545 per AF and San Francisco users pay $300. One irrigation district consuming 300,000 AF of water per year would provide enough water for San Francisco for 2½ years (Wall Street Journal, May 30, 1991). In Mexico, Mexicali farmers receive irrigation water at no charge.

These inefficiencies are compounded by bureaucratic interpretations. Water rights are based upon beneficial use; this effectively means the diversion and distribution of water for consumption and return flow. As such, the instream use of water is not considered a beneficial use. This includes recreational and ecological outputs of the river. By contrast, privately owned streams and creeks recognize instream use; charging fishermen for access, limiting access to preserve yields and maintaining the quality of the stream flow through environmental measures (Anderson, 1983).

Another restriction to efficiency is the concept of "preferential use" set up by law or government agencies. "Preferential use" rank orders categories of water rights users - municipal/industrial/agricultural. In case of shortfalls or drought, lower preferences are reduced first. Within categories, the prior appropriations doctrine holds (Tietenberg, 1988). Not only are the rank orders arbitrary, but transfers of rights across categories are often restricted or eliminated.

Quality of water adjustments can be incorporated as well in the market. While upstream users create positive externalities to downstream users in the form of return flows, the return flows are of degraded quality. According to the Coase theorem, static efficiency can be obtained by compensating downstream users to accept polluted water or bribing upstream users to control pollution under certain assumptions. These assumptions include minimal transactions costs and the maintenance of status quo regarding income distribution. With hundreds of thousands of users, transactions costs are not likely to be small, and income distribution disparities between the U.S.-Mexico will immediately raise equity considerations. Thus, the assumptions are unlikely to be met.

For dynamic, as well as static, efficiency, it is therefore argued that the locus of liability should be determined in environmental damage mitigation and the polluter pays principle should be adopted. Polluters pay in proportion to damages incurred; this encourages over time the development and introduction of environmentally biased technology to save on pollution charges.

The main problem with the above solution of course is that it does not ensure some definite level of pollution standard, only that pollution will be reduced. Where people are risk averse or there is concern with irreversibility of effects, standards are used.

If standards are adopted to achieve certain minimal water quality levels, then standards with market based incentives will permit flexibility in meeting the standards. Standards of water quality for downstream users may require all upstream users to invest in antipollution activities. Alternatively, the cost to one user may be far more excessive than the cost to another of achieving certain standards. If pollution permits are issued, this high cost firm can purchase permits from low cost firms to continue pollution. These low cost users invest in facilities for the pre-treatment and/or post-treatment of water to maintain the required level of standards for the downstream user.

There has been little reliance on market based incentives to reduce pollution in the case study under discussion. Rather, "command and control" mechanisms were used. However, given the lack of appropriate market instruments and incentives in the provision of water, this result is not surprising.

With the inefficiencies described, the prospects for increased market reliance for water allocation and environmental protection are increasing. Recall that the Riparian doctrine of water rights and use was rejected in the west as inappropriate and the Prior Appropriation doctrine adopted. As population and economic growth has progressed, the current prior appropriation doctrine is becoming outdated. Restrictions on transfers reduce conservation incentives and flexibility in converting water to higher values uses.

Prior appropriation with allowed water transfers would provide this flexibility. While it would vest the economic rents of the water rights in the current rights holders, many of these rents have already been capitalized in the land values of the farmers through earlier transfers. The gains due to reallocation to higher valued users and conservation incentives would be the result.

There are considerable institutional barriers to overcome the current entrenched property rights system. However, property rights will change, albeit slowly, when the public recognizes the waste from the current system outweighs the transition costs of changing the property rights system.

2.5 Summary

Surface water sources in arid lands represent a potentially valuable, scarce resource. Control of these surface waters through large scale multiple purpose dams involve considerable costs and raise questions concerning the allocation of the water among various users, including those in different political jurisdictions. In addition, increased economic activity as a consequence of control raise quality of water concerns. This is particularly true of irrigated agriculture.

A simple relationship linking the various dimensions of water quality and quantity can be expressed in terms of upstream (or senior appropriators) and downstream (or junior appropriators) as follows:

1) Upstream

$$SF_u - R/T_u = WD_u$$

$$WD_u = BU_u + RF_u$$

2) Downstream

$$SF_D = SF_u - R/T_u - BU_u + RF_u + NF_D$$

$$SF_D - R/T_D = WD_D$$

$$WD_D = BU_D + RF_D$$

where	SF_u, SF_D	=	stream flow in upstream (downstream) basin
	R/T_u, R/T_D	=	reservoir and transport losses of water in upstream (downstream) basin
	WD_u, WD_D	=	water deliveries to upstream (downstream) users
	BU_u, BU_D	=	beneficial use or actual consumption by upstream (downstream) users
	RF_u, RF_D	=	return flows by upstream (downstream) users
	NF_D	=	new stream flow in downstream basin

Potential externalities exist with return flows (RF) and improved beneficial use (BU) which reduces the level of water requirements or deliveries necessary for crop production. Improvement in beneficial use (BU) is unambiguously positive as it conserves water for subsequent or downstream appropriators. Return flows (RF) yields positive externalities with respect to water quantity, but negative externalities with respect to water quality as degradation occurs through salinity, pesticide, and fertilizer concentration increases in the drainage and return flow water.

How decision making units allocate surface water in arid lands and how they treat the externalities arising from their beneficial use is a key to the sustainability of the resulting irrigated agricultural settlements.

3 The Lower Colorado River and Irrigated Agriculture

This section provides a description of the allocation of water in the Colorado River Basin within the U.S. and between the U.S. and Mexico. These decisions provided an impetus for the development of irrigated agriculture in the Southwestern U.S. and Northern Mexico along the Lower Colorado River Basin.

A brief description of the Imperial Irrigation District (IID) in California and the Mexicali Irrigation District (MID) in Baja California and Sonora follows. The commencement of operations of the Wellton-Mohawk Irrigation District (WMID) in Arizona and the incremental discharge of highly saline drainage water into the Colorado River led to the U.S.-Mexico salinity dispute. This section concludes with the resulting negotiations towards a settlement.

3.1 Allocation of the Colorado River

The Colorado River Compact of 1922

The impetus to allocate the waters of the Colorado River came from several sources; the 1902 Reclamation Act which was to provide inexpensive water for irrigated agriculture, the rapid growth of southern California cities like Los Angeles, and the desire of slower growing upper Basin U.S. states to protect water supplies from senior lower Basin state appropriation. Initially, Mexican claims on the Colorado River were relatively minor, ranging from an annual use of 228,000-750,000 acre feet in the Mexicali Valley adjacent to the Imperial Valley of California. The unregulated river brought snowmelt torrents with flooding in late spring in Mexico and meagre late summer flows. As a result, agriculture in the Mexicali Valley was limited to approximately 240,000 acres (Glaeser, 1946).

The political subdivisions and the Colorado River Basin area are depicted in Figure 3.1.1. The drainage area of the Colorado River Basin represents some 242,000 square miles with an average historical flow or runoff estimated in the 1920s to be 15-16 million acre feet (MAF) per year. Prior to the construction and operations of dams and diversion facilities, Mexico as the downstream user suffered the annual fluctuations in streamflow.

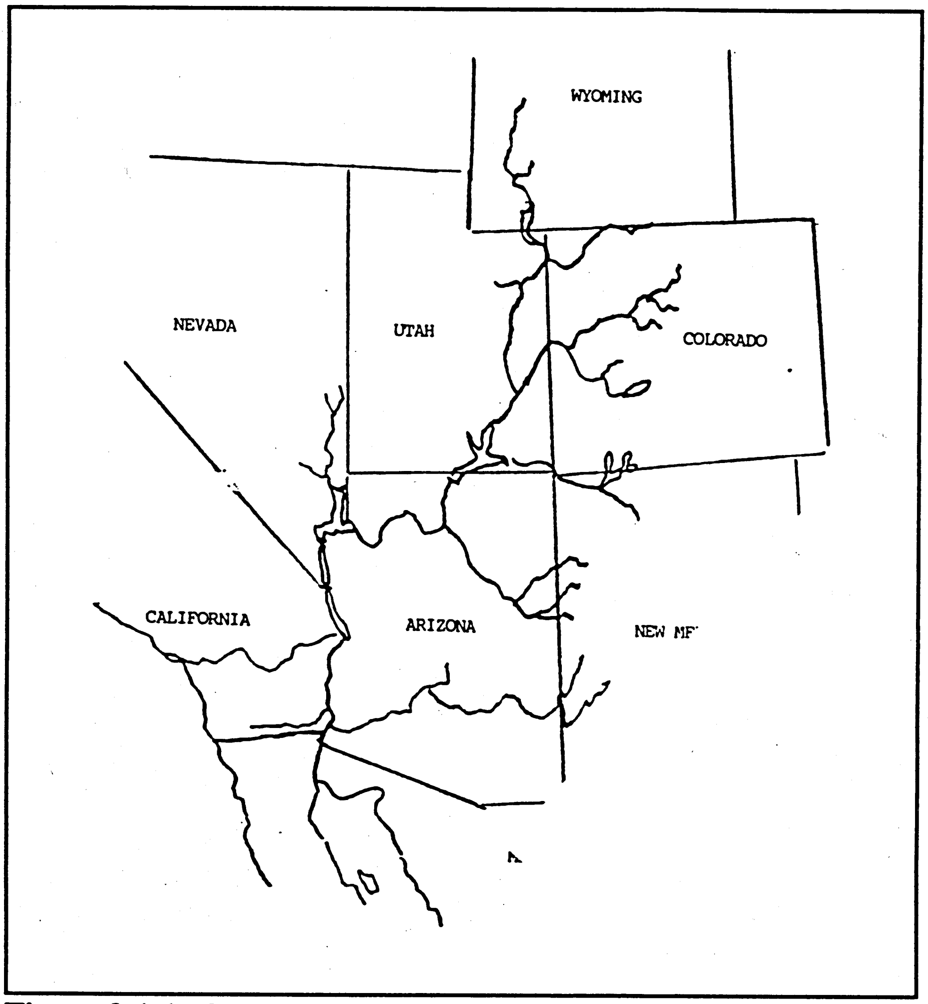

Figure 3.1.1 COLORADO RIVER BASIN: POLITICAL SUBDIVISIONS

Early efforts by California farmers to divert Colorado River water via a gravity canal through Mexico (the Alamo canal) increased irrigated agriculture on both sides of the border. As a concession, one-half of the water from the Alamo canal would be provided free to Mexico. However, the Imperial Valley District had a concession for agricultural production in the Lower Colorado area of Mexico through a subsidiary. Thus, U.S. interests were beneficiaries of the canal on both sides of the border.

The Upper Basin (Wyoming, Utah, Colorado and New Mexico) and Lower Basin (Arizona, California and Nevada) states negotiated an interstate compact in 1922 allocating the waters of the Colorado River. This compacts was approved by the U.S. Congress.

The main elements of the 1922 Colorado River Compact are as follows: (1) the waters of the Colorado River were divided between the Upper and Lower Basin states. Both Upper and Lower Basin states received guaranteed rights to water; (2) the Compact provided that <u>if</u> in the future the U.S. should guarantee allocations of water to Mexico, it would first come from any surplus water over the specified Upper and Lower Basin allocations. If no surplus deliveries were available, then the water delivered to Mexico would come equally from the Upper and Lower Basin states.

The specific terms of the compact requires the Upper Basin states to deliver 75 million acre feet (MAF) of water over a 10 year period to Lee Ferry, Arizona (the division line between the Upper and Lower Basins). At the time of the Compact, based upon estimates of annual flows from 1897-1921, the runoff was 15 to 16 MAF per year. Thus, the Upper and Lower Basin states would each receive about one-half the Colorado flow although only the Lower Basin is guaranteed. The Upper Basin bears the risk of stream flow variation.

Actual apportionment of waters among the various states did not occur smoothly. California and Arizona could not agree on the division of Lower Basin waters after more than 30 years of Congressional fighting and lawsuits. Finally, the U.S. Supreme Court decided the allocation in the case Arizona v. California. The Upper Basin states agreed to distribute its share among the five states in the Upper Colorado River Basin Compact in 1948.

In addition to the 7.5 MAF the Lower Basin states would receive from the Upper Basin, it was estimated that an additional 1.0 MAF annually of water would be available from local streams in the Lower Basin.

The U.S.-Mexico Water Treaty of 1944

Multipurpose irrigation projects like those at Hoover Dam in 1935 brought flood control, irrigation water and electric power to the U.S. The regulated releases from U.S. dams reduced floods in the plains of the Mexicali Valley and stimulated irrigated agriculture development in the valley as well.

Mexico expanded its use of the Colorado River so that by the early 1940s it reached 1.8 MAF per year. The U.S. and Mexico had begun negotiations in the late 1920s, when usage was 750,000 AF. The U.S. had offered that amount, Mexico had demanded 3.6 MAF. A drought in 1943 caused a resumption of serious negotiations. The result was the Water Treaty of 1944 codifying U.S.-Mexico water rights along the Colorado River, the Rio Grande and the Tijuana River.

The Treaty guarantees Mexico 1.5 MAF per year from the Colorado River. Defending this allotment, the U.S. State Department argued that up to 750,000 AF would come from return flows below the Imperial Dam which would go to Mexico regardless of a treaty (Holburt, 1982). The Lower Basin States, particularly California, argued against that interpretation. U.S. negotiators insisted that Mexico's negotiators understood that they would have to accept the water regardless of quality. Mexico's negotiators maintained it was understood by the U.S. that all water delivered must be of good quality. These positions were reiterated by both sides when the salinity question was later debated (Utton, 1973).

The allocation of the Colorado River waters among the Upper and Lower Basin states and between the U.S. and Mexico has remaining concerns as Table 3.1.1 illustrates. Column 1 represents the allocation system explicitly and implicitly defined in the 1922 Colorado River Compact. Streamflows was based upon 1897-1921 data. Of 15 MAF, some 7.5 MAF must be delivered to the Lower Basin, giving each Basin approximately one-half.

Column 2 illustrates the impact of the Water Treaty of 1944. Each basin must relinquish 750,000 AF of their allotment to comply with the treaty. Estimated evaporation losses of the reservoirs which come out of the Upper basin allocations are also included.

Table 3.1.1
Allocations of Colorado River (Millions of Acre Feet)

	1922 Compact	1944 Treaty	1990-Revisions[1]
Total Stream Flow	15-16	15-16	13.5
Lower Basin	7.5	6.75	6.75
California	4.4	4.0	4.0
Arizona	2.8	2.5	2.5
Nevada	.3	.29	.29
Reservoir Losses	NA	NA	0
Upper Basin	7.5	6.75	5.25
Reservoir Losses	NA	NA	.50
Mexico	NA	1.50	1.50
Total Allocations	15.0	15.0	13.50
Balance	+1.0	+1.0	0

[1] **Revisions include long term estimates of stream flow at 13.5 MAF; reservoir losses of .5 in upper basin; net inflow in lower basin offset by reservoir losses (.8) and proportionate reductions in Lower Basin states.**

The last column revises the estimated annual streamflows along the Colorado River. The initial figure of 15 MAF upon which the Compact of 1922 relied was found to be upwardly biased for two reasons. The first was poor measurement and sampling in the initial 10 year period 1897-1907. The second was that the 1906-1929 years constituted a wet period, of above average stream flow. More recent studies indicate that the actual long term river flows are about 13.5 MAF per year. When reservoir and transport evaporation losses are considered as well, it is clear that reliance on good quality return flows of waters is necessary by all parties, if actual allocations are to approximate compact and treaty obligations.

Today while the Upper Basin is still not at complete appropriation in terms of its allocation, all Lower Basin water is allocated. This is complicated by the coming on line of the Central Arizona Project (for the Tucson and Phoenix areas) which requires 800,000 AF from the Colorado River. This new allocation will result in reduced allocations: Arizona to 2.5, California 4.0 and Nevada .29 MAF, respectively. Reservoirs could of course be drawn down in drought circumstances. However, this could conflict with power production needs.

In sum, it appears that the Colorado River, especially the Lower Basin, may be overallocated in terms of more recent estimates of long term supply availability and current and anticipated demands.

3.2 Irrigated Agriculture in Lower Colorado River Basin

With the negotiation of the Colorado River Compact of 1922, construction of multipurpose dams to control the flow of the river system to enhance economic development began in earnest. Of 19 major dams on the Colorado River, 17 were built between 1927 and 1964, impounding some 70 MAF of water (Graf, 1984). Included are two of the largest dams in the world, Hoover Dam at 221 meters high, impounding 30 MAF in Lake Mead and Glen Canyon Dam at 216 meters high, impounding 27 MAF in Lake Powell.

In addition to major dams, there are numerous diversion dams which have limited reservoir capacity. The Imperial Dam in the southwestern U.S. and the Morelos Dam in northern Mexico are diversion dams designed to divert and distribute waters of the Colorado River for agricultural, municipal and industrial users.

Irrigated areas in the southwestern U.S. and Mexico served by diversions of water at or below the Imperial Dam are depicted in Table 3.2.1. The areas in the U.S. include irrigation districts in Arizona and California. The large Mexicali irrigation district in Mexico is situated in the states of Sonora and Baja California. The areas depicted in Figure 3.2.1 refer to total areas farmed by irrigation, and duplication of irrigated areas due to multiple cropping has been eliminated. These acreage figures change slightly from year to year.

Table 3.2.1
Irrigated Areas Below Imperial Dam

	Irrigated Acres
United States	
Imperial Dam	
Yuma Valley	45,779
Reservation Division	12,276
Yuma Mesa	16,629
Yuma Aux. Project	2,695
South Gila	9,575
North Gila	5,436
Wellton-Mohawk	59,135
Coachella Valley	58,106
Imperial Valley	460,965
Warren Act	80
Nonproject lands	12,560
Total U.S.	683,236
Mexico	
Morelos Dam	
Mexicali Valley	529,850
Total U.S. and Mexico	1,213,086

Source: International Boundary and Water Commission, U.S. Section. Flow of the Colorado River and Related Data, 1988.

Further detail will be provided on only three of these districts. In the U.S., the operations of the Wellton-Mohawk Irrigation and Drainage District in the late 1950's and early 1960's precipitated the salinity controversy between the U.S. and Mexico.

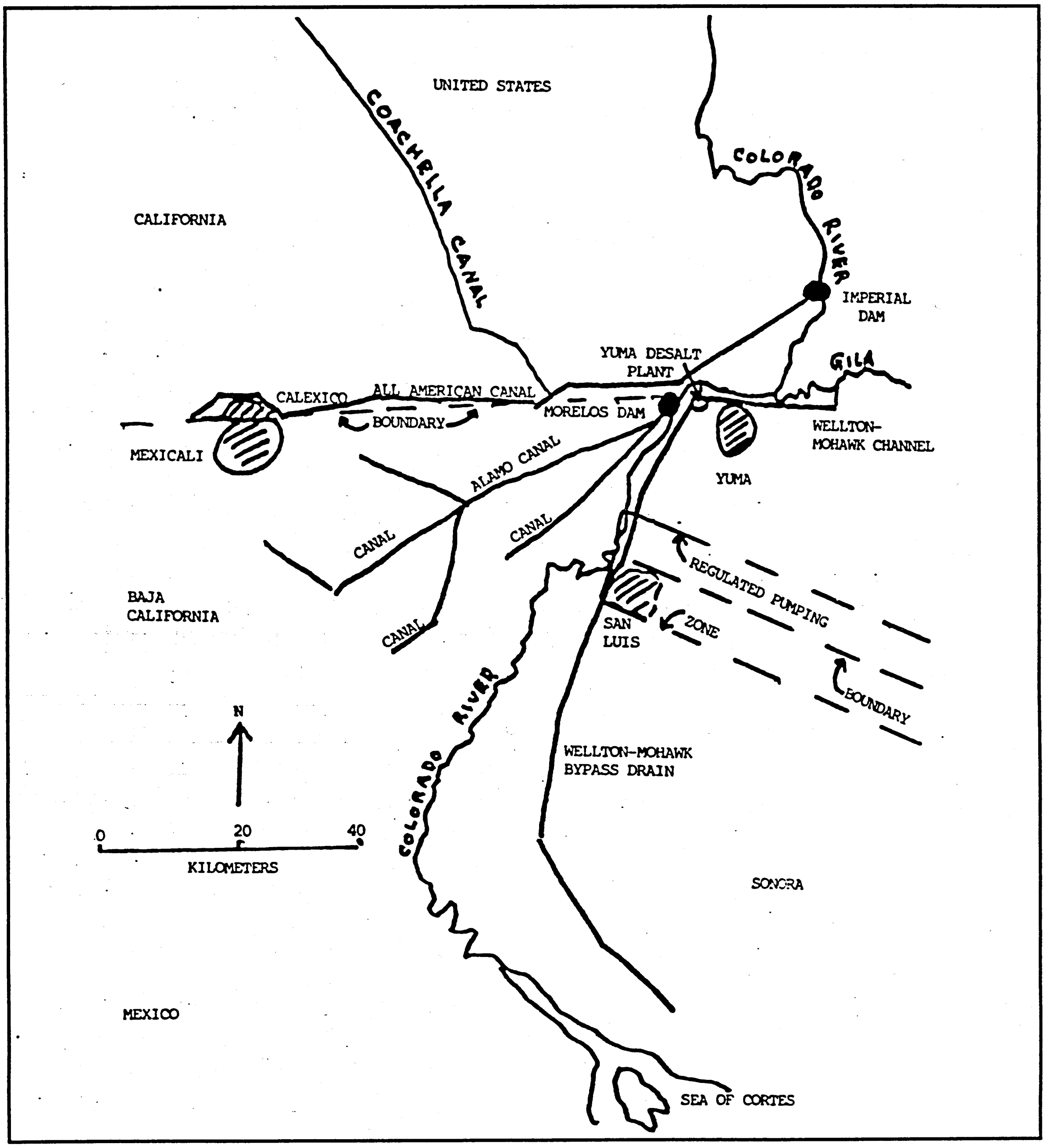

Figure 3.2.1 IMPERIAL AND MEXICALI IRRIGATION DISTRICTS

The other two districts examined are the Mexicali Valley Irrigation District (Federal District No. 14) in Mexico and the Imperial Irrigation District in California. They are both large districts, similar in soil types and are roughly adjacent to each other. They are served by the twin cities of Calexico, California and Mexicali, B.C. Each district is well developed from an agricultural standpoint with large networks of irrigation channels, canals, and related infrastructures.

The Imperial Irrigation District (IID)

The IID distributes approximately 2.6 MAF of the Colorado River from the All American Canal which originates at the Imperial Dam. This diverted water serves nine towns and nearly 500,000 acres of agricultural lands. The IID was formed in 1911 and in a 1964 U.S. Supreme Court decision the District's 2.6 MAF of water rights were defined. In times of shortage, the IID water rights must be satisfied first, even before the Metropolitan Water District in Southern California (incorporating Los Angeles).

Of the 2.6 MAF available to the IID, approximately 98 per cent is used by agriculture, or about 5 AF per acre. Irrigation methods are varied, some are water conserving including sprinkler, drip and return flow irrigation. Others are more wasteful and include basin and open furrow irrigation. However, irrigation choices depend on crops chosen and soil conditions.

Average consumptive use of water (i.e., water use by crops to build plant tissue, water transpiration from plants and water evaporation from soils) averages 3.7 AF per acre. With water applications averaging 5.0 AF per acre, the IID system-wide irrigation efficiency is about 74 per cent. Some of the excess water use over consumptive use is due to leaching requirements, to remove salts from the soil profile (IID, 1989).

The irrigation facilities are as follows. Water reaches the IID from several main channels from the All American Canal as Figure 3.2.1 illustrates. Within the District boundaries, there are 1,675 miles of delivery canals. Some 900 miles are concrete lined to reduce losses due to percolation. A gravity flow drainage system exists designed to provide a drainage outlet for each 160 acres. Drainage canals are 1,457 miles in total and direct drain flows into three main areas that flow directly into the Salton Sea as Figure 3.2.1 indicates. The Salton Sea is a closed saline body of water.

In 1988, the total value of agriculture from the IID was $672 million or about $1,450 per irrigated acre. This production came from 4,733 full-time and 1,841 part-time farm units. The total farm population (ignoring hired labour) was 12,655 (U.S. Crop Production Report, 1988). In terms of acreage and in total value, the most important crops are alfalfa, lettuce, onions and fresh tomatoes. Alfalfa is an important crop in the District because 10-12 or more cuttings per year are obtained as it is grown year around. It is a heavy water user. Lettuce, onions and tomatoes are important as they are fresh vegetables destined for the U.S. market before more northern farm crops are planted and mature.

Most of the hired labour in the IID are Mexican nationals or Mexican-Americans. Calexico, the major U.S. city near the IID and Mexicali, the major Mexican city in the Mexicali Valley, are twin cities and border crossings for shopping, sightseeing and work are relatively uncomplicated on either side.

Mexicali Irrigation District (MID)

The irrigated area within the Mexicali Valley is called the Mexicali Irrigation District (MID) or Distrito De Riego No. 014, Rio Colorado of the Comision Nacional Del Agua. Representing some 529,000 acres, it is one of the four most important irrigation districts in Mexico. Table 3.2.2 depicts the sources and uses of water in the district. By land area, approximately two-thirds depends upon the Colorado River, the remainder on federally or privately operated wells. It is widely acknowledged that overpumping of the aquifer is occurring. The quality of the underground water is poor. Precipitation is negligible. By category of user, the Colorado River diversions are important for municipal and industrial users as well as agriculture. Little underground water is used for anything but irrigation.

In terms of fulfilling the 1944 Treaty between the U.S. and Mexico, the MID receives 1.5 MAF of water per year, 1.37 MAF diverted through Morelos Dam and .13 MAF through the Yuma canal near San Luis. Figure 3.2.1 depicts the broad features of the MID. After diversion at Morelos Dam, the Colorado River is often dry, or receives drainage discharge water from irrigation users.

Table 3.2.2
Water Use in Mexicali Valley

	Gravity[1] (mm^3)	Wells (mm^3) Federal	Private	Total
Irrigation	1,381.5	672.6	197.2	2,251.3
Domestic	91.4	.1	..	91.5
Industrial	4.7	..	..	4.7
Other	99.0	4.6	3.0	106.6
Total	1,581.6	677.3	200.2	2,454.1

Source: Comision Nacional del Agua, Distrito de Riego 014, Resultados Plan de Riegos (various years).
[1] Essentially water from Lower Colorado River.

The MID irrigation facilities are as follows. About 85 per cent of the MID by area is located west of the Colorado River and is irrigated by canals originating at the Morelos Dam. The area east of the Colorado in the vicinity of San Luis Rio Colorado receives water from the Yuma valley through the Sanchez Mejorada Canal. There are 282 miles of main canals (210 miles are lined) and 1,460 miles of lateral canals (1,130 miles are lined) and some 7,731 different irrigation structures (Palacios, 1987).

Drainage facilities exist but are incomplete. The MID area has two water sheds. The northern drains into the New River (see Figure 3.2.1) and eventually into the Salton Sea in California. The southern watershed (60 per cent of area) drains into the Colorado River and into the Sea of Cortes. This network comprises 253 miles of main drains and 744 miles of lateral or secondary drains. There is no field drainage at all, and as a consequence waterlogging can be serious in certain areas. It is estimated that 135,000 acres have a water table depth of less than 2 meters (and 62,500 acres have less than 1 meter). In areas which rely on underground water (mostly in the northeast part of MID), there is also no horizontal drainage network of canals. Instead, infiltration into the subsurface is relied upon.

Water allocation is centralized within Mexico's National Commission on Water (CONAGUA). First, estimates are made of irrigation needs at planting time and subsequent periods by soil type (light, medium, heavy) and irrigation practice (furrow or basin) and crop choice (CONAGUA, 1990a). Next, CONAGUA decides the total of each crop that the MID can plant in the coming year. This is an attempt to develop a water balance - between available supplies and water demand based upon crop, soil and irrigation requirements. This total crop choice is coordinated with banks providing credit to farmers. Farmers with water rights make choices on what crop to grow, subject to overall limits. If a particular crop has reached its aggregate acreage limit, an alternate crop must be chosen (Jonish, 1990).

This lack of available water through restricted deliveries and poor on-farm use-efficiency impacts considerably on the MID production and employment potential. Since the soil profiles and climate of the MID is very similar to that of the Imperial District (IID), more water available or more efficient use of water would permit similar patterns of double cropping and perennials. For the Mexicali district, this would imply a 25 per cent increase in the annual value of production and associated employment. In 1988 U.S. dollar terms (from the IID crop reports), the value of this increased production would be about $130-140 million per year or $290 per acre.

There are 13,126 farm users in the MID. Some 5,655 are private owners and 7,471 are communal property owners. The average size farm for each is 36 acres and 42 acres, respectively. Thus, farms are of small size, whether private of communal (Palacios, 1987).

<u>Wellton-Mohawk Irrigation District (WMID)</u>

Modern irrigated agriculture in the Wellton-Mohawk Irrigation District (WMID) area dates to about 1909. underground water was utilised from 1915 to the late 1930s but a rapid declining water table, plus excessive salinity led to an abandonment of many farms. Local farmers turned to the U.S. Bureau of Reclamation for assistance in obtaining irrigated water. Eventually, the U.S. Congress authorised the construction of facilities for the Wellton-Mohawk district comprising 75,00 acres or a maximum use of 300,000 AF of water per year. Construction began in 1949 and the first water was delivered in 1952.

As with the Imperial and Mexicali Irrigation Districts, irrigation water has made the Wellton-Mohawk Irrigation and Drainage District highly productive. In 1988 dollars, the gross value of production was $117.2 million or $1,965 per irrigated acre. Major crops are alfalfa, cotton and lettuce. Lettuce production is 52 per cent of the gross value of production (U.S. Crop Report, 1988). The WMID has 132 full and part-time farms and a farm population, ignoring hired labour, of 479 people. As in the Imperial Irrigation District, most hired labour are Mexican-Americans or Mexican nationals.

Although it was recognised that drainage facilities would eventually be required at additional project costs, the drainage works were initially delayed in the WMID. With irrigation water applied, the water table rose and it was highly saline. Leaching of the soil to reclaim the lands led to rapid waterlogging of soils. Some areas went out of production in the late 1950s (Wellton-Mohawk, 1978).

To discharge this water, a concrete lined channel was constructed in 1959 into which drainage pumps, many of which were former irrigation pumps, could discharge their flows. The end of the newly constructed drainage channel was allowed to flow into the Colorado River. Discharge water was as high as 6,500 PPM in the early 1960s. This incremental loading of salt in the Colorado River was the genesis of the U.S.-Mexico water salinity problem. It was further aggravated by the impoundment of water behind the newly constructed Glen Canyon Dam (Lake Powell) which reduced Mexico's water deliveries to 1.37 to 1.8 MAF per year from the Colorado River during 1961-70. Prior to that, deliveries ranged from a low of 2.3 to 6.0 MAF from 1957-60. Larger flows, of course, would dilute the impact of any salt loadings.

3.3 The Salinity Controversy and Resolution

With the installation and operation of a number of drainage wells and the completion of a concrete lined drainage channel in 1961, the Wellton-Mohawk district waterlogging problems were being resolved. But the discharge of a substantial volume of saline drainage in the Colorado River below the last diversion point in the U.S. but above the diversion at Morelos Dam in Mexico, led to international complications. Salinity at the Morelos Dam had averaged 785 ppm in 1959 and 1960, increased to 1360 ppm in 1961 and 1490 ppm in 1962. Salinity figures for 1955 to 1970 are illustrated in Table 3.3.1. Mexico objected strongly and vociferously and the salinity question became an important issue in Mexico's political elections. Even within Arizona, impacts were felt. The city of Yuma, downstream from the Wellton-Mohawk district, received its drinking water from the Colorado River. The Arizona Water Company, which treated and delivered this water to Yuma, had to change its source of potable water after 1961 from the Colorado River to a main channel from the All American Canal. This water from the Colorado River is diverted at the Imperial Dam, upstream from the Wellton-Mohawk district (Wellton-Mohawk, 1978).

To resolve the salinity dispute, Mexico and the U.S. entered into negotiations to arrive at a joint resolution. Governors of the seven U.S. Basin States each appointed two members to a Committee of Fourteen to advise the U.S. State Department on their position in the negotiations, and to protect their interests. A new treaty was not called for, but an adjunct agreement on quality standards was necessary.

The legal views of a number of participants can be summarized by Gantz and Sobarza (Utton, 1973). Gantz argued that U.S. "just and reasonable beneficial use" of water must increase salinity. The question is how much. He doubted whether salinity increases to 1,200-1,400 PPM would have much effect on yields. Thus, the U.S. has attempted to act reasonably. Further, the 1944 International Treaty provided no standard as to the quality of water received. This resurrected the now discredited "Harmon doctrine" which stated in a 1895 dispute that "rules, principles and precedent of international (river) law impose no liability upon the United States" (Lester, 1963). Other countries have also relied on the Harmon doctrine in international river basin disputes.

Sobarza attacked the U.S. position that 1.5 MAF regardless of quality fulfils the treaty. The Treaty provides that water to Mexico is to be used for domestic/municipal and agricultural uses. If the quality is so poor it cannot be used for these purposes, does it not violate the Treaty, or certainly the good faith of the Treaty. Sobarza calls for the U.S. to control salinity at Wellton-Mohawk and to compensate farmers in Mexico for damages (Utton, 1973).

A number of interim solutions were negotiated. In 1965, a five year agreement was reached entitled Minute 218. A "minute" is a record of the International Boundary and Water Commission, U.S. and Mexico (IBWC). Under Minute 218, the U.S. extended the Wellton-Mohawk Drain to the Morelos Dam so Mexico could by-pass the drainage water past its diversion point at Morelos Dam. Also, the U.S. supplied an additional 40,000 AF per year to replace the drainage water that had been considered part of the U.S. quantitative allotment to Mexico. Salinity, though reduced, still remained high (Holburt, p. 107) as Table 3.3.1 illustrates.

Mexico remained dissatisfied and negotiations continued. Finally, an interim agreement was formalized as Minute 241 of the IBWC in 1972, replacing Minute 218.

Basically, it provided that the U.S. increase diversions of high salinity water below the Morelos Dam and replace it with increased deliveries from the Colorado River and underground water from the Yuma Mesa. This resulted in greater quantities and further reductions in salinity at Morelos Dam.

Table 3.3.1
Salinity Levels and Differentials: Imperial and Morelos Dam 1955-1970

	Morelos	Imperial	Differential
1955	820	807	13
56	910	891	19
57	870	818	52
58	720	726	-6
59	760	730	30
1960	810	769	41
61	1360	802	558
62	1490	820	670
63	1330	800	530
64	1300	821	479
1965	1380	888	492
66	1220	885	335
67	1210	841	369
68	1200	838	362
69	1190	877	313
1970	1140	896	244

Source: International Boundary and Water Commission, U.S. Section, Flow of the Colorado River and Related Data (various issues). See Appendix A for recent data.

Negotiations aimed at a more definitive solution continued with conflicting views of interested parties. Differences existed on the U.S. side. States desired a negotiated settlement for several reasons, including avoidance of the possibility of having to submit to World Court Arbitration. The Office of Management and Budget wanted an inexpensive solution. The Basin states did not object to temporarily increased quantities but opposed a permanent commitment that would raise obligations above 1944 Treaty levels. Mexico wanted the quality of the water delivered to the Mexicali Valley to equal the quality of that delivered to the Imperial Valley. Also, Mexico believed it was entitled to compensation for damages caused by the saline Wellton-Mohawk waters since 1961 (Holburt, p. 109).

Finally, differences were resolved and the new agreement was approved by the U.S. and Mexican Presidents in August, 1973 and incorporated in Minute 242 of the IBWC, terminating Minute 241. This was to be a permanent and definitive solution to the Colorado River salinity problem.

The main provisions of Minute 242 (Minute 242, 1973) are as follows. (1) By no later than July 1, 1974, waters delivered to Mexico will have an average annual salinity of no more than 115 ppm, plus or minus 30 ppm, over that at Imperial Dam (roughly 10 per cent more). (2) Extension of the concrete-lined Wellton-Mohawk drain to the Gulf of California (Sea of Cortes). The construction and operation was done by Mexico, but paid for by the U.S. (3) Limitations of groundwater pumping five miles each side of the Arizona-Sonora border. This was to prevent competitive overpumping of the aquifer by Mexico and the U.S. for agricultural use or to meet Treaty obligations. (4) The U.S. will pay for aspects of a rehabilitation of the Mexicali Valley connected with the salinity problem, including drainage. The amount to be negotiated later.

The major advantages to Mexico of Minute 242 are: (1) a guarantee of water quality at the Morelos Dam related to water quality at the Imperial Dam with the costs of achieving this to be paid by the U.S.; (2) the promise of U.S. financial assistance with respect to the salinity problem; and (3) a concrete lined canal constructed in Mexico at U.S. expense to discharge saline water. The major advantages to the U.S. are: (1) the elimination of prolonged future acrimony on this issue; and (2) the implicit waiving by Mexico of future rights to press for retrospective compensatory damages due to the salinity increases in the 1960s. Although Minute 242 is silent on the issue of salinity control upstream of Imperial Dam, all parties agree that upstream salinity control is necessary to the long-term success of the plan. Indeed Mexico apparently believes that the U.S. has committed itself to control the river's salinity upstream (Holburt, 1982).

The U.S. administration wanted the enabling legislation to cover only the necessary expenses connected with implementing Minute 242. The congressional representatives of the Colorado River Basin States felt that a basin-wide salinity control programme should be included and they prevailed. The Colorado River Basin Salinity Control Act, Public Law 93-320, became law on June 24, 1974. Title II was entitled Measures Upstream from Imperial Dam. Title I, implementing the agreement with Mexico, was entitled Programs Downstream From Imperial Dam.

4 Policy Responses and Cost of Compliance

Minute 242, the negotiated settlement to the salinity problem along the Colorado River, permits two major conclusions to be inferred. One, it recognizes the right of Mexico to receive water of reasonable quality and that the increment in salinity due to the Wellton-Mohawk drainage was unreasonable. Two, it acknowledges that the U.S. Federal government is responsible for the attainment of a reasonable standard of water quality in deliveries of water to Mexico. That liability for quality attainment rests with the Federal government is of interest since this influenced the technology choices in achieving salinity standards.

Other more direct participants in salinity degradation could be identified. Farming and irrigation practices of farmers in districts like the Wellton-Mohawk contribute to the salinity build-up with irrigation return flow. Management of irrigation districts which condone water waste through poor irrigation practices, low irrigation fees and resulting overuse of water represent another more direct participant. Gross agricultural and industrial economic activity in Upper and Lower Basin states along the Colorado River all contribute to increased salinity over time.

That individual, district or states pay for their salinity contributions by a user or pollution fee was never considered. The costs of compliance were to be funded out of U.S. Federal general revenues.

The people of Arizona and Wellton-Mohawk resented the implication that it was their district responsible for the high salinity and with some justification they argued that they contributed no more salt than those districts upstream. Western states irrigation interests supported Arizona in the view that international problems are a Federal government responsibility to be carried out without detriment to the Basin States interests (van Schilfgaarde, 1982).

The responsibility of monitoring the performance of Minute 242 rests with the International Boundary and Water Commission, U.S. and Mexico sections. Since 1974, water delivered to the Moroles Dam has fallen within the salinity standard agreed upon in Minute 242 (see Appendix A for data).

This section examines the U.S. implementation of the salinity agreement and the cost of compliance. Further, alternative salinity compliance measures are identified and orders of magnitude of costs developed. Reasons are identified for the low cost option not being selected.

4.1 U.S. Implementation of Salinity Control Measures

To implement the provisions of Minute 242 and to deal with salinity in general in the Upper and Lower Colorado River basin, the U.S. Congress passed PL93-320 in June, 1974. Title I provided for Lower Basin salinity control activities at a 1973 estimated cost of $155.5 million, while Title II provided for Upper Basin salinity control activities at an estimated cost of $125.1 million in 1973 prices.

Title I includes six major provisions. (1) To construct, operate and maintain a desalination complex near Yuma to receive and process saline water of the Gila bypass canal (built earlier) from the Wellton-Mohawk district. (2) To build a concrete lined bypass drain to carry reject water from the desalting plant to the Santa Clara slough in the Gulf of Cortes. (3) To drill and operate underground water wells (Minute 242 wells) to assist in providing up to 140,000 AF of water annually to meet water delivery requirements to Mexico. (4) To purchase lands (or exchange) within 5 miles of the border to meet water delivery requirements. (5) To purchase 10,000 acres of Wellton-Mohawk land and retire it from irrigated agriculture. (6) To provide for the lining of the Coachella canal as a water conservation measure.

The details of these provisions and their locations are illustrated in Figure 4.1.1. The desalination plant is located near the city limits of Yuma and is to be operated by the Bureau of Reclamation. The Wellton-Mohawk bypass canal carries reject water from the desalting plant through Mexico to the Santa Clara slough. The agreement to limit pumping of underground water within five miles of each side of the border is illustrated by the shaded area in Figure 4.1.1. It is approximately 19 miles from the Imperial Dam to the Morelos Dam. The large Imperial Valley and Mexicali Valley irrigation districts are centred near Calexico, California and Mexicali, Baja California, respectively. Through much of the year, the Colorado River below Morelos Dam is dry as all usable water has been diverted.

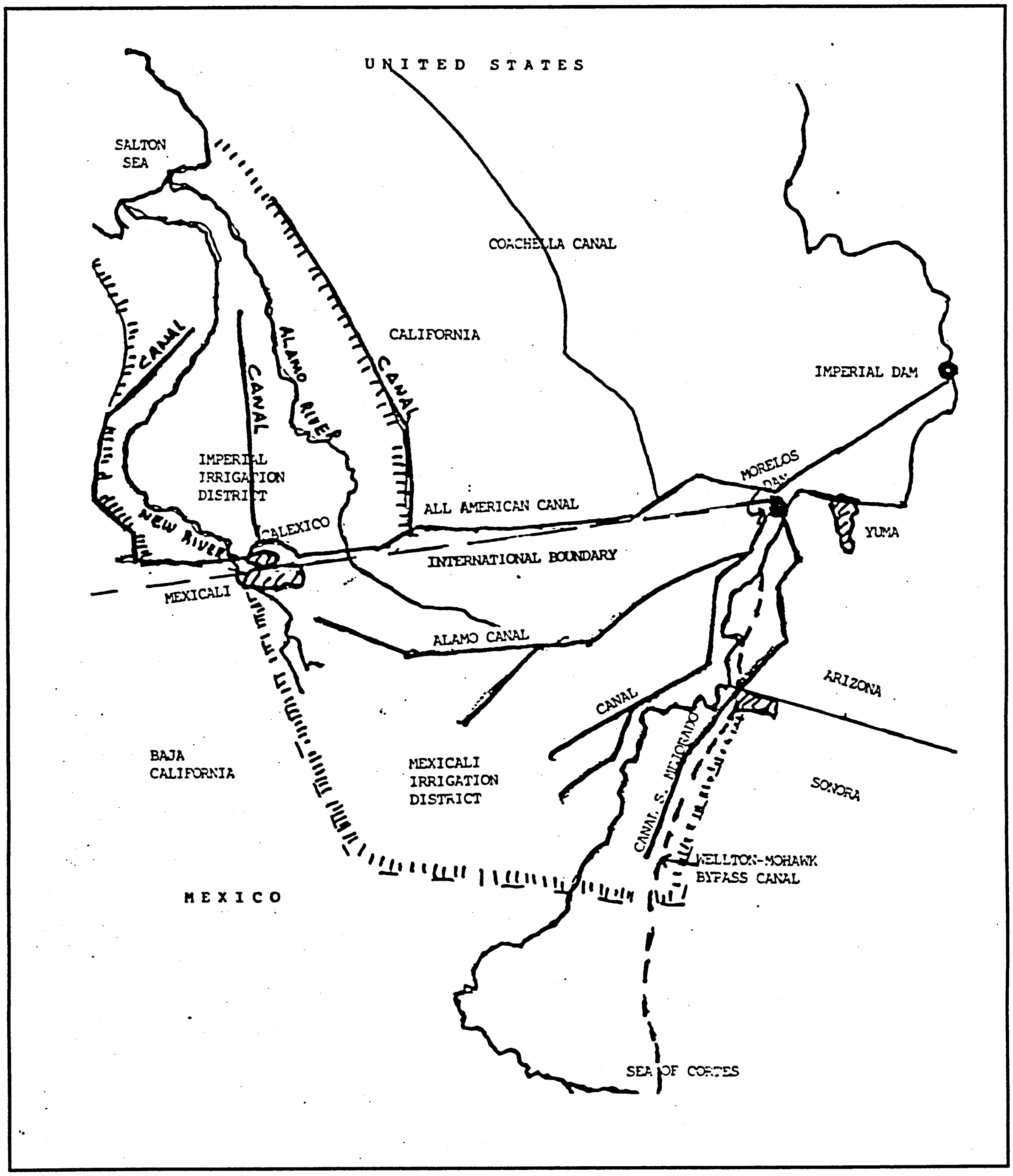

Figure 4.1.1 MINUTE 242 ACTIVITIES

The original plan regarding the desalination or desalting complex was to treat 120 million gallons per day, remove 90 per cent of the salt and total dissolved solids and recover 70 per cent of the water for delivery to Mexico. The remaining 30 per cent of reject water (of a near brine quality) would go to the Santa Clara slough. The original estimated cost of the desalting complex was $121.5 million of the $155.5 million total cost of Title I.

The desalting plant is to be the largest reverse osmosis plant in the world. The product water returned to the Colorado River for delivery to Mexico will be 300 ppm. When combined with untreated water in the river it will provide a sufficient quality and quantity of water to Mexico. It has been estimated that this will save 78,000-80,000 AF per year. The reject brine water will be about 10,000 ppm and will flow to the Santa Clara Slough in the already constructed bypass canal.

The process is as follows. The Wellton-Mohawk drainage water is input to the desalt plant in a lined bypass canal. Input will be approximately 110,000 AF per year. With 78-80,000 AF of product water this represents about a 73 per cent recovery rate. Intake pumps put the saline water into three reactors for chemical treatment for scale and to remove silt. Lime is added to develop a chemical compound for sludge which is removed and moved to storage some 22 miles away. The dried sludge can be sold. The treated water is moved to a settling facility and then pumped to desalting facility. Some 9000 membranes with pressure at 4000 lbs/sq. in. provided by hydroelectric power are involved in the desalting operations. After desalting through reverse osmosis, the product water is mixed with untreated river water, while the reject brine water is returned to the bypass canal for discharge. The full desalting plant operations are to commence in early 1992. A pilot facility of 1 mgd has been operational for a number of years. The other provisions of Title I have been implemented.

The desalting complex capacity has been scaled back in size twice; from 120 mgd to 96 mgd in 1985 and to 73 mgd in 1991. The cost estimates of the desalt complex have risen significantly even with the scale cutbacks. By 1977, it was $248 million, by 1984, $401 million and by 1991, $364 million with the capacity reduced to 73 mgd.

The desalting plant delay reflects the lack of legislative funding as higher priorities developed in the Reagan Administration, and as the immediate salinity crises abated with the construction of the bypass canal of 52 miles to the Santa Clara slough. In addition, above average volumes of water delivered to Mexico in the early and mid 1980s diluted and lowered the average salinity of the Colorado.

A number of difficulties arise in the desalting complex. Power requirements are estimated at 35 MW necessitating generating capacity of 49 MW. The Bureau of Reclamation, the desalt plant operator, maintains the power will come from the Government-owned share of power at the Navajo Generating Facilities, or Four Corners. That facility itself has its own environmental problems but the main point of critics is that this committed power is foregone for household or industrial use (Lopez, 1978). Further, membrane replacement and chemical costs estimates appear understated given the operating experience with the pilot plant (Jonish, 1990). In sum, it appears that the savings of water will be at the expense of considerable expenditure of energy.

The remaining provisions of Title I have been implemented and they include the lining of the Coachella canal for conservation purposes. This prevents percolation of the water into the ground during transport. The bypass canal takes current Wellton-Mohawk drainage past Yuma and the Morelos Dam to the Santa Clara Slough. On farm irrigation efficiency practices were also introduced with some success. These are discussed later.

4.2 Cost of Compliance: Existing Policy Interventions

Minute 242 provides for a relative salinity standard in terms of compliance. It is appropriate then to determine the most cost effective method to achieve this standard. Yet, in spite of early critical evaluations of reliance on the desalting complex and related actions (Martin, 1991; van Schilfgaarde, 1982), no effective least cost analyses of other options were considered. Instead, there was an emphasis on high profile technology, decisions involving Federal agencies and a status quo with respect to the irrigation district and the district farmers. To the extent decentralized efforts to control salinity were considered or adopted, these were of secondary importance.

Mexico's position has been that they consider the construction and operation of the bypass canal as having fulfilled the requirements of Minute 242 (Palacios, 1987). The saline water is delivered to the Sea of Cortes, bypassing the Lower Colorado River. Maintenance and operations costs of the Santa Clara bypass canal are paid for by the U.S. under terms of Minute 242 on both sides of the border.

However, U.S. Bureau of Reclamation officials have indicated that the desalting complex is extremely important. The current water which flows through the bypass canal does not "count" as part of U.S. obligations to deliver water to Mexico. Water treated and recovered by the desalting plant for return to the Colorado River would "count" towards Mexico's allocation. This recovery rate is now estimated at 80,000 AF per year with full operations of the desalting plant.

While true, the cost of this reclaimed water is exorbitant. Annual maintenance and operations cost of the desalting complex is estimated at $31 million per year. Plant capacity costs are estimated at $289 million (Jonish, 1990). Using one of two simple cost recovery model, the variable average cost of water is $387.50 per recovered AF (31,000,000/80,000) of water considering only maintenance and operations costs or $928 per AF ((289,000,000*.15+31,000,000)/80,000,000) if the full costs are considered at a capital cost recovery factor of 15 per cent. By contrast, irrigators pay about $10.00 per AF of water used in the Wellton-Mohawk region. Currently, irrigators do not pay for any of the desalting costs in the form of higher irrigation rates.

These average cost figures ($387.50 or $928) per acre foot are understated by subsidized energy prices and unknown membrane maintenance and operations costs in the desalting plant. Energy will come from federally-sponsored power plants at subsidized prices of 2.2 cents per Kwh. By contrast, the city of Yuma power plant costs are 8.9 cents per Kwh. Pricing energy use at full costs means that annual operating costs will be $52 million per year, not $31 million. The respective average costs of reclaimed water is $654 per AF considering only maintenance and operations costs, or $1190 per AF if the full costs of energy and construction are considered.

At the end of 1990, the actual and estimated costs of complying with Minute 242 provisions (Title I of PL93-320) are as follows in Table 4.2.1.

Table 4.2.1
Title I Project Costs: Estimates and Actual Costs to date

Cost Components (US$ millions)	Estimates	Actual
Desalting Complex includes[1]		
Yuma Plant at 73 mgd	357	281
Other Title I Works	94	82
Total Title I	451	363

Source: Bureau of Reclamation, September 1990.

4.3 Alternative Salinity Compliance Measures

In fulfilling Minute 242 requirements, a number of alternatives could have been utilized. In most instances, increased water recovery or availability was a byproduct of the improvements in salinity. These include the following options.

Retire Wellton-Mohawk Land

Nearly 10,000 of the 75,000 acres were retired as part of Title I provisions. What of complete retirement? Of 65,000 acres remaining, the average value per acre of land in late 1990 was quoted as $2,500 per acre in the Wellton-Mohawk region. Complete retirement at today's market value would be $162,500,000. This is only 44 per cent of the estimated cost of the desalting plant and it would not incur further costs of annual maintenance and operations.

Of interest to note is that the land retirement would reduce salinity and increase water availability for other users. The Wellton-Mohawk allocation is 300,000 AF per year. This "new" water through land retirement would cost $81.25 per acre foot, expensive but favourable to the desalting plant costs for recovery. This amount of water is equivalent to 2½ years of water use by San Francisco. These users pay $300 per AF.

The retirement of Wellton-Mohawk land would involve agricultural losses and population dislocation. However, the magnitude here is not likely to be great. According to a recent crop production report (Wellton-Mohawk, 1988), the gross crop value of the district was $117.2 million, or $1965 per irrigated acre. In terms of value, the most important crops were lettuce (52 per cent), alfalfa (15 per cent) and cotton (11 per cent). Even within a regional context, only lost lettuce production is likely to have an impact on market prices.

The direct and indirect loss of employment is also anticipated to be small. There were 132 farms operating in the district full-time or part-time in 1988 with a total farm population of 479 persons. With land retirement, these directly related jobs would be lost as dryland farming is not feasible. While some hired farm labour would be displaced from the area as well, much of this is migrant labour which follows the harvest season in any event. The adjacent urban area contains 2,500 persons who might also be at risk if the Wellton-Mohawk land were put into retirement. Retail and wholesale sector impacts would be severe in the near term, as would agricultural service related businesses. However, the urban area is near enough to Yuma by major highway that alternative employment opportunities exist. For transitional purposes, Federal government training and/or relocation assistance might be required as the additional cost of this policy choice.

Against the annual loss of agricultural production in the district and the dislocation of 132 farm families, who would be compensated for their land, is the annual gain of 300,000 AF of released water for agricultural or non-agricultural uses and the net savings of $31 million per year for maintenance and operations costs from the desalting complex. Using the Bureau of Reclamation's own M and O figures for the reclaimed water ($375 per AF), the imputed value of the 300,000 AF of water released from the Wellton-Mohawk district is $112.5 million per year.

Bypass canal

Perhaps the most cost effective choice is to maintain the status quo with respect to the Wellton-Mohawk district and to continue to utilize the bypass channel for discharged irrigation water. This channel which now extends from the Wellton-Mohawk valley along the city of Yuma to the Morelos Dam and then to the Santa Clara Slough at the Sea of Cortes. This 65-mile channel was completed in 1977 and it has been operational since that time, diverting saline water to the Sea of Cortes.

The cost of this channel is part of the desalting complex estimates and it was not available separately. However, the cost of lining the Coachella canal of 49 miles was $47.8 million or $975,000 per mile in 1980 dollars (Bureau of Reclamation, 1990L). This is part of Title I of PL93-320 to satisfy Minute 242. The bypass extension consisted of 16 miles between Morelos and the border of San Luis and 37 miles between San Luis and the Santa Clara Slough. Based on equivalent costs per mile, this means that the bypass channel completed to meet Minute 242 requirements would be approximately $52 million dollars in 1980 prices ($68 million in 1990 prices).

Thus, the bypass channel extension at a cost of $52 million would be the most cost effective method to cope with Minute 242 requirements. Mexico is satisfied with the bypass channel as a solution (Palacios, 1987). However, as indicated earlier, the U.S. Bureau of Reclamation and other U.S. water interests find this solution unacceptable as the water in the bypass channel does not "count" toward U.S. annual deliveries to Mexico.

The historic drainage volume in the channel is about 270 x 10^6 cubic meters per year, or 122,000 acre feet. With the Colorado River fully allocated (or overallocated depending on a number of critics) this waste is looked upon unfavourably. No state is willing to yield part of its allotment which would be required if the bypass canal water remains unreclaimed.

On Farm Efficiency Improvements

While the desalting complex was the preferred Federal solution, it was recognized early on that cost estimates would be escalated considerably. A U.S. Interagency Advisory Committee was established in 1973 to examine and evaluate irrigation efficiencies to reduce the drainage flow of water from the Wellton-Mohawk district. If successful, this would reduce salinity in the Colorado River.

The initial report of the Advisory Committee identified educational and physical programmes to improve on farm efficiency (van Schilfgaarde, 1982). These included laser land levelling, lining of lateral canals, automating gravity irrigation systems, installing trickle irrigation systems for trees and soil moisture monitoring probes. Annualized costs of on farm improvement and the desalting complex were estimated and are summarized in Table 4.3.1 for 1974 dollars. Each level represents incorporating more Wellton-Mohawk acreage into the Federal technical assistance programme. As return flow is reduced at each level, the operations and sizing of the desalting plant is correspondingly reduced.

As Table 4.3.1 illustrates, the benefit-cost rate of improving irrigation efficiency as compared to desalting is very favourable. For example, in comparison with the base case and level 3 on farm improvements, the desalting complex "savings" are $2.6 million per year at a cost of $.45 million per year or nearly 6:1. While the desalting complex was still being relied upon, a Federal technical assistance programme was initiated with the provision for 75 per cent federal cost sharing on physical improvements. As one farmer indicated, it was difficult not to accept the government's offer (Jonish, 1990).

Table 4.3.1
Estimates of On Farm Improvement and Desalting
Annualized Costs: 1974 dollars

Level	Water Efficiency (%)	Return Flow	Annualized Cost On Farm	Annualized Cost Desalt
Base Case	62	216	-	15.0
1	64	206	.10	14.5
2	69	181	.33	13.1
3	72	168	.45	12.4
4	82	116	.67	-

Source: Advisory Committee on Irrigation Efficiency. Measures for Reducing Return Flow from Wellton-Mohawk Irrigation and Drainage District. U.S. Bureau of Reclamation Special Report, 1974.

Irrigation efficiencies during 1974-78 did improve with subsequent reduced flows. Net gains in irrigation efficiencies in some crops were dramatic, alfalfa at 24 per cent, cotton at 28 per cent and lettuce at 44 per cent (Advisory Committee, 1978). While the on farm efficiency programme is still an important component of reducing return flow and salinity, reliance on the desalting complex remains. However, the improved on-farm irrigation efficiencies has permitted a down-sizing of the desalting plant to 56 per cent of its original size with consequent savings of construction costs and energy, chemical, membrane and other operating costs. Additional on-farm improvement efficiencies are possible in view of emerging technologies and past experience.

<u>Water Pricing, Transfers and Conservation</u>

In the arid western U.S. states, water rights are based upon the doctrine of prior appropriation, or "first in time means first in right." In this context, senior appropriation rights are based on chronological pattern of use, not location of user or type of user (industrial; municipal, agriculture, etc.). In practice, nearly 85 per cent of all Colorado River water is used in irrigated agriculture. Under the doctrine of prior appropriation, beneficial consumptive use was the standard adopted for obtaining the water right to encourage investment in facilities and to limit appropriation and speculation in unappropriated water. Beneficial consumptive use allows diversion of a quantity of water for a specified purpose as indicated in a contract. The question of ownership of return flows is generally ignored.

The Wellton-Mohawk district contract with the U.S. was for use on 75,000 acres or for 300,000 AF per year, diversion less returns. With Minute 242, some 10,000 acres of high water use land was retired. This retirement has reduced the return flow or drainage as well. Approximately 65,000 acres remain under irrigation today, receiving 300,000 AF per year.

Incentives for individual on farm conservation are negligible. Table 4.3.2 depicts the schedule of irrigation charges to farmers in the Wellton-Mohawk district for the 1991 year. For 10 acre feet per year, irrigation water would be $11 per acre foot. The cost of water to the district from the U.S. Bureau of Reclamation is designed to cover repayment of construction and maintenance and operations costs of storage and diversion facilities only. The Bureau charges the district about $1 per AF. These water charges to farmers do not change much over time. Looking at relative prices over time, the real price of water has declined through much of the period since 1974 to date. In terms of relative prices, rather than irrigation water being a scarce resource, one would anticipate that it is a relatively abundant resource.

Table 4.3.2
1991 - Wellton-Mohawk Irrigation Assessments

	Rates
Demand Charge	
•Entitles to 4 acre feet p.a.	$42.45 per acre
Supplement Water	
•5th through 10th AF	$11.25 per acre foot
•11th and 12th AF	$16.45 per acre foot
•13th AF and over	$17.45 per acre foot

Source: Wellton-Mohawk Irrigation and Drainage District, Water Rate Schedule No. 1, effective January 1, 1991.

It would appear that conservation of water would require greater market incentives (realistic pricing), direct federal subsidies furthering distorting true irrigation costs or an ability of the Wellton-Mohawk district to market or transfer any conserved water to other users. For example, if the district receives 300,000 AF and conservation results in usage of 225,000 AF, the district might "sell" or "transfer" its conserved water. Once again the desalting plant will reclaim 80,000 AF of water at $387.50 per AF. Alternatively, they could buy the Wellton-Mohawk conserved water at the same cost per acre foot. This would bring in a maximum of $30 million of additional revenues to the district each year, a significant incentive to conservation.

However, as indicated in Section 2.0, there are limitations on the transferability of water rights that reduce the efficient use of water. The U.S. Bureau of Reclamation contracts with the irrigation district, not individual farmers. The Bureau is interested in allocating charges for repayment to contracted users. Transfers would complicate accountability. Further, the Bureau does not allow carry over of water from year to year. Rather, it is a "use it or lose it" contractual arrangement.

The Lower Basin states do not look on water transfers favourably. In Arizona, although no statute law exists, case law appears to preclude water transfers of salvaged or conserved water. In Salt River Users Association v. Kovacovich, the Arizona court ruled that farm irrigators who line their ditches could not apply the "saved" water to irrigate adjacent land (Colby, 1988). Nevada's position is that water saved is considered unappropriated and any applicant may file to appropriate it. Nevada statutes allow water transfers in principle but the State's Engineer has denied applications to transfer conserved water.

California does allow transfers of water subject to statute provisions. Thus sales, lease, and other exchanges are acceptable. Water rights not fully utilized due to conservation are not lost (Colby, 1988).

The contract for water deliveries is between the Bureau and the irrigation district. Without marketing of conserved water, the management of the Wellton-Mohawk Irrigation and Drainage District felt conservation was not cost effective. It was argued that total district expenditures would remain approximately constant, so conservation of water would necessitate an increase in water rates (Gould, 1990).

The limitations on transferability of water rights reduces economic efficiency in general. In the current situation it also precludes a less costly solution to the salinity problem while increasing the available water for alternate uses. In a more general case for the Western States, a 10 per cent reduction in agricultural water usage would allow a 60 per cent increase in water availability for nonagricultural uses (Burgess and Quirk, 1978). Given existing technology, this 10 per cent reduction would not be difficult to achieve. With appropriate water marketing or transfers allowed, there would be significant incentives to voluntarily reduce water use.

4.4 Results and Future Issues

Results

To implement the terms of Minute 242 between the U.S. and Mexico, the U.S. Congress passed PL93-320. The emphasis was on the desalting complex to reclaim the saline water for delivery to Mexico along with a discharge canal to send the waste byproducts to the Sea of Cortes. Other measures were designed to improve conservation efficiency (lining Coachella canal), to provide additional supplies of water from underground sources and some land retirement. Any water savings through conservation or desalination would permit increased agricultural production and farm employment. Alternatively, municipal/industrial growth and employment might be supported.

As a rough estimate, in the U.S.-Mexico southwest region, each irrigated acre requires approximately 5.0 AF of water application (assuming consumptive use of 3.0-4.0 AF per acre). Savings of 80,000 AF per year in the Yuma desalting plant would permit the delivery of water to sustain 16,000 acres of agricultural land. Based upon existing farm sizes in the Mexicali Irrigation District (36 acres) or the Imperial Irrigation District (70 acres), this water would support about 440 additional farm users in Mexico (or 230 in U.S.). Based upon the 1988 value of production in the Wellton-Mohawk district of $1,965 per acre, this water savings through desalination could produce some $31.5 million in agricultural produce.

Other options were possible, then and now, as the desalting complex is still not operational as of mid 1991. Table 4.4.1 summarizes some of these options discussed here. They are not mutually exclusive options.

The most cost effective solution to the salinity problem is the construction and maintenance of the bypass canal. In effect, this portion has been operational since 1978 and has resolved the salinity crises. However, since this wasted water is considered unacceptable as a long term solution, the quantity of water available as well as its salinity represent joint objectives in implementing Minute 242.

The other options yield salinity reductions and increased availability of water. The desalting complex option remains the least cost-effective solution. Even in its down-sized capacity of 73 mgd in 1991, versus 120 mgd in 1973, it will reclaim 80,000 AF of water per year at an average cost of $387-$654 per AF considering maintenance and operations costs alone, or $928-$1190 per AF considering full costs including construction. This is contrasted with the $1 per AF the Bureau of Reclamation charges the W-M district for water or the $11 per AF that the District charges individual farmers.

Some early analysts recommended the retirement of all Wellton-Mohawk district land. This would cost less than construction of the desalting complex and would save the annual maintenance and operations costs of $31 million. Furthermore, it would release the entire 300,000 AF allocation for other Arizona uses (including disputed Indian lands), nearly 4 times the desalting plants contribution of reclaimed water. While economically justifiable, this was politically unacceptable.

Table 4.4.1
Salinity Control Options for Minute 242 Compliance

Option	Estimated Federal Cost (1990 dollars in millions)	Comments
Bypass Canal	68.0	Loss of 120,000-200,000 AF of water per year
Retire Wellton-Mohawk land	162.5	Local political Mohawk Land resistance; saves 3000,000 AF per year
Desalting Complex	289.0 capital costs 52.0 annual M/O	Highly visible technology; central government control; saves 80,000 AF of water per year
On Farm Efficiency	Government subsidies required; less necessary with realistic prices	Relies on voluntary cooperation and realistic water prices; saves 25-40% of water use
Water Marketing and Conservation	No government costs; windfall gains to current appropriators	Relies on individual economic incentives including marketing or exchange water rights legal restriction; considerable potential

Source: Text.

The last two options are more speculative but have considerable promise, not only in the current setting but in general resolution of other broader issues. On farm irrigation efficiency improvements, while Federally subsidized, did improve the efficiency of agricultural irrigation, reducing return drainage flow. This contributed to the decision to downsize the desalting plant. The comparative benefit-cost ratio of on farm improvements on desalt plants cost savings is about 6:1.

More realistic water pricing schedules coupled with water transferability offers potential for both on farm irrigation efficiencies reducing return flows (and salinity) and the release of conserved water to meet the needs of other users. Both salinity improvements and water quantity increases would be expected.

The Federal government did not rely exclusively, or even in a major fashion, on farm efficiency because of the need for voluntary cooperation and compliance, and perhaps the uncertain impact on salinity levels. As for water marketing and transfers, there are still significant restrictions due to Federal, state laws and practices. These restrictions do hamper the efficient use of water, and there are discussions under way at various government levels and agencies to improve water marketing practices.

Emerging Issues

Minute 242 and its implementation provided a political solution to the salinity dispute that arose between the U.S. and Mexico as a result of the Wellton-Mohawk and related projects. However, early analysts (Furnish and Ladman, 1975; Holburt, 1982) identified two unresolved issues in the agreement; a failure to identify an absolute salinity standard at Imperial Dam and the overpumping of ground water on both sides of the border near San Luis. In the latter instance, 160,000 AF per year is provided by the U.S. to Mexico to meet the 1.5 MAF of deliveries required under the 1944 treaty.

The upward trend in salinity measures at the Imperial Dam reflects the increased economic activities in the Upper Basin. This is not covered in Minute 242 although Title II of PL93-320 recognizes the effect that upper basin activities have on salinity and salinity damages in the U.S. and Mexico portions of the lower basin. Recent record high flows in the Colorado River in the 1980s have flushed and filled the reservoirs, resulting in significantly lower salinity levels. In 1989-1990, lowered river flows have resulted in high salinity levels again. The Bureau of Reclamation (Bureau, 1989) projects that salinity will reach about 966 mg per litre at the Imperial Dam by 2010 without salinity control measures in place. Under Minute 242, Mexico will have to accept water at 1,111 mg per litre. This is the salinity level at the Morelos Dam in the late 1960s and early 1970s which was considered unacceptable by Mexico.

Pumping from the underground aquifer near San Luis is utilized to deliver up to 160,000 AF to Mexico. There is no salinity standard of quality of this water. Average salinities from the underground water delivered to Mexico on the land boundary at San Luis under Minute 242 are quite high. Since 1974, annual salinities from this source range from a low of 1273 ppm in 1990 to a high of 1582 ppm in 1980 (IBWC, U.S. Section, 1990). Mexico is also pumping from this aquifer and it is recognized that an overdraft of the aquifer along the border is occurring.

In late 1990 and early 1991, interviews were conducted with a number of U.S. and Mexican water officials to determine emerging issues on the lower Colorado and the international water agreement. There was uniformity on the two issues mentioned above; the rising salinity at Imperial Dam and the overdraft along the border. Beyond that, the

U.S. and Mexican concerns differ.

The U.S. views are primarily concerned with the quantity of water available to the lower basin. The Colorado River has been overallocated among lower basin users relative to the long term sustained yield now thought possible. If the 8.25 MAF (including Mexico's 1.5 MAF) to the lower basin is not sustainable, how will reduced allocations be implemented. The view expressed by U.S. personnel is that all users will receive an equi-proportionate reduction. But this will violate the 1944 Treaty unless supplemental pumping of the aquifer occurs.

The allocation question is aggravated by renewed Indian claims for increased allocations on Indian lands. Recent Congressional sessions have taken a more favourable view of Indian claims. New proposed legislation will reduce the Wellton-Mohawk deliveries by 22,000 AF per year. This will be accomplished by retiring land from cultivation.

Finally, U.S. officials express concern over the lack of on farm efficiency in water use, in the U.S., but primarily in the Mexicali Valley. Unlined canals, open irrigation conveyances on farms, lack of land levelling and drainage systems and appropriate irrigation practices lead to excessive use of water and increased soil salinity affecting crop yields. In other words, they are concerned with the combined effects of water salinity due to Colorado River deliveries and soil salinity due to poor on farm water management practices.

The concerns expressed by Mexican officials are understandably different. In addition to the trends in salinity at the Imperial Dam and the overdraft of the border aquifer, there is concern over the proposed lining of the All American canal by the U.S. Such a step would reduce waste through percolation into the soils for the U.S. However, this waste serves as a source of water recharge to the aquifer used in the Mexicali Valley. Once lined, the aquifer will be depleted even more rapidly. It has been estimated that nearly 1,100 wells on the Mexican side draw from percolation of the All American Canal (Jonish, 1990).

The salinity requirements under Minute 242 refer to annual salinity in parts per million. Mexican personnel are also concerned with the seasonal variation in this salinity. In the fall and winter, when water deliveries are lowest, salinity is highest. It is argued that this seasonal variation in quality and quantity prevents multiple cropping in much of the Mexicali Valley as compared to say the Imperial Valley. More generically, there is concern about the increase in total dissolved solids (TDS) in general in water deliveries due to industrial and municipal waste near the border.

In sum, the salinity concerns of the U.S. and Mexico are similar. Activities in the upper basin are increasing salinity at the Imperial Dam. Minute 242 does not deal with that issue, but Title II of PL93-320 implementing the provisions of Minute 242 does deal with the upper basin.

The quantity concerns can be in conflict. Conservation of water on the U.S. side (lining of the All American Canal) can affect aquifer withdrawals in Mexico. Overpumping on both sides of the border has occurred. Pressures for reallocation within the U.S. (Indian lands, agriculture-urban) will intensify as demand for water outstrips supply with ineffective price and marketing mechanisms for water use and transfer.

With the forthcoming U.S.-Mexico free trade agreement, demand for water in the southwestern U.S. and northern Mexico will increase. Municipal and industrial users will increasingly compete for water given agricultural users whose rights were determined under widely different economic conditions.

5 Conclusions

5.1 U.S.-Mexico Water Quality Agreement

The Colorado River has involved the U.S. and Mexico in two major transboundary resource issues in this century, the allocation of waters for beneficial use and the quality of the water allocated. In each case, the negotiations were lengthy, often acrimonious, but a peaceful negotiated settlement evolved in each instance.

The allocation question was resolved around the principle of prior appropriation. Mexico's downstream appropriations were based upon water use developed in the Mexicali Valley during the late 1930s and early 1940s, even though this beneficial use was the result of U.S. efforts to control the Colorado River through large scale dams and diversion structures. This allocation to Mexico of 1.5 MAF per year will come at the expense of earlier U.S. efforts to allocate the Colorado River among Upper and Lower Basin states.

The question of water quality, specifically increases in salinity of water deliveries to Mexico after 1960 with incremental saline discharge from the Wellton-Mohawk Irrigation District, led to a negotiated permanent settlement with Minute 242 in 1973. Two major points were established. The water deliveries to a downstream recipient, Mexico, must be of reasonable quality in terms of salinity and the upstream user, the U.S., is responsible for mitigation. Thus, the polluter pays principle was adopted. Mitigation charges come from the Federal general revenues. No attempt was made to impose user or pollution charges on the more direct participants contributing to salinity in the U.S.; the individual farmer through higher water charges, the irrigation districts, or the individual Upper or Lower Basin states in terms of an activity or water use tax. Thus, individual incentives to reduce salinity discharges are absent.

To comply with Minute 242 provisions and reduce salinity, the U.S. had a number of options. The least cost option was not chosen. Instead, perhaps the most costly option was selected, the building and operation of a large reverse osmosis desalination plant near Yuma, Arizona. This choice reflects, perhaps, two considerations. One is that the desalting plant has two objectives, to provide water of sufficient quality to satisfy the provisions of Minute 242 and to reclaim water to "count" toward the quantity requirements for Mexico's allocation of 1.5 MAF. One least cost option, the bypass canal, provides the quality standards for Minute 242 but does not save or reclaim the waste water.

The second consideration is the locus of control or responsibility in reducing salinity. The desalting plant relies on established agencies (i.e., U.S. Bureau of Reclamation) and maintains the status quo with respect to other institutions and practices (irrigation districts, water contracting, water transfer restrictions) in reducing salinity and reclaiming water. The other more cost effective mechanisms for reducing salinity and releasing or reclaiming water supplies rely on more voluntary, cooperative efforts (on farm efficiency) of an uncertain magnitude, or they require a restructuring of existing water rights and use provisions (alter water pricing, water marketing and transfer practices, water contracting). These latter options would change the legal and institutional status quo quite dramatically.

The salinity differential between Mexico and the U.S. has narrowed considerably since the early 1960s as data in Appendix A illustrate. The interim agreements Minute

218 (1965) and Minute 241 (1972) were to reduce salinity by discrete steps until 1973. Minute 242 (1973) provides the salinity standard currently in effect for the Morelos Dam, salinity of no more than the Imperial Dam measure plus 115 ppm plus or minus 30 ppm. This differential standard has been met from 1974 to 1990. The rather surprising negative differentials in 1979 and 1980 are the results of excess water deliveries along the normally dry Gila River as the upstream reservoir became full during periods of excess moisture. The Gila River is downstream from the Imperial Dam. Again, the compliance with Minute 242 is being obtained without the desalting plant in operation, but at a cost of 120,000-200,000 AF of water wasted per year as discharge to the Santa Clara Slough and the Sea of Cortes.

It seems unlikely that a permanent and definitive solution to the salinity problem in the Colorado River has been reached. Long term salinity trends at the Imperial Dam are increasing. This has necessitated that salinity control measures be undertaken in the Upper Basin (Gardner et al., 1988), again relying upon Federal agencies with little reliance on market based incentives for control.

Demand for water in the southwestern U.S. and northern Mexico continue to grow while the Prior Appropriation doctrine locks in water rights and uses which are increasingly anachronistic given the changing population and economic structure of the region. The anticipated U.S.-Mexico free trade agreement will bring forth many transitional changes and adjustments for the integration of the two economies. This will place further burdens on the current water allocation system. In the meantime, overpumping of aquifers along the border are continuing.

It is anticipated that some form of property rights modification will develop in response to these pressures. Prior appropriation with allowable water transfers - first in state, then between states seems most likely given institutional complexities. While current water rights holders will receive windfall gains, the gains of conservation and reallocation to higher valued users would be the result.

These conservation and reallocation gains would be accelerated if the Bureau of Reclamation were to adopt more realistic pricing practices. At a minimum, full financial costs of irrigation structures and maintenance would be covered by the price of water.

5.2 Changes in Economic Structure

The current economic structure and associated employment and income patterns of the southwestern U.S. and of northern Mexico are strongly influenced by the 1902 U.S. Reclamation Act to build large scale irrigation projects to provide inexpensive water to the 17 western U.S. states (and northern Mexico). Subsidized water prices plus restrictions on transfers have maintained this economic structure. For the two largest irrigation districts, the Imperial District (U.S.) and the Mexicali District (Mexico), irrigated water supports a total of some 19,700 farm units and perhaps a total direct farm population of approximately 65,000-70,000 persons (ignoring hired labour). However, these two districts receive 4.2 million acre feet of water per year.

Any reallocations of water, as a result of increased reliance on water marketing or transfer mechanisms and more realistic pricing of water and its quality will bring transitional adjustments to the region and a changed economic structure. The long run benefits will be more efficient use of scarce resources, including quality water; the short run transitional costs will be the adjustments necessary in irrigated agriculture and associated employment. For reasons cited below, these transitional costs are anticipated to be low relative to the long run benefits.

Water Reallocation

In the affected region, if water transfers and more realistic pricing are adopted, no one questions that water will be reallocated from farm users to municipal/industrial users. Irrigated agricultural output (employment) will decline and nonagricultural output (employment) will increase. Without any irrigation water, as opposed to improved irrigation water efficiency, much of the farm land in the various districts would be retired. Marginal grazing might be sustained in some regions but dryland farming is not an effective option in most districts' lands.

Will non-agricultural output (employment) more than compensate these agricultural losses? While no empirical estimates have been made, it is evident that the agricultural production function (and associated employment function) with water as a recognized input is much more water intensive than is the nonagricultural production (and employment) function. San Francisco, a city of 680,000, consumes less than one-half the annual allocation of 300,000 AF to the Wellton-Mohawk District. The latter supports a farm population of 479 directly and at most a total rural population of 3,000.

Further, the opportunity cost of alternative supplies of water to municipalities/industry is quite high. Wastewater treatment plants for water reclamation and irrigation reuse are being developed along the border. San Diego and Los Angeles are pursuing ocean water desalination proposals to provide 112,000 AF per year at a construction cost of 1-2 billion dollars. With further border growth anticipated by the U.S.-Mexico free trade agreement, both Mexicali and Tijuana are pursuing options to buy desalinated water. Capitalized cost estimates of these options are in the range of $900-1,500 per AF.

Thus, the factor intensity argument indicates that employment gains in nonagricultural sectors will exceed employment losses in agriculture. The high opportunity cost of alternative supplies indicates a willingness and ability to pay for these water transfers.

Transitional Adjustment Costs

The previous section is not meant to trivialize the burdens of adjustment. The affected sectors will suffer from a severe impact. A reduction or loss of irrigated water will reduce output, employment, economic rents and land values which have capitalized the value of water into their transactions price. Individuals have made rational decisions based upon government policies toward the guaranteed provision of quality water at subsidy. Changes in government policies can invalidate these decisions; equity would suggest some damage mitigation scheme.

Two mechanisms suggest themselves. One is to introduce the policy changes gradually over a number of years. Such an "announcement effect" would allow farm units to evaluate conservation and crop choice alternatives and make appropriate decisions in view of the increasing real price of water and perhaps increased marketing of water as well. The second mechanism would be to provide transitional adjustment assistance to farm owners, farm workers and related agricultural business employees displaced by the changing environment. This assistance could take the form of low interest loans and cost sharing to introduce new irrigation equipment and practices for farm owners, and retraining/relocation allowances for displaced workers. Such assistance provisions were critical to the acceptance by the U.S. - Canada automobile free trade agreement (Jonish, 1970).

In the current situation, the transitional damage mitigation may be more straightforward. To a great extent, in Mexico and the U.S., the directly affected farm units (owners) and workers are the same people. Currently, irrigation districts have rights to water, not individual farms. If farm units could receive individual rights to the districts normal water use (i.e., 5 AF per acre of land), this would mitigate their damages by providing them the economic rents of the scarce water. They could decide not to irrigate, sell the water rights and use the proceeds to start a new business, retrain, etc. If they decide to remain in irrigated farming, the rising price of water would encourage conservation and the sale of conserved water would finance new irrigation equipment and technologies as well as alternate crop choices.

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Appendix A

Table A.1
Colorado Salinities and Water Delivery to Mexico

Annual Salinities, PPM				Water Delivered to Mexico Annual Discharge in Acre Feet	
Year	Morelos Dam	Imperial Dam	Differen-tial	Morelos Dam	Imperial Dam
1989	800	682	118	1,452,191.0	5,972,526.0
1988	733	655	78	2,218,278.4	6,608,386.0
1987	656	610	46	4,531,314.9	8,705,055.0
1986	639	607	32	11,700,371.3	14,959,933.0
1985	600	579	21	10,688,900.6	14,701,685.0
1984	676	675	1	15,430,412.0	19,108,000.0
1983	742	733	9	14,091,870.1	16,930,057.0
1982	933	825	108	1,441,620.7	5,410,056.0
1981	924	806	118	1,926,478.6	6,267,768.0
1980	740	755	-15	6,938,372.1	9,433,843.0
1979	739	809	-70	3,079,719.9	6,131,662.0
1978	928	812	116	1,464,482.4	5,696,946.0
1977	943	820	123	1,478,823.1	5,705,376.0
1976	955	823	132	1,449,516.0	5,897,000.0
1975	964	829	135	1,395,899.0	6,154,000.0
1974	972	832	140	1,336,355.0	6,206,000.0
1973	993	843	150	1,281,064.0	5,864,000.0
1972	1103	861	242	1,325,049.0	5,793,000.0
1971	1170	892	278	1,316,193.0	5,823,000.0
1970	1140	896	244	1,312,728.0	5,703,000.0
1969	1190	877	313	1,319,855.0	5,616,000.0
1968	1200	838	362	1,326,556.0	5,738,000.0
1967	1210	841	369	1,322,572.0	5,616,000.0
1966	1220	885	335	1,420,358.0	5,854,000.0
1965	1380	888	492	1,524,179.0	5,723,000.0
1964	1300	821	479	1,501,747.0	5,903,000.0
1963	1330	800	530	1,833,823.0	6,532,000.0
1962	1490	820	670	1,810,655.0	6,457,000.0
1961	1360	802	558	1,671,923.0	6,293,000.0
1960	810	769	41	2,337,719.0	7,109,000.0
1959	760	730	30	3,050,730.0	7,695,000.0
1958	720	726	-6	5,908,260.0	10,493,000.0
1957	870	818	52	2,853,380.0	7,439,000.0
1956	910	891	19	1,637,560.0	6,269,000.0
1955	820	807	13	3,058,330.0	7,709,000.0
1954	750	707	43	4,346,360.0	8,943,000.0
1953	700	669	31	5,223,640.0	9,946,000.0
1952	670	647	23	0,145,760.0	14,749,000.0
1951	710	686	24	3,639,140.0	8,007,000.0

Source: U.S. Section. International Boundary and Water Commission Flow of The Colorado River and Related Data (various issues).

Table A.2
OLS Regression of Salinity at Morelos Dam (Annual Average)

Variables[1]	1	2	3	4
Volume of Water	-.00001*	-.00002*	-.1225**	-.1175**
Salinity at Imperial Dam	+1.7324**	+1.7856**	+1.0473**	+1.1046**
Time Trend	-.914		-.0014	

*Significant at .05
**Significant at .01
[1]Columns 1, 2 are arithmetic, columns 3, 4 are natural logarithms (except time trend).

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