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Global International Waters Assessment

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Gulf of California/ Colorado River Basin

GIWA Regional assessment 27

Arias, E., Albar, M., Becerra, M., Boone, A., Chia, D., Gao, J., Muñoz, C., Parra, I., Reza, M., Saínz, J. and Vargas, A.

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Global International Waters Assessment

Regional assessment 27
Gulf of California/Colorado River Basin

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Preface

The GIWA region 27 covers the Gulf of California and its drainage basins. This report focuses on the Colorado River Basin with emphasis on the delta area. The report presents the results of research, information development and policy analysis. The methodology covers issues such as water availability, regional imbalances, relationships between water use and water quality, and alternative low-cost natural systems for treating wastewater. The papers range from addressing fundamental scientific questions regarding the linkages between land use and water quality, to the ecological impacts of excessive water consumption, to the feasibility of applying alternative treatment options.

The GIWA region 27 Task team, integrated from personnel of WWF Gulf of California Program, the Berkeley Public Policy team and personnel from the Instituto Nacional de Ecología (Mexico, City), conducted the research described in this report. During the GIWA workshops for the Scaling and Scoping held August 21-23, 2002 in Hermosillo, Son, Mexico and the Causal chain analysis and Policy options (April 7-9, 2003) the main thematic was based on problems concerning transboundary issues in international waters and how to apply the results from scientific assessments to manage water resources.

The study makes use of the work of others, especially in its descriptions of the region and the issues that it faces. We are grateful for the cooperation and permission that have been granted by the region's planning agencies, the Instituto Nacional de Ecología (INE), Mexico City Office, the Comisión Nacional del Agua (CNA), Gerencia Regional Peninsula de Baja California, Mexicali, and the Instituto del Medio Ambiente del Estado de Sonora (IMADES). We also appreciate the many persons from the study area who participated in the GIWA workshops, and those who provided invaluable guidance throughout the project.

The Global International Water Assessment (GIWA) and the World Wildlife Fund (WWF), Gulf of California Program Project Number QQ98, funded the research.

The information herein is believed to be reliable, but the assessors and their institutions do not warrant its completeness of accuracy. Opinions and estimates are the judgments of the research team. The sole purpose of this research is to provide information to the many stakeholders and jurisdictions of the region regarding issues, strategic planning choices, and their possible consequences related to the sharing of international waters.

While the scientific community still debates the meaning of international water management, the concerns of environmental institutions still rely on how to interact with the environmental impacts with scarce water resources of an unsustainable urban development.

Executive summary

In regions where water demand approaches or exceeds the limit of available supplies, competition intensifies amongst various users, turning water scarcity into a potential source of conflict. This report applies an analytical methodology developed by the GIWA programme, that consists of: (i) the regional definition, based on its main physical, socio-economic and legal framework; (ii) an assessment which identifies and prioritises five predefined GIWA concerns based on the magnitude of their impacts on the environment and societies in the region; (iii) a causal chain analysis to identify the root causes of these problems; and (iv) the analysis of policy options that address these root causes in order to reverse negative trends in the aquatic environment.

The Gulf of California, GIWA region 27 has its limits to the north of the Pacific and extends to the southeast of the Pacific, and comprises a portion of the American Southwest and Mexico's Northwest. The region includes land surrounding the river systems that feed the Gulf of California, also known as Sea of Cortez. The largest of them is the Colorado River Basin, which is almost entirely located in the United States, while the oceanic component of the region (Upper Gulf of California) and small tributaries (e.g. San Pedro and partly Santa Cruz rivers) are in Mexico. Within the GIWA Gulf of California region, the Colorado River Basin is the system with the most prominent transboundary character. The Colorado River Basin is of great significance considering that the River supplies more water for consumptive use than any other river in the U.S and supports not only a booming economy but also a vast number of terrestrial and marine species. Therefore, the analysis in this report has been focused on the Colorado River Basin.

From an environmental point of view the Colorado River Delta and Upper Gulf of California is of great importance to the region, and correspondingly was declared an International Biosphere Reserve in 1993. Today the delta consists of 60 000 ha of wetlands and riparian forests (prior to the construction of dams the delta maintained 780 000 ha). The delta ecosystems are important for migratory shorebirds travelling along the Pacific Flyway; serve as a breeding ground for marine species of the Gulf of California; support a number of endangered species; improve the quality of water that flows in from various sources and out to the Gulf; deliver a steady flow of freshwater to near-shore marine (brackish) environments in the Gulf, improving breeding and nursery grounds for the endangered vaquita; and produce important vegetation utilised by indigenous peoples. In addition to these environmental services, the delta has historically been a source of income for riparian communities, supporting lucrative fisheries and ecotourism activities.

The Colorado River Basin is extremely dynamic with expanding economies and increasing industrialisation, especially in the California and Baja California border regions. The population of the Basin is growing rapidly and urban areas are sprawling, often in an uncoordinated manner. Unmanaged growth in the Basin has produced serious transborder environmental problems and concerns, for example, the impact of urban development on the fauna and flora of already sensitive ecosystems. The principle demand for water in the basin arises mainly from agriculture; 80 to 90% of all water resources are used to irrigate agricultural lands. Considering that the region is characterised mainly by arid and semiarid zones, the problem of freshwater shortage is accentuated in the Lower Basin.

The assessment focused on the Colorado River Basin and the Upper Gulf of California and was conducted based on the five GIWA concerns. The assessment conducted through a participatory process and based on concepts and criteria developed by the GIWA Task team, ranked the concerns in the following order:

1. Freshwater shortage
2. Pollution
3. Habitat and community modification

4. Unsustainable exploitation of fish and other living resources
5. Global change

Freshwater shortage was the most significant GIWA concern for the region. The modification of stream flow by dams, the canalisation of riverbeds, and the alteration of riparian zones by agricultural activities in the Colorado River Basin have resulted in major environmental changes causing loss of fish, wildlife, and native flora, particularly in the Colorado River Delta region. The main impacts on the hydrological cycle include changes in the seasonal hydrology, water temperature and sediment loads of the Lower Colorado River. In the absence of sufficient sediment discharges, the deltaic basin has transformed from an estuarine setting to a hypersaline, anti-estuarine and erosive one.

Since the construction of major dams along the Colorado River, the Delta is sustained only by flood flows and, during dry years, groundwater seepage, agricultural drainage water and tidewater are its only sources. Presently, the economic impacts of freshwater shortage are largely associated with silt accretion and salinisation of agricultural lands, which today account in the U.S. for approximately 700 million USD per year. Programmed reductions of water to California, the rising costs of water treatment, and the high cost of restoring degraded water sources are prominent socio-economic issues that could potentially initiate conflicts over freshwater resources in forthcoming years.

Pollution of water resources in the Colorado River was considered a major concern affecting the ecology and population, since heavy metals, arsenic, lead pesticides, uranium, and other toxins have all been found in excessive levels in the soils and waters resources of the Basin. Salinity is considered as a significant and continuous issue, historically affecting U.S.-Mexico relations since the early 1940s. Stream flow modification has resulted in increased cases of water pollution by salts and selenium, which occur naturally in the Colorado River. The reduction of freshwater flows has diminished the dilution capacity of the region's water bodies, consequently increasing water pollution in the Lower Colorado River. Economic impacts associated with pollution were assessed as moderate, particularly due to increases in water treatment costs. There is also considerable evidence of impacts on health from chemical pollution, especially from contamination of the regions aquifers.

The construction and operation of dams has modified riparian habitats and changed seasonal flow patterns. As a result, large extensions of riparian habitat, wetlands and marshes have declined drastically. The reduction in native forest vegetation has led to a decline in the value of riparian habitats for native species. In the U.S., as in Mexico, increases in riverbank salinity and other alterations to riparian zones have favoured the establishment of invasive, salt tolerant species (e.g. Tamarix ramosissima), occupying great extensions of modified habitat.

Various forms of human activity (shrimp trawls, pollution and freshwater shortage) are modifying the ecosystems of the Upper Gulf of California, which ultimately affect local fisheries. The semi-enclosed nature of the Upper Gulf serves to magnify the impact of these activities. By-catches and discards, as well as habitat destruction by trawling nets, have been important factors in altering these ecosystems, although studies have demonstrated that overexploitation and the reduction of freshwater flows to the Upper Gulf have been the main reasons for the commercial collapse of some fisheries.

The causal chain analysis addressed the following problem: too little water is being allocated for ecosystem maintenance or restoration in the Colorado River Delta. The immediate causes of freshwater shortage in the Colorado River Delta were primarily associated with increased diversion, reduced peak flows and changes in return flows.

The most important sectors responsible for these immediate causes are:

- Agriculture;
- Urbanisation;
- Industry;
- Energy production.

The root causes focused primarily on the agricultural sector, since from a historic point of view many of the changes made throughout the 19th century were influenced by agriculture, both in the U.S. and Mexico .

Some of the root causes behind these immediate causes were identified as:

- Demographic: Migration policies and incentives carried out during the 1940s in the U.S. Western states and Mexico.
- Technological: Increased development in irrigation technology throughout the Colorado River Basin.
- Economic: The existence of historical subsidies and the lack of economic valuation of water resources.
- Legal: Inappropriate legal framework to adequately manage water use, due to a lack of effective legal instruments.

It is proposed that the following options could secure freshwater resources for the Colorado River Delta in the short, medium and long-term:

- Lease water rights in the Mexicali and San Luis Rio Colorado Valleys and transfer associated water to the delta ecosystem;

- Convert electricity subsidies for Mexican farmers to cash subsidies, and eliminate price subsidies to municipal water users in Mexico as preliminary measures to ensure at least minimal flows of freshwater reach the delta;
- Increase the efficiencies of water use in Mexico through market mechanisms, thereby "freeing up" water potentially available for the delta;
- Amendment of a Minute to the 1944 Water Treaty to specifically stipulate water deliveries for the delta.

Presently the Colorado River Delta and the Upper Gulf ecosystem only receive flows of freshwater whenever a surplus of water exists in the River in excess of the amount of water necessary to supply the U.S. base flows and periodic flows should be consistent to the delta despite the 1944 Treaty stipulations, due to the river ecosystem survival does not depend on treaties or political factors.

In order to implement effective conservation programme more water flowing directly into the delta is needed. Economic and technical support from the U.S. will however be necessary, and realistically, the Lower Colorado River Basin states will probably not agree to allow more water to reach Mexico. Therefore the preservation of the Colorado River Delta ecosystem will remain a complex task. To maintain sufficient stream flows in the River, the alignment of numerous institutions, agreements, and organisations will be required. As a transboundary representative, the International Boundary and Water Commission (IBWC) still remains as the most eligible institution to achieve this goal in the long-term, although it remains cautious in its jurisdiction over environmental problems relating to the Colorado River Delta; therefore the criticism of the way it operates and manages problems concerning to the environment.

Acknowledgement

This report for the Global International Water Assessment is the result of two workshops and background desk research. We gratefully acknowledge the support of the World Wildlife Fund-Gulf of California Program, the Instituto Nacional de Ecología (INE) México City Office, the Comisión Nacional del Agua (CNA), Gerencia de la Peninsula de Baja California in Mexicali, the Instituto del Medio Ambiente del Estado de Sonora (IMADES) and the Berkeley Team of Public Policies.

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Abbreviations and acronyms

AAC	All American Canal
AUM	Animal Unit Months
BECC	Border Environment Cooperation Commission (Comisión de Cooperación Ecológica Fronteriza)
CNA	National Water Commission, Mexico City Office (Comisión Nacional del Agua)
CVWD	Coachella Valley Water District
DBCP	Dibromochloropropane
DOF	Federal Official Gazette, Mexico (Diario Oficial de la Federacion)
DWA	Desert Water Agency
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ESA	U.S. Endangered Species Act
FWS	U.S. Fish and Wildlife Service
GEF	Global Environment Facility
GIWA	Global International Waters Assessment
IBWC	International Boundary Water Commission
IID	Imperial Irrigation District
IMADES	State of Sonora Institute for the Environment and Sustainable Development (Instituto del Medio Ambiente del Estado de Sonora)
INE	National Institute of Ecology, Mexico (Instituto Nacional de Ecología)
INEGI	National Institute of Statistics, Geography and Information, Mexico (Instituto Nacional de Estadística, Geografía, e Informática)
ISC	Interim surplus criteria
LCRB	Lower Colorado River Basin
LROC	Long Range Operating Criteria
MEXUS	Mexico-United States
MODE	Main Outlet Drain Extension Canal
MTBE	Methyl tertiary-butyl ether
MWD	Metropolitan Water District of Southern California
NADBank	North American Development Bank
NAFTA	North American Free Trade Agreement
NGO	Non Governmental organisation
NEPA	U.S. National Environmental Policy Act
NIB	Northerly International Boundary
NWL	National Water Law
OECD	Organisation for Economic Co-operation and Development
PES	Payment for Environmental Services
PROCAMPO	Program for Direct Assistance in Agriculture
PVID	Palo Verde Irrigation District
SAGARPA	Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food, Mexico (La Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación)
SEDESOL	Secretariat of Social Development (Secretaría de Desarrollo Social)
SEMARNAT	Department of Environment and Natural Resources (Secretaría del Medio Ambiente y Recursos Naturales)
SIB	Southerly International Boundary
SLRC	San Luis Rio Colorado
TDS	Total dissolved solids
TSH	Thyroid Stimulating Hormone
TSS	Total Suspended Solids
UGC	Upper Gulf of California
UNEP	United Nations Environment Programme
USBR	United States Bureau of Reclamation
USGS	United States Geological Survey
WMIDD	Wellton-Mohawk Irrigation and Drainage District
WWF	World Wildlife Fund

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Regional definition

Arias, E., Albar, M., Parra, I. and M. Reza

This section describes the boundaries and the main physical and socio-economic characteristics of the region in order to define the area considered in the regional GIWA assessment and to provide sufficient background information to establish the context within which the assessment was conducted.

Figure 1 The Gulf of California region.

Boundaries of the region

The Gulf of California region

The Gulf of California GIWA region 27, has limits to the north of the Pacific and extends to the southeast of the Pacific, and comprises territories in the American Southwest and northwestern Mexico. In the United States it includes the states of Utah, Wyoming, Colorado, Nevada, New Mexico, California and Arizona, meanwhile in Mexico, it contains the states of Baja California, Baja California Sur, Sonora, Sinaloa, Nayarit and partly Chihuahua, and Durango (see Figure 1).

The Gulf of California region is situated between GIWA region 2 Gulf of Mexico, 26 California Current and 65 Eastern Equatorial Pacific, and differs from them in terms of water temperature: in the North Pacific the upper ocean layers are much colder, with large-scale monthly mean ocean temperatures remaining below 21°C throughout the year and in the southeast with temperatures averaging above 30°C (Talley et al. 1998).

The oceanic component of the region is exclusively the Gulf of California, also known as the Sea of Cortez. The Gulf of California opens into the Pacific at its southern end and is long and narrow (1 500 km long and 175 km wide). There are approximately 100 islands within the Gulf, each with its own differentiating characteristics. The Gulf of California is one of the youngest ocean bodies and was formed by the separation of the North American Plate and the Pacific Plate by tectonic movement.

There are four hydrological units in the region considered as transboundary waters; Colorado River, Tijuana River, Santa Cruz River and San Pedro River (Table 1). Despite these last three drainage basins having international implications, their importance is essentially regional and only contributes water to small cities with less than 200 000 inhabitants, with the exception of the Tijuana River Basin, which provides water to over 3 million inhabitants.

Table 1 International rivers in the Gulf of California region.

River	Drainage area (km^2)	Length (km)	Water discharge (km^3/year)	Average discharge (m^3/s)	Population served
Colorado	632 000	2 330	20.1	4 900	25 000 000
Tijuana	4 484	500	0.33	100	3 939 000
Santa Cruz	1 380	360	0.35	1 300	199 000
San Pedro	1 919	240	0.80	2 500	152 000

(Source: CILA 2000, U.S. Census Bureau 2000, INEGI 2001)

The Colorado River Basin region

The Colorado River and its tributaries flow through the Great Basin, the Sonoran and the Mojave Deserts, providing the vital lifeline to the arid American Southwest (Figure 2). The Colorado River is born about 3 048 m above sea level in the Rocky Mountains of Colorado and flows southwest to the Gulf of California in Mexico. It is the international boundary between the United States and Mexico for 27 km. Before the construction of a number of dams along its route, it flowed 128 km through Mexico to the Gulf of California.

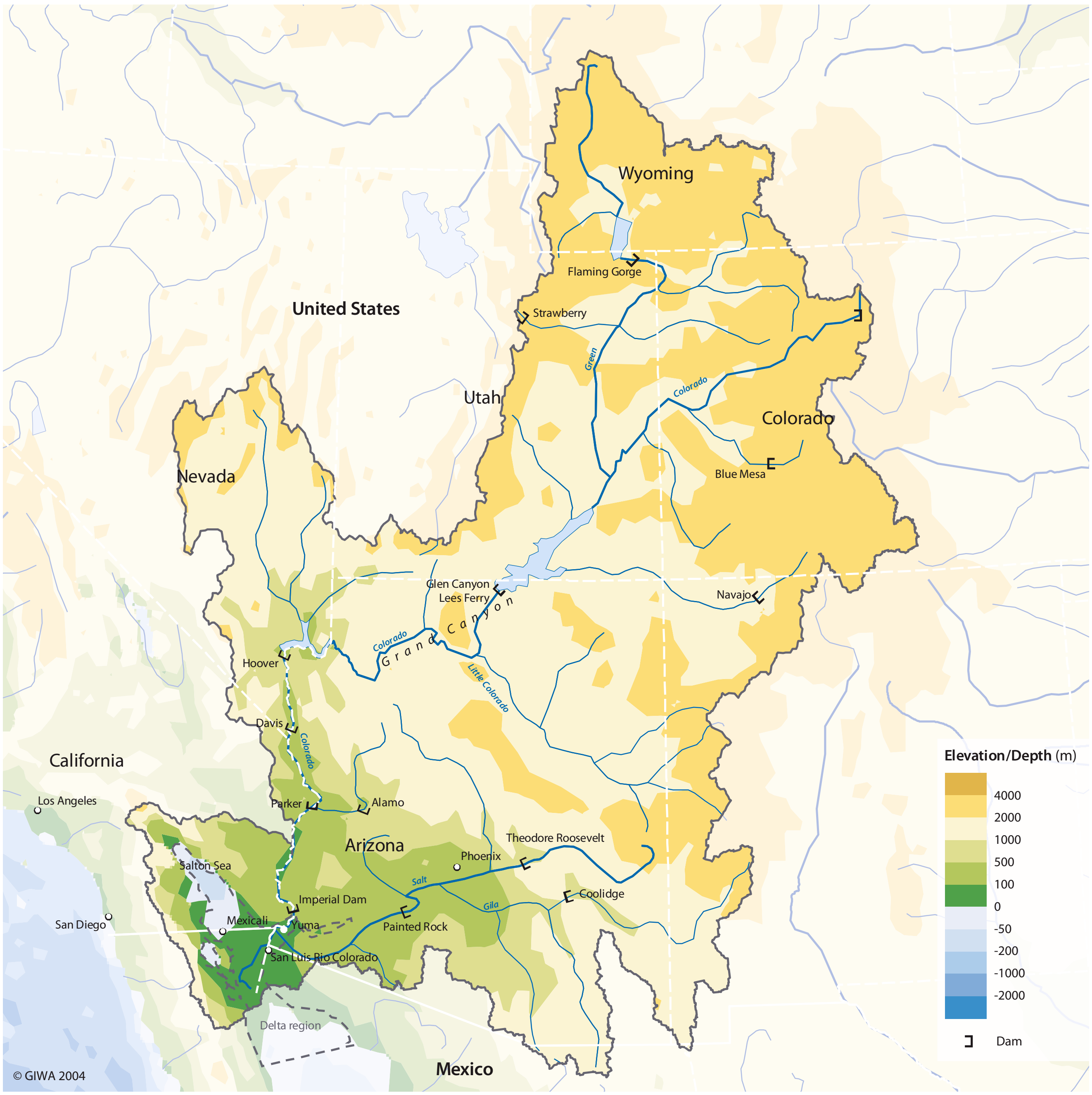

Figure 2 The Colorado River Basin.

The 2 330 km of its route in the United States makes it the nation's fifth longest river. It drains a large portion of the North American continent covering 632 000 km^2 in the United States and 5 200 km^2 in Mexico. The Colorado River and its tributaries drain southwestern Wyoming and western Colorado, parts of Utah, Nevada, New Mexico and California, and almost all of Arizona. Three quarters of the Basin is federal land devoted to national forests and parks and Indian reservations.

Physical characteristics

Physiography and geology

The terrain of the Colorado River is very unique. It consists of wet upper slopes, irregular transition plains and hills, deep canyon lands, and dry lower plains. The wet upper slopes consist of numerous streams that feed into the Colorado River from stream cut canyons and small flat floored valleys, often occupied by alpine lakes and adjacent steep walled mountain peaks. These areas are heavily forested and contain swiftly flowing streams, rapids, and waterfalls.

The Rocky Mountains of Wyoming and Colorado have altitudes oscillating between 4 270 and 1 520 m above sea level. Canyons and plateaus are located in Utah, Colorado, New Mexico, Arizona and Wyoming, where the elevation varies between 1 830 and 1 220 m, and finally the lower and upper zone of the Nevada, New Mexico and California with minor altitudes of 1 220 m above sea level (González-Casillas 1991).

Hydrology

Great quantities of sediment are washed into the rivers and for many years (since the last glacial period, approximately 140 000 years) have been deposited in the lower reaches of the Basin forming marginal sand bars and terraces. These have been accumulating at the river mouth in the Upper Gulf of California, forming what today is known as the Colorado River Delta, and constituting the Mexicali and Imperial Valleys. The accumulated sediments formed a land elevation, cutting one arm of ocean in the Gulf and created the old Lake Cahuilla. This ancient lake, according to botanical studies and geologists, dried up during the Spanish conquest (16th century). Although, due to the derivation of return flows from the Imperial Irrigation District and flooding periods in 1905, the Lake was filled again, forming what today is known as the Salton Sea.

Principal tributaries to the Colorado River upstream of Glenn Canyon Dam include the Green, San Juan, Escalante, Gunnison, and Dolores rivers. Principal tributaries between Glen Canyon and Hoover Dams include the Paria, Virgin, and Little Colorado Rivers. Downstream from Hoover Dam are the Bill Williams and Gila rivers.

The two principle reservoirs in the Colorado River are Lake Mead and Lake Powell, each with a usable capacity greater than 30 km^3. Numerous smaller reservoirs include Flaming Gorge, Mohave, Strawberry Reservoir, Lake Havasu, Roosevelt Lake, Taylor Park Reservoir, Blue Mesa Reservoir, McPhee Reservoir, Vallecito Reservoir, and Navajo Reservoir.

Historically, the annual flows of the Colorado River at Lee's Ferry have exceeded 29.6 km^3 and have been less than 4.6 km^3 (USGS 2004a) (Figure 3). Most of the flow for the Colorado originates in the Upper Basin, which encompasses some 284 400 km^2. About 86% of the annual run-off originates within only 15% of the area, in the high mountains of Colorado.

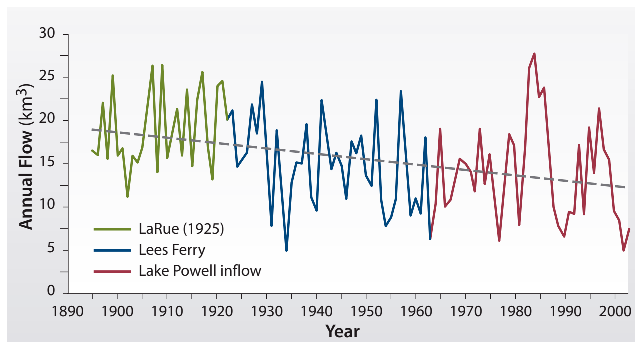

Figure 3 Colorado River annual flow.
(Source: USGS 2004a)

By examining river sediments, scientists have determined that on a number of occasions over the past 4 000 years the River reached peak flow rates of over 7 080 m^3/s (Andrews 1990). The natural flow of the Colorado followed a distinct seasonal pattern, with more than 70% occurring in the months of May, June, and July (Harding et al. 1995). Historically, the floods of May and June peaked at over 2 435 m^3/s (Collier et al. 1996). Since the construction of several major dams that now regulate the stream flows, peak flows have been significantly reduced. After the construction of the Glen Canyon Dam (1961), peak daily discharges at Lee's Ferry average at only 567m^3/s in May and 729 m^3/s in June (USGS 1996).

The River contains alternating sections of rapids and calm sections. The depth of the River varies from 1.8 m to 27 m, averaging about 6 m. The rapids are the shallow sections and the calm sections tend to be the deepest parts. Some deep holes have also formed at the base or foot of some of the major rapids. The rapids represent only 10% of the River's

Table 2 Sediment delivery for the Colorado River.

Gauging station	Years of data	Source	Water discharge (m^3/s)	Sediment load (million tonnes/ year)	Sediment yield (tonnes/km^2/ year)
Paria River	1947-1976	Andrews 1991	0.72	2.7	820
Colorado River at Lee´s Ferry	1947-1957	Andrews 1991	450	59.8	220
	1948-1962	USGS*	ND	58.9	ND
Colorado River near Grand Canyon	1925-1940	Smith et al. 1960	ND	176	ND
	1941-1957	Andrews 1991	472	77.9	204
	1941-1957	Smith et al. 1960	ND	59.9	ND
	1948-1962	USGS*	ND	76.2	ND
	1970-1989	Andrews 1991	ND	9.9	ND
	1984-1998	Webb et al. 2000	ND	2.8	230

*Notes: * Data was obtained from Webb et al. 2000. ND = No Data.*
(Source: Webb et al. 2000, Andrews 1991, Smith et al. 1960)

total length through the Grand Canyon, but are responsible for more than half of the total drop in altitude.

Before construction of the Glen Canyon Dam the River would carry an average of 176 million tonnes of sediment per year through the Grand Canyon (Andrews 1990). The sediment load is presently 2.8 million tonnes per year, the numbers vary depending on the source and year as seen in Table 2. The primary purpose for the construction of the Glen Canyon Dam was energy generation and to prevent silt from building up behind Hoover Dam, at the head of Lake Mead, on the other side of the Grand Canyon.

The water temperature, which used to reach 26.6°C, is now because it is drawn from deep within Lake Powell, icy-cold all year and averages at approximately 5.5°C (Carothers & Brown 1991, Schmidt et al. 1998). The constant temperature of the water released from the cold bottom of Lake Powell limits the types of plants and aquatic animals that can survive and reproduce in the water. As a result of changes in water temperature some native fish, such as the Bonytail (*Gila elegans*), Roundtail chub (*Gila robusta*) and Colorado pikeminnow (*Ptychocheilus lucius*), have become extinct, whilst others, for example the Humpback chub (*Gila cypha*) and Razorback sucker (*Xyrauchen texanus*), are endangered (USBR 2000b).

Aquifers

Mexicali Aquifer

The aquifer, situated in the central part of Mexicali Valley, is more than 5 km thick (Roman & Ramirez 2003). The Mexicali Aquifer is conceptualised in its first 120 m as an unconfined aquifer, non-homogeneous and isotropic, over a regular impermeable floor, with horizontal flow in stationary and transitional regime. Regional flow in the aquifer shows two main directions. One flows northeast of the Mexicali Valley to the entrance of the Colorado River, and then moves toward the Gulf of California in a southwesterly direction. In the other direction, it flows from the northern border of the crest of the delta, heading southwest to the Cucapah Hills, then rotates northwest towards the basin of Salton Sea.

Aquifer recharge depends on returning water from irrigation and infiltration processes back to the Colorado River. In this desert area, rain is practically non-consistent , and annual precipitation averages 65 mm, and completely dry years have been known to occur (Dowd 1956 in Roman & Ramirez 2003). The ratio of precipitation to evaporation is 1 to 40.

Geohydrological studies have estimated that original aquifer recharge came from the Colorado River infiltration. Today recharge is directly related to infiltration from irrigation channels, return of irrigation water, and infiltration from the Colorado River. In the Mexicali Valley, three fronts of horizontal underground recharge can be identified. The first one comes from the All American Canal (AAC) infiltration, the second comes from the Arizona-Sonora border toward the San Luis sandy table, and the third comes along the bed of the Colorado River on the border between Arizona and Baja California.

The Colorado River Delta's depositional process was influenced directly by the chemical water quality. The Colorado River created an aquifer with low saline concentrations. Nevertheless, the gradual decrease in water volume and quality of the recharge has increased the water's salt concentration. For that reason, it is possible to find wells with salt concentrations between 800 and 2 200 ppm.

This geologic formation has characteristically high permeability because the sandy-textured soils surpass the basic infiltration speed of 7.6 cm per hour, which is the technically recommended maximum level for gravity irrigation methods in agricultural uses (Roman 1990 in Roman & Ramirez 2003). In the dunes area, most of the filtered water flows underground naturally toward the south and becomes a very important part of the water recharge of the Mexicali Valley aquifer.

Imperial Valley groundwater basin

The Imperial Valley groundwater basin is located in the southwestern part of California at the international border with Mexico. The Basin lies within the southern part of the Colorado Desert hydrologic region, south of the Salton Sea. The physical groundwater basin extends across the border into Baja California where it underlies a contiguous part of the Mexicali Valley (CDPW 1954). Major hydrologic features include the New and Alamo rivers, which flow toward the Salton Sea.

The Basin has two major aquifers, separated at depth by a semi-permeable aquitard that averages 18 m thick and reaches a maximum thickness of 85 m. The aquifers consist mostly of alluvial deposits of late Tertiary and Quaternary age. The average thickness of the upper aquifer is 60 m with a maximum thickness of 137 m. The lower aquifer averages 115 m thick with a maximum thickness of 457 m. As much as 24 m of fine-grained, low permeability prehistoric lake deposits have accumulated on the early flat valley floor and cause locally confined aquifer conditions (Montgomery Watson Inc. 1995).

Recharge is primarily from irrigation return. Other recharge sources are deep percolation of rainfall and surface run-off, underflow into the basin, and seepage from unlined canals which traverse the valley (CDPW 1954). Principal areas of recharge from surface run-off are in the east and west Mesa, where the surface deposits are more permeable than in the central valley (Loeltz et al. 1975). Another source of groundwater recharge occurs along the lower reaches of the New River, near Calexico (Montgomery Watson Inc. 1995).

Groundwater levels remained stable within the majority of the basin from 1970 to 1990 because of relatively constant recharge and an extensive network of sub-surface drains (Montgomery Watson Inc.1995). The total storage capacity for the basin is estimated to be 0.0172 km^3 (CDPW 1975). A large portion of this groundwater is undesirable because of high TDS (Total Dissolved Solids) concentrations (Montgomery Watson Inc. 1995). TDS content ranges from 498 to 7 280 ppm (Loeltz et al. 1975). Department of Health Services data from five public supply wells show an average TDS concentration of 712 ppm and a range from 662 to 817 ppm.

The All American Canal

The All American Canal (AAC) originates at a reservoir behind the Imperial Dam on the Colorado River. The AAC is the main conduit for delivering water and energy to the region that includes the agricultural valleys of Coachella and Imperial. The 128 km canal carries two-thirds of the 6.4 km^3/year of water that California has recently been drawing from the Colorado River. Besides being the main vein of water supply, the AAC is important because of the water volume filtered to the aquifers in the region.

Yuma Valley groundwater basin

Yuma Valley groundwater basin underlies a southeast trending valley in southeast Imperial County. The elevation of the valley floor ranges from about 30 m above sea level at the Colorado River near Winterhaven to about 182 m along the northwest and southwest margins. Low-lying alluvial drainage divides form boundaries on the northwest and southwest, and the Colorado River bounds the Basin on the south and east. Annual average precipitation ranges from about 25 to 76 mm. Surface drainage is southeast towards the Colorado River (CDPW 1954). The water-bearing material within the Basin is alluvium, which includes the unconsolidated younger quaternary alluvial deposits and the underlying unconsolidated to semi-consolidated older Tertiary to Quaternary alluvial deposits (CDPW 1954, 1975).

Natural recharge to the basin is derived mainly from sub-surface inflow from the Ogilby groundwater basin on the west and infiltration of surface run-off through alluvial deposits at the base of the bordering mountains. Additional recharge comes from the seepage loss from the All American Canal and other unlined canals and from the percolation of irrigation return flows. In the eastern portion of the basin along the Colorado River, high groundwater levels and fluctuations in the elevation of the water table are in direct response to various stages of the River. Groundwater moves southeast and is discharged to the Colorado River (CDPW 1954, 1985). Groundwater storage capacity is estimated to be about 5.6 million m^3 (Loeltz et al. 1975). Natural recharge is estimated to be 494 m^3/year.

Climate

The temperatures in the Colorado River Basin vary from -45°C in the mountains, to 54°C in the deserts of California and Arizona (González-Casillas 1991). Over 95% of the Colorado River Basin is classified as arid or semiarid. The medium annual temperature is 22.5°C with an extreme warm period, that lasts from June to September with medium temperatures of over 30°C. July is the hottest month with an average temperature of 32.3°C and a maximum average of 41.8°C; January is generally the coldest month with an average of 12°C. The annual average precipitation varies spatially, from 63.5 mm to 1 524 mm in the mountains in the form of rain or snow (USGS 1996). The annual average precipitation in the U.S. portion of the Basin is of 762 mm; of which 560 mm are evapotranspirated directly to the atmosphere and the rest forms part of the surface and groundwater flow (USGS 1996).

Marine part of the region – the Upper Gulf of California

The Upper Gulf of California is the shallow, northernmost part of the Gulf of California, also known as Sea of Cortez. It has unique oceanographic characteristics because its long axis and the Baja California Peninsula limit moderating influences from the Pacific Ocean circulation. Strong winds, tidal action and upwelling characterise the Gulf. It has mixed semi-diurnal tides and one of the greatest tidal ranges on earth. Maximum registered spring tidal range at San Felipe is 6.95 m (Gutierrez & González 1999), with even larger amplitudes at the entrance to the delta. Depth is less than 30 m, with shallower waters at the Baja California side than at the Sonora side. The northern Gulf of California has three main natural fertilisation mechanisms: wind-induced upwelling, tidal mixing and thermohaline circulation.

East of the Gulf of California is an important mountain range called the Sierra Madre Occidental which gives origin to important rivers in the Mexican portion of the region. The Sierra Madre Occidental enters through the state of Sonora and crosses the states of Sinaloa and Nayarit, ending in the state of Jalisco in Mexico. This mountain range has an average height of 2 100 m. A large proportion of these rivers flow into to the Gulf of California (Yaqui, Mayo, Fuerte, Sinaloa and Culiacan).

The only river in the Upper Gulf of California is the Colorado. The fluvial channel of the Colorado River widens, forming a 50 km long estuarine basin. For most of the rivers length it is 2-8 km wide and widens to 16 km wide at its mouth. High turbidity levels are a permanent feature of the Upper Gulf due to the constant re-suspension of Colorado silt (Alvarez-Borrego et al. 1975). However the amount of suspended sediment in this area varies geographically, seasonally, and during tiding cycles. Due to sediment re-suspension, the water in the estuary is brownish in appearance.

In the absence of freshwater flows from the Colorado River, the delta is an inverse or negative estuary, in which salinity levels are higher in the north (39‰) than in the south (35.5‰) (Alvarez-Borrego et al. 1975). However, in years of very high precipitation and/or abnormal snowmelts in the upper river basin salinity is then lower in the north (32‰) than in the south (35.4‰) (Lavín & Sánchez 1999).

Despite the ecological impact caused by the construction of dams, life in the estuary is abundant, even during the long periods without surface freshwater input. The Gulf of California has one of the most diverse biological communities in the world constituted by 4 852 species of invertebrates (excluding copepods and ostracods), 767 endemic to the Gulf, 891 species of fish (88 endemic to the Gulf), and 222 species of non-fish vertebrates (4 endemic to the Gulf) (Findley et al. 2001). The American Fisheries Society's official list of marine fish at risk of extinction notes 6 species from the Gulf of California (4 endemic); all are large serranids and sciaenids, sensitive to overharvesting because of late maturity and the formation of localised spawning aggregations (Musick et al. 2000).

Soils and land use

Over 56% of the land area in the Colorado River drainage basin is owned and managed by federal government agencies, 8.5% is state owned land and an additional 16.5% is occupied by Indian reserves. Three quarters of the 56% federal owned land is devoted to national forests and parks and Indian reservations. Approximately 19% of the watershed is privately owned. 2% of the Basin is in Mexico.

Approximately 80% of the river supply is used for agriculture. Of the 0.2 million ha irrigated in the upper basin, feed for livestock is raised on 88% of the irrigated land. In the lower basin states, California, Arizona, and Nevada, 85% of water is utilised for agricultural purposes, with a significant but slightly less percentage going to grow feed for livestock. Of the 45 million ha in the lower basin, 27 million ha are rangeland or pasture, while only 202 350 ha are classified as urban (Brown 1995).

The largest user of agricultural water is the Imperial Irrigation District (IID) in southern California, which alone accounts for approximately 3.5 km^3 annually (1964-1996 average), or almost 20% of the River's average annual flow (Pontius 1997). Other major agricultural users include Palo Verde Irrigation District, the Coachella Valley Water District, and the Mexicali and San Luis Rio Colorado Irrigation Districts (Table 3).

There are roughly 45 million ha of irrigated cropland and 22 million ha of dry cropland in the Basin. This land use is expected to decline as residential and commercial development, associated with population growth, increases over the next 20 years. Grazing is a significant form of land use in the drainage basin (see Table 4). The number of animal unit months (AUM) is a measure of the consumed forage for a 362 kg grazing animal over a 1-month period. As of the midd-1990s, there were estimated almost 10 million AUMs in the Basin.

Table 3 Annual water applied for irrigation in the Colorado River Delta region's major irrigation districts.

Diverter	Colorado surface water (million m^3)		Groundwater (million m^3)	
	Non-flood year	Flood year	Non-flood year	Flood year
Arizona				
North Gila Irrigation District	55.5	53	-	-
Yuma Irrigation District	67.8	65	13.3	13.3
Yuma Valley Irrigation District	308.3	298	32.3	36
Other irrigators	66.1	70	-	-
Arizona total	497	486	45.6	49.3
California				
Coachella Valley Water District	340	343	79.8	80
Yuma Project, Reservation Division	101	95	26.1	30.2
Imperial Irrigation District	3 180	3 070	-	-
California total	3 620	3 510	106	110
Mexico				
District 014	1 670	2 250	949	777
Total Colorado River Delta region	5 790	6 240	1 100	937

(Source: CNA unpublished data, USBR 1996)

Table 4 Livestock grazing on public lands.

State	Area grazed (ha)	AUM[1]	Total estimated value of livestock (USD/year)	Annual generated (USD/year)
Arizona	4 537 000	681 000	54 501 000	1 342 000
California	3 161 000	380 000	30 384 000	748 000
Colorado	3 128 000	800 000	64 032 000	1 474 000
Nevada	18 955 000	2 736 000	218 856 000	5 389 000
New Mexico	5 063 000	1 911 000	152 866 000	3 764 000
Utah	8 934 000	1 331 000	106 483 000	2 622 000
Wyoming	7 041 000	2 010 000	160 768 000	3 959 000
Mexicali	59 000	76 000	50 000	ND
Total	50 878 000	9 925 000	787 940 000	19 298 000

Note: [1]Animal Unit Months (AUM) is a measure of the consumed forage for a 362 kg grazing animal over a 1-month period. (Source: Holechek 1993, INEGI 1992, based on U.S. Dept. of the Interior 1990 land- and AUM statistics, and Torell and Doll's economic evaluations)

Socio-economic characteristics

The Colorado River Basin and Upper Gulf of California contribute to the local economies of the area and enhance the quality of life for the inhabitants. The Colorado River provides a valuable habitat for fish and wildlife, and supports one of the leading trade centres on the West Coast. There are increasing human population pressures in the Basin, especially in southern California. In the Gulf, an increase in the demand for oil, gas, and mineral resources has stimulated an exploration of the non-living resources of the Exclusive Economic Zone.

Population

The population increased in the Colorado River Basin by 45% between 1970 and 1980, according to the U.S. Bureau of the Census (USCB 1996).

The population in 2000 surrounding the Colorado River Basin was approximately 62.8 million (USCB 2000, INEGI 2001). The United States has the majority of this total population with 49.8 million (79%). The states that comprise the Colorado River Basin have high population densities: the U.S. part has an average population density of about 30 per km^2, whereas in the Mexican part the average population density is 22 per km^2. During the last two decades urban centres have become increasingly crowded; in 2000, the U.S. population was 77% urban and 23% rural, and Mexico 75% urban and 25% rural (USCB 2000, INEGI 2001). Three of the 30 urban centres are cities with more than 4 million inhabitants, and 11 are cities with over 300 000 inhabitants. The rural migration to urban areas in the Mexican portion has created huge marginal areas on the outskirts of the cities without infrastructure and zoning service. The states in the American Southwest have the highest percentage of persons of Hispanic/Latino origin (Arizona 25.3%, California 32.4% and New Mexico with 42.1%) (USCB 2000, INEGI 2001).

The western states within the Basin in the United States (Nevada, Utah, Arizona, New Mexico, Wyoming and Colorado) are considered the fastest growing states in the country, with a 20% population increase between 1990 and 2000 (U.S. Census Bureau 2000). Nevada has been the fastest growing state in the nation (10.64%) for the past several years. Population growth in rural areas has been far less dramatic, and in some areas has shown a decline.

Concerning population densities, the northern states of the Mexican portion surrounding the River Basin are not very dissimilar to those states of the U.S. For example, the states of Baja California, Chihuahua, Sonora and Sinaloa each have a population of over 2 million inhabitants (INEGI 2003). Problems such as overcrowding, health hazards, pollution, poor housing and unsanitary conditions, that affect the population's quality of life, are magnifying both poverty and socio-economic gaps. The increase in marginal urban settlements is a consequence of an unsustainable development applied model that limits new opportunities for rural inhabitants and is the origin of major environmental problems, especially in the U.S.-Mexico border region. Approximately 84.1% of the states of the Colorado River Basin had access to drinking water services in 1999. In the same year 78% of the Basin's population had access to sanitation and waste disposal services (U.S. Census Bureau 2000, INEGI 2001).

Socio-economic development is greater in the U.S. states than in Mexico (Peach & Williams 2003). Regarding the percentage of the population living below the national poverty line, the Colorado River Basin countries have a large disparity: U.S. 12.7% (1999) and Mexico 27% (1998) (Bishaw & Iceland 1999, INEGI 1999b). Most of the households living in poverty in the Basin were in rural areas. The infant mortality rate for the Basin countries is an average of 7 per 1 000; in the U.S it is 6.76 per 1 000, and for Mexico 25.36 per 1 000 (USCB 2000, INEGI 2001). The literacy rates (age 15 and over) are in U.S. 97% and in Mexico 89.6%.

Economy

Although the industrial sector largely contributes to Gross State Product, agriculture in the southwestern states (Wyoming with 2.4%, New Mexico 1.9%, California 1.8% and Arizona 1.4%) is a major contributor to the Colorado River Basin economy (Beemiller & Woodruff III 2000). The agricultural sector has a major economic importance at national, regional and international levels. Although agriculture, cattle and the fisheries are now the main exportation activities of the entire Basin, the

Table 5 Gross domestic product by sector in United States and Mexico 1999.

Sector	United States (% of GDP)	Mexico (% of GDP)
Agriculture	2	5
Industry	18	27
Services	80	68

(Source: Beemiller & Woodruff III 2000, INEGI 2000a)

Table 6 Change in real gross state product by sector in the Colorado River Basin 1999-2000.

State	Agriculture, forestry and fishing (%)	Mining (%)	Manufacturing (%)	Services (%)
Arizona	1.9	-6.4	14.4	6.4
New Mexico	1.2	-12.7	25.5	3.3
Colorado	0.4	-15.5	5.1	9.6
Utah	6.9	-6.6	6.4	5.6
Wyoming	2.3	-9.5	8.9	3.2
California	6.3	-11.0	10.1	9.5
Nevada	10.3	-7.0	7.1	4.4
Baja California	-1.0	-0.5	-0.1	0.3
Sonora	-4.8	-9.4	2.2	0.1

(Source: Panek & Downey 2002, INEGI 2000a,b)

timber and mining industry continues to play an important role in the Basin economy through domestic and international exportation. Finally, tourism, though not easily identifiable as a separate economic sector, is an important economic activity in the Basin. Both the U.S. and Mexican economies are shifting to services (Table 5).

Maquiladora (industries)-related development is occurring within the states of Arizona and New Mexico, especially in the southern part of the states. The rapid growth of the industry south of the border is due to the close proximity to the Mexican border. The contribution of Arizona and New Mexico's industrial activities has become a key element for the regions economy (Table 6).

The economic development in the Mexican portion of the Colorado River Basin is distinctively agricultural and industrial. Tijuana, Mexicali and San Luis R.C. constitute the urban use of the Colorado River waters. Agriculture once the economic stronghold in Mexicali and San Luis represents a decreasing share of the state's total output. Mexicali, Tijuana and San Luis Rio Colorado all have experienced a dramatic growth in the industrial sector, although in 2001 the manufacturing industry experienced a declivity in the physical production volume. The value of the agricultural output in Wyoming annually approaches or exceeds 1 billion USD with cash income. The cattle industry is by far the largest component of Wyoming's agriculture, accounting for over 70% of all cash receipts. Cattle also led the way in 2001 in terms of value production at 545 million USD.

Since mid-1999 there has been some growth in industrial production in both countries. However, regional output grew at a very slow pace (0.5%) in 2001 (Panek & Downey 2002). This situation was directly linked to the global economic crisis and the events of September 11th 2001, which has affected the Basin primarily through a disruption of trade links in the midst of unstable world financial markets. However, given the scope of these adverse external factors the Basin's economies have succeeded in averting serious domestic or external disequilibria.

The U.S. states in the years 1994-2000 witnessed solid increases in real output, low inflation rates, and a drop in unemployment to below 5% (Beemiller et al. 2000) Long-term problems include inadequate investment in economic infrastructure, rapidly rising medical costs of an aging population, sizable trade deficits, and stagnation of family income in the lower economic groups. On the other hand, the existing economic situation for the Mexican states has been less positive. Mexico has a free market economy with a mixture of modern and outmoded industry and agriculture, increasingly dominated by the private sector. Private consumption became the leading driver of growth in 2000, accompanied by increased employment and higher real wages. Mexico still needs to overcome many structural problems as it strives to modernise its economy and raise living standards. Income distribution is very unequal, with the top 20% of income earners accounting for 55% of income.

California the seventh largest economy in the world is by far the largest exporting state in the River Basin, generating some 107 billion USD per year in exports. The state by itself receives more foreign direct investment than any other state of the Basin. It also tops the tourism and travel category, with 68 billion USD in sales in 1999. California has been the number one food and agricultural producer in the Basin. California's agricultural output is nearly 25 billion USD per year and produces over 350 different crops.

Colorado has the second largest economy in the Basin. Its economy is not dependent on any single sector, but has a strong base of diverse businesses especially in high-tech durable goods and traditional industries. In 2001, Colorado ranked fifth in the nation for venture capital investment, with 1.5 billion USD invested in 111 Colorado companies. Nevada's primary source of investment is in the casino and tourism industry, although agriculture provides a cornerstone to the economies of many of Nevada's rural communities.

Border region towns have experienced an average annual population growth of 38% per year over the last 5 years (Ganster 1996), largely associated with the maquiladora industries and trade with the U.S. The largest are Tijuana and Mexicali in Baja California, but there has also been rapid growth in a number of smaller border towns in B.C. (Ensenada) and Nogales (Sonora).

Tijuana and Los Angeles are located outside the Colorado River Basin but are still important water users of the Colorado River Basin due to basin transfers. There are 183 maquila plants operating in Mexicali, which puts Mexicali as the second most important city with direct capital investment in the Mexican portion of the River. Regardless of the economic growth in the maquila industry, the agricultural sector represents an important income to the rural areas of the Colorado River and provides employment for thousands of workers (Braceros).

Table 7 Water resources and dams in the Colorado River Basin.

	Upper Colorado	Lower Colorado	Total
Total area (km^2)	290 364	360 346	650 710
Total number of dams	4	19	23
Total storage (km^3)	57 168	59 644	116 812
Total annual run-off (km^3)	18 574	23 406	41 980
Population	714 000	5 318 000	6 032 000
Area/Dam (km^2)	248	810	
Storage/Area (km^3/km^2)	1.072	0.429	
Storage/Run-off (m^3/s)	3.08	2.55	
The year storage>Run-off	1950	1936	
Persons/Dam	613	11 924	
Storage/Person (km^3)	0.08007	0.01122	

(Source: USFWS 2002)

Water resources

The primary source of water supply in the Colorado River Basin states comes from the Colorado River. Groundwater is also an important resource, accounting in some states (e.g. Arizona, California, Baja California and San Luis) for up to 37% of total water use. As the West's population and need for water have grown, the Colorado River has been tapped through a system of dams and diversions that begin close to its source in the mountains of Colorado and Wyoming (Table 7). More than 60 major diversions carry water away from the River for agriculture and other uses.

The majority of water diverted at Morelos Dam in Mexico is used by the irrigation districts in the Mexicali Valley. In total, including groundwater (the second main source of water in the region), there is about 2 740 km^3 of water available to the region annually. Groundwater about 197 km^3 annually, is used in the San Luis Region (23 million) and for urban areas like San Luis Rio Colorado, Mexicali (82 million), Tecate 3.3 million), Ensenada (9 million) and Tijuana (80 million). Agriculture also uses groundwater (about 500 km^3 annually), 200 million km^3 of which are for private use (CNA 2000b).

Due to conflicts between agricultural and urban uses, industries prefer establishing themselves in places where groundwater sources are available for their use, causing investment losses to cities like San Luis Rio Colorado (Cambio 2004), where ground water resources are scarce. The urban region of the Colorado River Delta includes seven cities in the Imperial Valley, and Mexicali and San Luis Valley, which are located 193 km east of San Diego. The region has 1.2 million inhabitants and nearly more than 0.5 million ha of agricultural land. Of California's total water volume of 6.4 km^3 per year, some 3.7 km^3/year is now applied to farmland in the Imperial Valley. Imperial Valley agricultural activities total more than 1.4 billion USD every year.

As a partial solution to the reduction of California's water volume, the U.S. government is seeking to line the nearby All American Canal to reduce seepage into the U.S. and the Mexicali aquifers. The U.S. loss is an estimate of 100 million m^3 per year of water, from which 80% infiltrates into Mexican territory (Mexicali Valley) (CNA 2000b).

There are more than 1.5 million ha of irrigated land (including Mexico) throughout the Colorado River Basin that produce about 15% of the nation's crops, 13% of its livestock, and agricultural benefits of more than 1.5 billion USD per year in the United States.

While irrigated agriculture tops the list of Colorado River water uses (Table 8) in the United States and Mexico, the second largest consumption of water is evaporation from reservoirs. Diversions out of the Colorado Basin, such as water piped through the California Aqueduct to Los Angeles, San Diego and Tijuana are the third largest draw, and are followed by municipal and industrial uses. Hydroelectric plants along the Colorado River generate about 16 960 GWh of electricity annually (Solley et al. 1998). Due to various economic factors such as urbanisation, past federal set-aside programmes and increasing energy and water costs, agricultural water use has declined in the U.S. Probably the single most important contributing factor in this decrease is a reduction in planted hectares.

Table 8 Water withdrawals and uses in the Colorado River Basin.

Region	Surface water withdrawals							Surface water uses			
	Public supply (million m^3/year)	Irrigation (million m^3/year)	Livestock (million m^3/year)	Industrial (million m^3/year)	Mining (million m^3/year)	Thermal power (million m^3/year)	Total	Population served	Area irrigated (ha)	Thermal power (GWh)	Hydropower (GWh)
Upper Colorado	146	9 660	69	5.5	4.8	200	146	407 000	1 813 300	94 000	7 220
Lower Colorado	964	5 800	9.4	7.6	36	23	964	2 510 000	1 157 000	62 400	9 740
Total	1 110	15 470	78.4	13.1	40.8	223		2 917 000	2 970 300	156 400	16 960

(Source: Solley et al. 1998)

Legal framework

United States

In the United States, water allocation is controlled by state law, with the western and southern states generally relying on prior appropriation systems for surface water allocations, and the northern and eastern states relying mainly on riparian rights systems. Groundwater allocation, which is also under state jurisdiction, is often managed separately from surface water - a perpetual problem in water resources management, given the pervasive interactions between groundwater and surface water.

The federal Environmental Protection Agency implements laws to protect the environment, including water quality and aquatic habitat, for which many states have assumed administrative responsibility. Through the U.S. Bureau of Reclamation and the U.S. Army Corps of Engineers, the federal government has participated in the development of large water projects.

Mexico

In recent years, the government has shifted toward decentralisation of federal water management, particularly in the area of sewage and water infrastructure. The 1992 National Waters Act, administered by the National Water Commission (Comisión Nacional del Agua, CNA), is the main institutional framework for water management in Mexico. CNA, whose responsibilities are primarily operational, oversees the development and use of Mexico's water resources. Since its creation in 1989, CNA has sought to reduce the level of federal centralisation in water resources management by conceding more operational functions to states, municipalities and private firms.

The Department of Environment and Natural Resources (Secretaría del Medio Ambiente y Recursos Naturales, SEMARNAT) is directly charged with implementing federal environmental laws. By law, SEMARNAT is the leading agency responsible for protecting water quality, which it does by setting standards and enforcing compliance with regulatory requirements. Its authority in this area, however, is largely administrative rather than operational. Most operational functions (for example, ownership and management of waste treatment facilities), inspections and monitoring are carried out by CNA and other federal, state and municipal entities.

According to Mexican National Water Law and its regulations, river basin councils (Consejos de Cuenca) coordinate federal, state, and municipal dependencies and entities, and negotiate with water users. Their main objectives include the formulation and execution of programmes and actions to improve regional water management, support of hydraulic works development and related services, and the preservation of river basin resources.

In modern water management, river basin councils play a basic role since they are plural, open forums where existing problems are ventilated, and actions to be carried out are agreed upon for the benefit of river basins and their population, according to a previously accepted water agenda or, conveniently, an orthodox master water plan.

Interstate commissions administer water compact agreements between state governments

Apportionment of water from the Colorado River within the United States and Mexico is governed by a series of agreements constituting the "Law of the River". The Law of the River is the legal and institutional framework for managing the River and defining the states and individual entitlement holders' rights and obligations (see Annex III and IV).

The Colorado River Compact of 1922

Seven western states (Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming) and Mexico have interests in the Colorado River Basin. Each state is party to the Colorado River Compact entered into Santa Fe, New Mexico, on November 24, 1922.

The Colorado River Compact divided the Colorado River Basin into the Upper Basin and the Lower Basin. The division point is Lee's Ferry, Arizona, a point in the main stem of the Colorado River about 48 river-km south of the Utah-Arizona boundary. The Upper Basin includes those parts of the states of Arizona, Colorado, New Mexico, Utah, and Wyoming within and from which waters naturally drain into the Colorado River system above Lee's Ferry, and all parts of these states that are not part of the River's drainage system but may benefit from water diverted from the system above Lee's Ferry. The Lower Basin includes those parts of the states of Arizona, California, Nevada, New Mexico, and Utah within and from which waters naturally drain into the Colorado River system below Lee's Ferry, and all parts of these states that are not part of the River's drainage system but may benefit from water diverted from the system below Lee's Ferry.

The Colorado River Compact apportioned to each basin the exclusive, beneficial consumptive use of 9.251 km^3 of water per year from the Colorado River system in perpetuity. In addition, the Compact gave the Lower Basin the right to increase its annual beneficial consumptive use of such water by 1.233 km^3 (Table 9.

The Water Utilization Treaty of 1944

The 1944 Treaty Relating to the Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande, also known as the 1944 Water Utilizations Treaty (IBWC 1944), is considered the centrepiece of the U.S.-Mexico legal framework for managing transboundary waters. It established the bi-national International Boundary Water Commission (IBWC), which has many responsibilities including oversight of transboundary water allocation (as established in the 1944 Treaty and subsequent agreements), management of reclamation works, and development of joint sewage and sanitation facilities.

The Treaty guarantees Mexico 1.85 km^3 of Colorado River water annually, equivalent to roughly 10% of the average annual flow, but was silent on the quality of water to be delivered. As a result, serious problems have arisen, the most important of which is the increased salinity caused by upstream irrigation. This problem was addressed in 1973 by Minute 242 to the 1944 treaty, but it continues to be a concern for Mexico.

The 1944 Water Utilization Treaty has permitted IBWC's administration role to evolve in response to emerging needs and circumstances. The commission has assumed responsibility for addressing the persistent problem of high salinity in waters flowing from the United States to Mexico, particularly the Colorado River. "In the event of extraordinary drought or serious accident to the irrigation system in the United States, thereby making it difficult for the United States to deliver the guaranteed quantity of 1 500 000 acre-feet (1 850 234 000 cubic meters) a year, the water allotted to Mexico under subparagraph (a) of Article 10 of the 1944 Mexican Water Treaty will be reduced in the same proportion as consumptive uses in the United States are reduced" (IBWC 1944).

Table 9 Water allocations in the Colorado River Basin.

Entity	Apportionment		Authority
	(km^3/year)	(million acre-feet/year)	
Upper Basin	9.251	7.5	1922 Colorado River Compact. (The Upper Basin has the right to use 9.251 km^3 only if that quantity is available after it has satisfied its delivery requirements of 9.251 km^3/year to Lower Basin plus the amount required to satisfy the Mexican Treaty obligation.)
Arizona	0.06	0.05	1948 Upper Colorado River Compact.
Colorado	4.76	3.85	1948 Upper Colorado River Basin Compact. (Colorado is apportioned 51.75% of the remaining flows after the Upper Basin's delivery requirements have been met.)
New Mexico	1.03	0.84	1948 Upper Colorado River Compact (New Mexico is apportioned 11.25% of the remaining flows after the Upper Basin's delivery requirements have been met.)
Utah	2.10	1.71	1948 Upper Colorado River Compact (Utah is apportioned 23% of the remaining flows after the Upper Basin's delivery requirements have been met.)
Wyoming	1.28	1.04	1948 Upper Colorado River Compact (Wyoming is apportioned 14% of the remaining flows after the Upper Basin's delivery requirements have been met.)
Lower Basin	9.25	8.5	1922 Colorado River Compact.
Arizona	3.45	2.8	1963 U.S. Supreme Court decision Arizona vs. California.
California	5.43	4.4	1963 U.S. Supreme Court decision Arizona vs. California.
Nevada	0.37	0.3	1963 U.S. Supreme Court decision Arizona vs. California.
Mexico	1.85	1.0	1944 Mexican Water Treaty.
Additional	1.20	1.5	Article III (b) of 1922 Colorado River Compact.

(Source: Pontius 1997)

The Upper Colorado River Basin Compact of 1948

On October 11, 1948, the Upper Basin states entered into the Upper Colorado River Basin Compact, which apportioned use of the Upper Basin waters among them. The compact permits Arizona to use 0.061 km^3 of water annually from the Upper Colorado River system, and apportioned the remaining water to the Upper Basin states in the following percentages: Colorado 51.75%, New Mexico 11.25%, Utah 23%, and Wyoming 14% (Table 9).

The U.S. Supreme Court Decision Arizona vs. California of 1963

The Lower Basin states of Arizona, California, and Nevada were not able to reach agreement. In 1952, Arizona filed suit in the United States Supreme Court to determine how the waters of the Lower Basin should be divided. In October 1963, the Court ruled that of the first 9.25 km^3 of main stem water in the Lower Basin, California is entitled to 5.43 km^3, Arizona 3.45 km^3, and Nevada, 0.370 km^3 (Table 9 and Figure 4). The United States has contracted with the states of Arizona and Nevada and with various agencies in Arizona and California for the delivery of Colorado River water. These contracts make delivery of the water contingent upon its availability for use in the respective states under the Colorado River Compact and the Boulder Canyon Project Act.

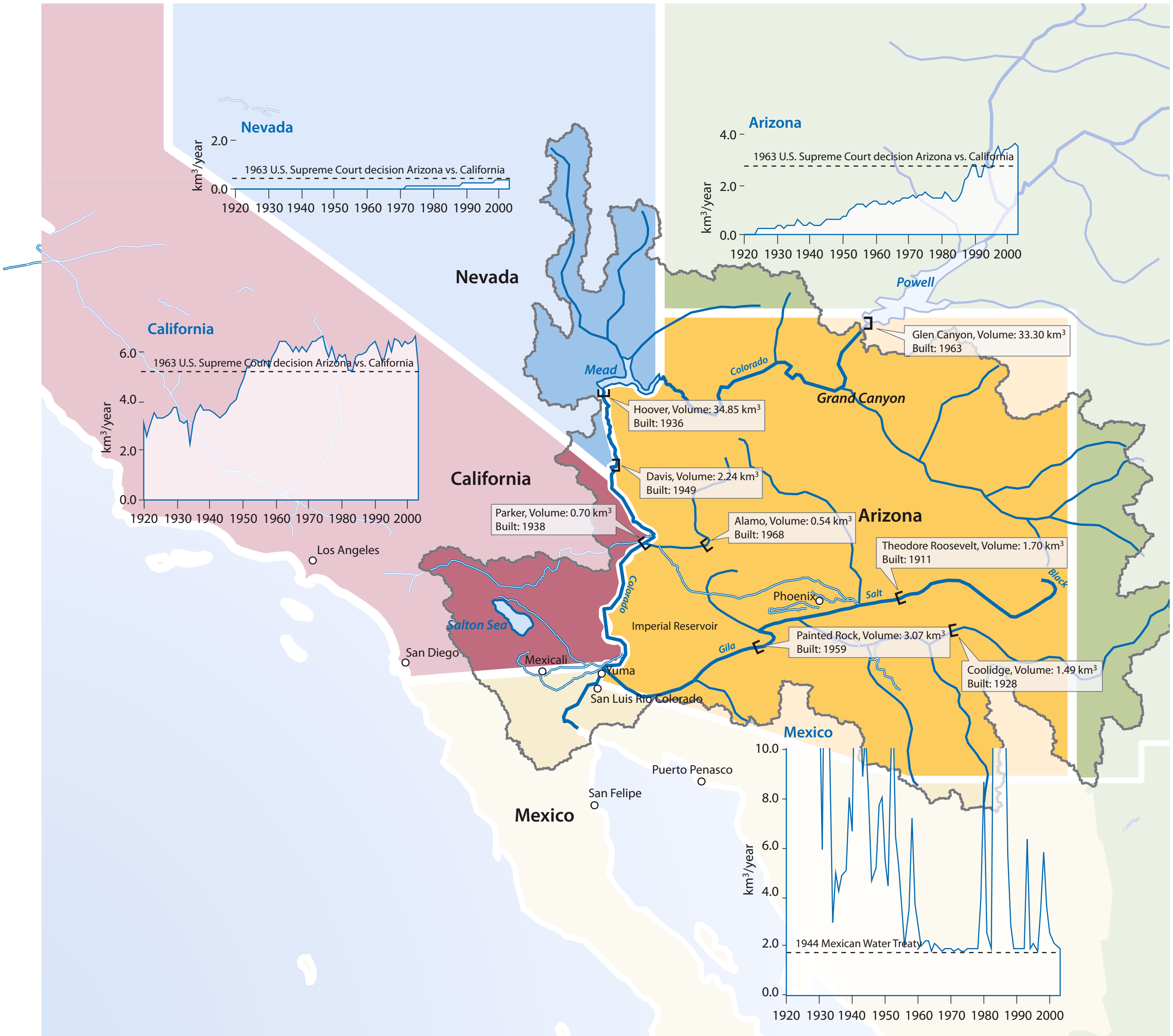

Figure 4 Water consumption along Colorado River.
(Source: ESRI 1996, USBR 2003)

For decades, California used approximately 6.63 km³ annually from the Colorado River. This was allowed because California was the first state to have a water distribution system. In recent years, however, three significant events greatly altered California's favourable position. First, under the 1963 decision of the U.S. Supreme court, California's entitlement was set at 5.43 km³ annually (Table 9). Second, Arizona is approaching its full entitlement because of the completion in the late 1980s of the first phase of the massive Central Arizona Water Project. Third, Nevada reached its allotment in 2000.

This situation obligated the U.S. Bureau of Reclamation to implement diverse actions of technical and political character, among them the Colorado River Interim Criteria strategy. This strategy consists of criteria under which surplus water volume in the Lower Basin of the Colorado River could be declared during the next 15-year period (USBR 2000 in Roman & Ramirez 2003). Interim surplus criteria (ISC) are used annually to determine the conditions under which U.S. Department of Interior may declare the availability of "surplus" water for use within the states of Arizona, California and Nevada.

The Long Range Operating Criteria (LROC) for the Colorado River define a normal year as one in which annual pumping and release from Lake Mead is sufficient to satisfy the 9.20 km^3 of consumptive use in accordance with the decree. A surplus year is defined as per year in which water in quantities greater than normal (9.20 km^3) is available for pumping and release from Lake Mead.

Under Article 10 (b) Mexico may schedule up to an additional 0.246 km^3 when a surplus of water exists in the Colorado River in excess of the amount necessary to supply the United States. As a result of current operating experience, particularly during recent years when there has been an increase in demand for surplus water, the U.S. Department of Interior has determined that there is a definite need for specific surplus criteria. The ISC could help implement the specific provisions.

The United States-Mexico Border Environmental Cooperation Agreement of 1983

Growing concerns about environmental quality in the border region have fostered the creation of several recent bi-national institutions with responsibilities for transboundary water management. The United States-Mexico Border Environmental Cooperation Agreement (the La Paz Agreement) of 1983 established a process to reduce and prevent various forms of pollution in the border area. Working groups under the La Paz process have collaborated with IBWC to address specific problems, such as sewage and the discharges of hazardous substances into transboundary waters.

The Border Environment Commission

The Border Environment Cooperation Commission (BECC) is a bi-national commission established in 1994 to address shortcomings in environmental infrastructure along the U.S.-Mexico border. The Commission was created at the same time as the North American Development Bank (NADBank), and both grew out of the North American Free Trade Agreement (NAFTA). BECC and NADBank have been particularly active in providing technical assistance to border communities for water and sanitation projects that meet strict environmental criteria. Another recent bi-national initiative, the Integrated Border Environmental Plan, or Border XXI, promotes intergovernmental cooperation and public involvement in sustainable development in the border region.

Assessment

Arias, E.

Table 10 Scoring table for the Colorado River Basin region.

Assessment of GIWA concerns and issues according to scoring criteria (see Methodology chapter)

- 0 No known impacts
- 1 Slight impacts
- 2 Moderate impacts
- 3 Severe impacts

The arrow indicates the likely direction of future changes.

- ↗ Increased impact
- → No changes
- ↘ Decreased impact

Colorado River Basin	Environmental impacts	Economic impacts	Health impacts	Other community impacts	Overall Score**	Priority***
Freshwater shortage	2.6* →	1.8 ↗	1.0 →	2.3 ↗	2.0	1
Modification of stream flow	3					
Pollution of existing supplies	1					
Changes in the water table	2					
Pollution	1.1* →	2.3 →	2.2 →	2.4 →	2.0	2
Microbiological pollution	1					
Eutrophication	1					
Chemical	2					
Suspended solids	1					
Solid waste	1					
Thermal	0					
Radionucleid	1					
Spills	1					
Habitat and community modification	3.0* ↘	1.8 →	0 →	1.6 →	1.5	3
Loss of ecosystems	3					
Modification of ecosystems	3					
Unsustainable exploitation of fish	2.9* ↘	1.4 →	0 →	1.6 →	1.3	4
Overexploitation	3					
Excessive by-catch and discards	3					
Destructive fishing practices	3					
Decreased viability of stock	2					
Impact on biological and genetic diversity	3					
Global change	0* →	0 →	0 →	0 →	0	5
Changes in hydrological cycle	0					
Sea level change	0					
Increased UV-B radiation	0					
Changes in ocean CO_2 source/sink function	0					

* This value represents an average weighted score of the environmental issues associated to the concern.

** This value represents the overall score including environmental, socio-economic and likely future impacts.

*** Priority refers to the ranking of GIWA concerns.

This section presents the results of the assessment of the impacts of each of the five predefined GIWA concerns i.e. Freshwater shortage, Pollution, Habitat and community modification, Unsustainable exploitation of fish and other living resources, Global change, and their constituent issues and the priorities identified during this process. The evaluation of severity of each issue adheres to a set of predefined criteria as provided in the chapter describing the GIWA methodology. In this section, the scoring of GIWA concerns and issues is presented in Table 10.

Freshwater shortage

Before 1936 a sizable freshwater flow reached the mouth at the Upper Gulf of California, which replenished the delta with silt and delivered nutrients to fish and other marine life. Tides that typically reached 30 m or more in amplitude extended the tidal estuary 56 km upriver. From 1936 to 1980, the River became a trickle and the delta dried up following the impoundment of the river's water in huge reservoirs behind the Hoover and Glen Canyon dams. During this period, water rarely flowed all the way to the Gulf. In the past century, river flows into the delta have been reduced by nearly 75%. The lack of freshwater flows has had far-reaching impacts. Today, native populations of species like the Colorado pikeminnow (*Ptychocheilus lucius*) are extinct in the Lower Colorado River, and several others are on the brink of extinction. The Cucapá people have inhabited the delta for a millennium, depending on its natural resources for their survival. They numbered about 20 000 at the arrival of the Spanish in the 16th century, but today only 200-300 remain. Freshwater shortage is considered by the GIWA Assessment to be severe and the most critical issue in the Colorado River Basin.

Environmental impacts

Modification of stream flow

Although at times the Colorado River is considered an abundant source of freshwater, the significant changes in the hydrologic regime throughout the River Basin has provoked the diminishment of the River's natural flow, and has consequently caused an accentuated problem in the Mexican borderland.

Prior to development, the Colorado River flowed unimpeded for 2 735 km. Although the Colorado River Basin drains 632 000 km^2, including 5 200 km^2 in northern Mexico, it is estimated that no more than 25% of Colorado waters reach Mexican territory (Lueck et al. 1999). The estimated total water demand for the Colorado River Basin is 24.5 km^3/year (USBR 2000b). The average flows between 1906 and 1930 were almost 22.1 km^3/year, but this average reduced to only 17.5 km^3/year during the last 70 years (1930 to 1998) (Table 11 and Figure 5). Today the Colorado River Delta is sustained by only flood flows and, during dry years, its only supply is from groundwater seepage, agricultural drainage and tidewater (Glenn 1998). The construction and location of major dams in the Colorado River (Hoover Dam and Glen Canyon Dam) had the most drastic impact upon the amount of freshwater flow that reaches the Colorado River Delta due to their reservoir capacity (CNA 1999).

Table 11 Estimated Colorado River budget.

Water demand	Quantity (km^3/year)
Upper Basin (9.25 km^3) Lower Basin (9.25 km^3) – 1922 Colorado River Compact	18.5
Central Arizona Project (rising to 3.48 km^3) – 1922 Colorador River Compact	1.2
Mexican allotment – 1944 U.S. Mexico Water Treaty	1.8
Evaporation from reservoirs	1.8
Bank storage at Lake Powell	0.6
Phreatophytic losses (water demanding plants)	0.6
Budgeted total demand	= 24.5
1930-1998 average flow of the River	17.5

(Source: USBR 2002)

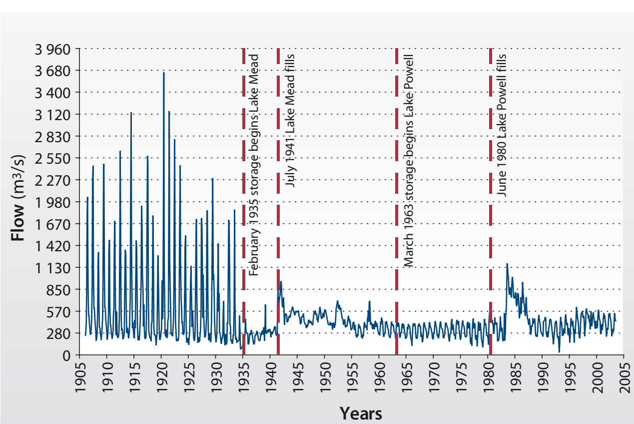

Figure 5 Flow of the Colorado River below Hoover Dam 1905-2003.
(Source: USBR 2002)

Before the filling of Hoover Dam in the 1930s (creating Lake Mead), the delta experienced a perennial discharge from the Colorado River (USGS 2002a). By the time Glen Canyon Dam was completed in 1962, regular input of Colorado River water to the delta and Upper Gulf of California had completely ceased with the exception of allotments to Mexico stated in the 1944 Water Treaty (Cohen & Henges-Jeck 2001)

Sediment carried by the Colorado River was originally transported to the Gulf of California, with a calculated sediment load of approximately 160 million tonnes per year (Carriquiry & Sánchez 1999). Upon completion of the Hoover Dam however, much of the River's sediment was deposited in the quiet waters of Lake Mead (USGS 2002a). It has been estimated that this human intervention has led to a 99.5% reduction of the original sediment discharge to the Colorado River Delta; the deltaic basin having transformed from an estuarine setting to a hyper saline, anti-estuarine and erosive environment (Daesslé et al. 2001). In the absence of new sediment supply from the River, the delta has become subject to destructive processes such as strong tidal currents and wind waves (Carriquiry & Sánchez 1999).

Pollution of existing supplies

The most critical concern for the Lower Basin is salinity and is consequently the only water-quality parameter studied under this issue. Other water quality issues are discussed in the Pollution concern assessment. Even in the best-case scenario salinity criteria are consistently exceeded at all points in the Lower Basin for most years. Decreases in run-off of only 5% cause salinity criteria to be exceeded in virtually all years. Even if average flows were to increase by 20%, salinity criteria are exceeded continuously for long periods (Nash & Gleick 1993).

Groundwater beneath the River Basin is in general unusable for domestic and irrigation purposes without treatment. TDS values typically exceeding 2 000 ppm are reported from a limited number of test wells drilled in the western part of the Basin. Groundwater in areas of the Basin has higher than recommended levels of fluoride and boron (Loeltz et al. 1975). In addition to salinity, the Basin has also experienced groundwater quality problems related to the intensive use of pesticides by farmers. In 1979, a private well near Yuma Arizona registered the highest levels of DBCP (dibromochloropropane) ever recorded in U.S. drinking water. Subsequent tests indicated widespread contamination by this pesticide, which is used to control root parasites in citrus orchards (Arizona Daily Star 1982, U.S. GAO 1984).

In general, salinity in the Colorado River is inversely related to stream flow. Salinity tends to be higher when stream flows are low and lower when there are high stream flows. However, the effects of stream flow on salinity might depend to some degree on the time of year. In 1971, the Environmental Protection Agency (EPA) concluded that nearly half (47%) of the salinity concentration arriving at Hoover Dam was from natural sources (EPA 1971).

The Colorado's salinity increases as it flows downstream (Table 12) due to upstream evaporation and return flows from agricultural use. Mueller and Osen (1988), in a report submitted to the United States Geological Survey, estimated that the natural salt load of Colorado River at Lee's Ferry, Arizona is 4.8 million tonnes per year. The U.S. Bureau of Reclamation (USBR 1995b) has determined that the salt load currently entering Lake Mead is about 8.1 million tonnes annually. In addition to the salinity of the aquifers, the most serious problem today is that the diversions of the Colorado River water for urban and industrial uses exceeds 6.25 km^3 per year; 72.3 times more than the 1944 treaty allotted to Tijuana and Tecate.

Table 12 Salinity in the delta region.

Sample point	Total Dissolved Solids (TDS)	
	Non-flood year (ppm)	Flood year (ppm)
Colorado River at Hoover Dam[a]	723	-
Colorado River at Parker Dam[a]	747	-
Colorado River at Imperial Dam[b]	784	713
Colorado River at Northerly International Boundary[b]	906	760
Other deliveries near Southerly International Boundary[b]	1 274	1 222
Main Outlet Drain Extension canal (MODE)[b]	2 838	2 045
New River at border[c]	2 836	2 583
Hardy River[c]	1 810	560
Ciénega de Santa Clara[c]	3 000	5 000
Salton Sea[b]	42 271	43 304

(Source: [a] MWD/USBR 1998, [b] IBWC 1991-1998, [c] Valdés-Casillas et al. 1998)

The increase of Total Dissolved Solids (TDS) is detrimental to flood plain ecosystems and local fisheries. Studies have investigated the effect of salinity on the growth rate of penaeid postlarvae. During 1993 and 1997, increases in the amount of freshwater discharged by the River decreased the salinity of the Upper Gulf of California. This possibly expanded shrimp postlarvae habitat, as low salinity environments are preferred by *Litopenaeus stylirostris* (Aragón-Noriega & Calderón-Aguilar 2000). The relative abundance of postlarvae was shown to be relative to the patterns of river flow (Table 13) with a high and significant correlation ($r=0.8815$; $p<0.05$). It is important to mention that shrimps are a species whose short life cycle requires only one year to complete. Furthermore, strong variations in reproductive success shown in the recruitment of the exploited population are greatly determined by environmental variables.

Table 13 Changes in relative abundance of penaeid postlarvae during a 5 year period in the Upper Gulf of California.

Year	Average river flow (km^3)	Average postlarvae relative abundance ($larvae/m^3$)	Standard error
1993	312.01	43.6 [a]	13.6
1994	67.28	11.63 [b]	1.35
1995	76.25	11.20 [b]	2.25
1996	71.42	16.01 [b]	3.37
1997	115.65	33.32 [c]	8.06

Notes: [a] Relative abundance of postlarvae was high; [b] Abundances were the lowest; [c] High abundance. (Source: Aragón-Noriega & Calderón-Aguilar 2000)

In the years 1994 and 1996 the salinity in the Upper Gulf of California was higher than marine water. Presence of postlarvae was still observed during this period, but at a lower concentration than in those years when the Colorado River discharged water. During low rainfall years in the Colorado Basin, there is insufficient water for optimal agricultural production in the Mexicali Valley, given current water use practices. In addition to the increased levels of suspended solids, including salts, there is some evidence of agricultural chemicals and pesticides (DDT, DDE and DDD) entering surface streams through the sewage systems and through urban run-off. In the Mexicali and Imperial Valleys there is considerable concern about contamination of surface streams and aquifers by these chemicals (CNA 1999).

In 2000 García-Hernández (2001) found only DDT-family insecticides in the Basin. Concentrations of pp-DDE were detected in 26 out of 30 samples (86%) collected from the delta. Values ranged from <0.01 µg/g to 0.34 µg/g wet weight. The lowest dietary concentration of DDE that resulted in critical eggshell thinning and decreased production in the peregrine falcon (*Falco peregrinus*) was estimated by Blus (1996) at 1.0 µg/g wet weight. None of the samples from the delta however exceeded this value (García-Hernández et al. 2001).

Changes in water table

In addition to sediment problems, the changes in the water table have provoked a considerable diminishment of water supplies to the base of the rivers in the semiarid lands. The fluctuations registered in groundwater static levels in the Mexicali Aquifer are due to the variations in magnitude and distribution of recharge and pumping (Díaz-Cabrera

2001). The Mexicali Aquifer recharge depends greatly on the availability and management of surface waters (Colorado River).

In general, the records of 49 wells show that water levels have remained largely unchanged in those areas within the Colorado River floodplain south and east of the All American Canal. The water table remains shallow and ranges from about 1.5 to 6 m below the surface. In the few wells that exist north or west of the canal records show water levels have also remained mostly unchanged or have increased slightly over the period of record. Depth to water in these areas varies greatly, but generally ranges from about 12 to 73 m below the surface. In general, the groundwater is marginal for domestic and irrigation uses because of elevated levels of TDS, chloride, sulphate, and percent sodium. TDS levels range from about 600 to as much as 14 700 ppm (CDPW 1954, 1975).

Because the water volume assigned to Mexico was not enough to irrigate all the agricultural lands in Mexicali Valley, in 1955 the Mexican government established a programme to drill wells. As a result of these events the aquifer presented a progressive depletion between 1953-1979, a regional recovery during the period 1980-1987, depletion in the interval 1988-1994 and a recovery during the lapse 1995-1999 (Figure 6). These changes respond to flood events in the Colorado River from 1980 to 1993 due to abnormal snow melts (CNA 2000b).

Figure 6 Elevation of the static levels of the Mexicali Aquifer from 1957-1994.
(Source: CNA 1998)

The most visible and controversial groundwater problems are found in the lush irrigated delta of the Colorado River. The San Luis and Mexicali valleys of Mexico and the adjoining Yuma and Imperial valleys of the United States form one of the world's most productive agricultural zones. Groundwater is abundant in the delta area, replenished by the Colorado River and its radiant canals. Quality ranges from good to highly saline. Heavy irrigation has resulted in the build-up of saltwater

Table 14 Water balance in the Mexicali Aquifer with and without lining of the All American Canal.

		Without lining AAC (million m^3/year)		With lining AAC (million m^3/year)	
Inflow (Recharge)					
Sub-terranean	All American Canal (AAC)	100	220	20	140
	Arizona	70		70	
	San Luis R.C.	50		50	
Artificial	Drains	442	899	442	
	Return flow	457		457	
Superficial	Colorado River	7.8	8	7.8	
Inflow total			1 127		1 047
Outflow (Discharge)					
Well extraction	Pumping extraction average 1957-1994	894		894	
Sub-terranean	North Frontier	25		25	
Superficial	New River agricultural drainage	221		221	
Outflow total		1 140		1 140	
Change in aquifer Storage (ΔS_a)		-13		-92.8	

Note: To calculate the change in aquifer storage ΔS_a = [Inflow] – [Outflow].
(Source: Díaz-Cabrera 2001)

mounds in certain locations, with adverse effects on plant life and urban uses. Protective drainage undertaken by the Bureau of Reclamation in the United States during the 1960s was the source of the salinity crisis.

Mexican concerns consist mainly of future conditions in the Mexicali Aquifer and of an increased deficit in the water balance following the lining of the All American Canal (AAC) and a reduction of excess flows (Table 14). This immediately affect the geohydrological conditions of the aquifer, and lead to economic impacts on urban and agricultural sectors of the states of Baja California and Sonora. About 197 million m^3 of groundwater is used annually in the San Luis region (23 million m^3) and for urban areas like San Luis Rio Colorado, Mexicali (82 million m^3), Tecate (0.33 million m^3), Ensenada (9 million m3) and Tijuana (80 million m^3). Seepage from the All American Canal has created a series of wetlands totalling over 6 200 ha along the U.S.–Mexico border. Over half of these are in Mexico, east of the portion of the canal that is proposed for lining, and will therefore be affected by the lack of seepage in the future. The Andrade Mesa Wetlands are extensive and provide high-quality bird habitat in an isolated part of the northern Colorado River Delta where replacement habitat is non-existent. The loss of this critical habitat should be considered in assessing the potential environmental impacts of the canal-lining project (Hinojosa-Huerta et al. 2003).

Wastewater from the U.S. contains an annual average of 1 850 ppm of total dissolved solids, while water from the Mexicali Valley has an annual average of 950 ppm. Consequently, the mixed water in the Colorado River has an average salinity 1 300 ppm higher than its natural

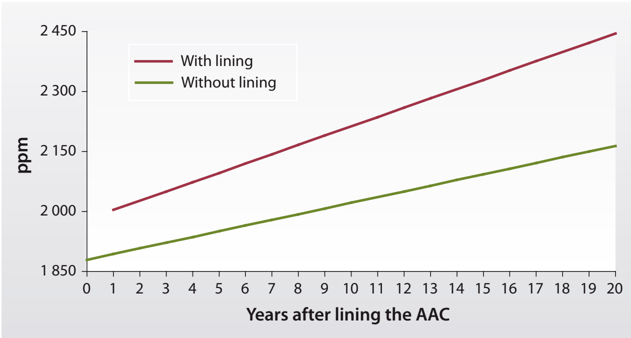

Figure 7 Concentrations of total dissolved solids in the Mexicali Aquifer with and without lining of the All American Canal. *(Source: Navarro 1998)*

concentration. Currently salts are leached from farmland on the left bank of the River. The lack of water recharge would induce a drawdown of the piezometric level of the Mexicali Aquifer and consequently lead to an increase in the salinity of its waters (Figure 7).

In 1972, in response to the salinity problem, Mexico constructed a field of 63 wells along the border of San Luis, Sonora, pumping 197.4 million m^3 of water annually. The location of the Mexican wells alarmed Arizona water authorities who feared they would draw down groundwater stock beneath Yuma Mesa, Arizona. Consequently, groundwater was incorporated into the bi-national discussions on salinity. Under the settlement, Minute 242, signed in 1973, each nation was permitted to pump up to but not in excess of 197.4 million m^3 of groundwater annually at San Luis-Mesa Yuma (IBWC 1973).

Approximately 8 600 m^3 per year of groundwater is estimated to recharge the Colorado Basin from the New River which drains the Mexicali Valley (Montgomery Watson Inc. 1995). This groundwater is related to surface flow from the highly polluted New River and negatively affects groundwater quality in the Basin (Setmire 1979).

Metropolitan water authorities from Los Angeles and San Diego are constantly working to find extra volumes of water for their expanding populations. Gary Wyatt, supervisor of district 4 of the Imperial Valley, affirms that San Diego will have to indemnify farmers of this region, with over 50 million USD for those that are willing to lay down their lands and let their water be transferred to San Diego Metropolitan Water District.

Socio-economic impacts

Economic impacts

There have been widespread economic impacts from the contamination of Colorado water with pollutants such as DDT, and increased levels of selenium and TDS. Based on an economic impact study by Lohman (Lohman 1988 in MWD/USBR 1998), damages by TDS in 1995 were estimated to be about 750 million USD per year in the United States. Major relevance is given to the size of sectors affected and to the severity of cases, due to immediate consequences in the regional and local economies.

Table 15 Saturation rates for softeners, dispensed and filtered water usage at different TDS levels, as well as the incremental costs per additional mg/l of TDS in southern California.

Consumer salinity damages							
	Softeners				Dispensed and filtered		
TDS	Change (%/added mg/l)	Household cost (USD/added mg/l)	Predicted use (%)	Predicted cost (USD/household)	Household cost (USD/added mg/l)	Predicted use (%)	Predicted cost (USD/household)
100	0.0076	0.025	7.49	24	0.002	61.96	38
250	0.0086	0.028	8.70	28	0.002	61.96	38
500	0.0102	0.033	11.04	36	0.002	62.65	39
750	0.0119	0.039	13.80	45	0.002	63.42	39
1 000	0.0137	0.044	17.00	55	0.002	64.26	40

(Source: MWD/USBR 1998)

Salinity requires expensive clearing systems (demineralisation, softening, etc.) that have direct economic impacts on industrial, residential, and agricultural water users, mostly in Mexico (no data available) and California (Table 15). The annual cost for owning and operating a self-regeneration softener in southern California is 324 USD per year. The median cost among households for dispensed and filtered water purchases was 62 USD per year, based on cost estimates and survey responses (MWD/USBR 1998). Industrial users are likely to have to intensify their treatment practices with increased chemical and energy costs to handle higher TDS levels. Higher TDS levels also affect residential consumers and agriculture.

To compensate for the high salinity of Colorado River waters, the agricultural sector has to constantly leach soils and invest in soil recovery, thus incurring additional costs during production (Table 16). The limited amount of surface water both in quantity and quality has forced farmers to abstract more groundwater resources with a consequential lowering of the water table. To extract sufficient water deeper wells were needed, with greater consumption of electricity to power the pumps. As a result of this, farmers have seen a significant decrease in the profitability of many of their activities.

In December 1989, the Imperial Irrigation District (IID) and Metropolitan Water District authorities signed an agreement for the sale of

Table 16 Increased leaching for ornamental crops, economic impact and equivalent crop salinity relationships.

Salinity (mg/l)	Increased application of water (m³/year)[1]	Economic impact (%)		Equivalent crop salinity yield relationship	
		Crop value[2]		Crop value[2]	
		8 100 USD/ha	20 200 USD/ha	8 100 USD/ha	20 200 USD/ha
200	0.0	0.0	0.0	100.0	100.0
300	0.0	0.0	0.0	100.0	100.0
400	0.041	0.5	0.2	99.5	99.9
500	0.076	0.9	0.4	99.1	99.7
600	0.107	1.2	0.5	98.8	99.4
700	0.150	1.7	0.7	98.3	99.2
800	0.198	2.3	0.9	97.7	99.0
900	0.251	2.9	1.2	97.1	98.7
1 000	0.312	3.6	1.5	96.4	98.5
1 100	0.384	4.4	1.8	95.6	98.2
1 200	0.463	5.3	2.1	94.7	98.0

Note: [1] Data from Joe Brummer, soil scientist for the U.S. Bureau of Reclamation. These calculations are based on roses. Crop irrigation requirements use is assumed to be 61 m³/year. [2]Two values were assumed for ornamentals; 8 100 USD/ha and 20 200 USD/ha, respectively.
(Source: MWD/USBR 1998)

123 million m³ for 34.5 USD per m³ for a 55 year period, with an option to renew the agreement (IID/MWD 2003). The water volume sold was determined in light of expected water savings that would be achieved via the concrete lining of most of its irrigation channels and the lining of the AAC over 48 km of its course. In 1998, a new agreement between IID and the San Diego County Water Authority allowed the transfer of as much as 246 million m³ of conserved water from agricultural users to the authority.

If the work is to be completed, the Mexicali Aquifer would lose 80 million m³ per year of water, that is currently extracted for mainly agricultural purposes, leaving 1 200 ha of agricultural land unproductive (Cortéz-Lara 1999). The aquifer supplies 400 wells for lands where 1 000 farmers operate. This plan would also leave 2 000 Mexican Braceros (day labourers) unemployed in the U.S., and considerable economic costs in agricultural lands in Mexicali, Tijuana and Sonora. Considering that 80% of the recharge volume of the Mexicali Aquifer comes from the All American Canal, a reduction in groundwater levels would also significantly increase costs as a result of deepening wells and increased pumping (CNA 1991).

As salinity increases in the Mexicali Aquifer, the potency required in pumping systems, kWh consumption, total cost in energy, and cost of extraction per m³ increases. On the contrary, and inversely proportional, there is a decrease in productivity, production value, net-benefit, utility per ha and marginal water productivity (Tables 17 and 18).

Table 17 Total consumption and electrical costs of pumping 158 wells operating in the area of the All American Canal.

	Present	Year 6	Year 10	Year 20
Energy consumption (kWh)	35 940	38 160	39 920	41 800
Pumping cost (USD/m³)	0.0023	0.0023	0.0025	0.0026
Total cost (USD)	587 000	611 000	640 000	657 000
Additional cost (%)		4.1	9.0	15

(Source: Navarro 1998)

Table 18 Variables considered in the effect of lining the All American Canal.

	Present		Year 1		Year 6	
	Quantity	%	Quantity	%	Quantity	%
Aquifer concentration (ppm)	1 880	0.8	2 000	6.7	2 100	6.8
Crop production (tonnes)	115 300	100	108 400	94.0	107 700	93.4
Crop production value (USD)	32 560 000	100	29 660 000	91.1	29 350 000	90.2
Net-benefit (USD)	21 150 000	100	18 250 00	86.3	17 950 000	84.8
Utility (USD/ha)	1 300	100	1 100	86.3	1 100	84.6
Marginal water productivity (USD/m³)	83	100	72	86.3	70	84.9
Required potency (kW)	70	100			70	105.3
Energy necessary (kWh)	35 900	100			38 100	106.2
Electric energy cost (USD)	587 000	100			611 000	104.1
Energy cost (USD/m³)	2 300	100			2 400	104.2

(Source: Navarro 1998)

Health impacts

In a regional context, the health of the people affected by the freshwater shortage concern is presently slight. For example, 90% of the population in the Mexican region has free access to relatively potable water (INEGI 2002). Major health concerns are related to the lack of water for cleaning duties and during the summer season when human demands increase. The frequency of water related health problems due to water shortage is still considered as occasional.

Other social and community impacts

Although only a small proportion of the community faces severe freshwater shortage, in certain localities and during dry periods there can be acute adversities for communities due their dependence on water resources. The effects of impounding and diverting large amounts of Colorado River water is felt particularly heavily in the delta region. Prior to these water developments, the native Cucapá cultivated an endemic plant - Palmer's salt grass (*Distichilis palmeri*) - that thrives in the intertidal marshes and was harvested for its protein content. Other crops in their flood-irrigated fields included corn, beans and pumpkin.

Their diet included numerous fish species, waterfowl, small mammals and large game such as mule deer, wild boar and big horn sheep. Native plants and trees provided materials for tools, housing and canoes to navigate the landscape, a labyrinth of wetlands. The degree of impact is considered severe, and the limitation in water supplies is almost chronic for the regional society.

In the U.S. portion of the Basin, Indian tribes are currently in the process of having previously unrecognised water rights granted and quantified. One of the most significant problems for all the stakeholders of the Colorado River is the complicated nature of the quantification process (Morrison et al. 1996). There has been considerable disagreement over both the quantity of water and the manner in which control should be balanced between the federal government and the Indian tribes themselves. Therefore, any Colorado River management plan developed with the U.S. Bureau of Reclamation's participation will have to address the water needs and rights of Indian tribes in the Basin (Morrison et al. 1996).

Conclusions and future outlook

The GIWA Assessment identified freshwater shortage as the most severe concern in the Colorado River Basin. The magnitude of the concern is expected to be exuberated over the next 20 years by rising demand, from an increase in uses and production, and population growth. In general terms, most of the experts associate the agriculture sector crisis to this concern, and state and local governments claim that water availability is an essential condition for the loss or attraction of investment to their territories.

However, there is potential to use available water resources more efficiency and reverse freshwater shortage trends; the challenge is set for the improvement of water services, reducing the pressure on the resource and increasing its profitability,

The reduction in water supplies has not been shown to coincide with health issues. Instead, trends show a low impact on society in general. The water distribution schemes for the next 20 years seem complicated, and considering the challenges to establish a water balance for the water re-assignation, more and more conflicts between Mexico and the U.S can be expected. Water issues concerning Indian American tribes and local communities (Cucapá) must be resolved as a fundamental part of any long-term management strategy for the Colorado River Basin.

Due to the Rio Grande crisis, both governments are now urged to take some decisions, which include radical changes in their legal framework. The primary Mexican tributary of the Rio Grande is the Rio Conchos, which flows out of the high desert of Mexico and fills the reservoirs that provide water for Texan farmers. Under the 1944 Treaty, Mexico must send about 432 km^3 water annually into the Rio Grande. The United States, in turn, releases 1.85 km^3 of Colorado River water to Mexico. Since 1992, Mexico has fallen more than 1.8 million m^3 of water in arrears, due to a severe drought in the Basin, escalating into an international standoff (Yardley 2002). The implication of these new regulations will have a tremendous impact on socio-economic terms in both sides of the border. A slow readjusting time is envisioned due to the bureaucracy of political agreements. However there are important ongoing political processes in the Basin, as is the case of California, which is expected to present a water restructure by the end of the year .

Imperial Valley Aquifer is not used for two reasons. Firstly, the low quality makes it unsuitable for agricultural uses. Secondly, the growers receive enough Colorado River water for their 250 000 ha of agricultural land. Therefore, aquifer water in this region is the only reliable contributor to water volume, which is why the Mexicali Aquifer is the most important source of local water available to Baja California. Consequently, any actions that affect aquifer recharge water volumes, such as the lining of All American Canal (AAC) or a decrease in Colorado River natural run-off (e.g. reduced frequencies of excess flows), will directly impact the availability of water to the Basin.

The lining of the AAC would cease 80% of the infiltrations and produce the dropping of the water table, causing depletion in groundwater levels in Mexican territory during the next 10 to 15 years, in addition to those caused by the exploitation of the aquifer in the Mexicali Valley. This should induce a drawdown of the piezometric level of the aquifer and result in the need for deeper wells; therefore increasing pumping costs for the agricultural sector.

The lining of the All American Canal could indirectly reduce the Colorado River Delta's water allocation. Mexico relies on groundwater pumped from the border region to augment its supplies. Groundwater coming from the seepage of the AAC presently irrigates 1 200 ha agricultural land in the Mexicali and a San Luis Valleys. Mexico´s concern consist of an immediate reduction of seepage into these aquifers, that would consequently put more pressure over water resources in the Mexican portion, which will ultimately reduce any possible source of water for ecological purposes. In addition to the canal lining a reduction of surplus water due to the USBRs Interim Surplus Water Criteria will be detrimental to the economy, environment and population of the Salton Sea and the Colorado River Delta.

Under Minute 242, paragraph 6 of the International Boundary and Water Commission "the United States and Mexico shall consult with each other prior to undertaking any new development of either the surface or the groundwater resources, or undertaking substantial modifications of present developments, in its own territory in the border area that might adversely affect the other country" (IBWC 1973). Therefore the lining of the AAC requires the approval of both countries; the project should not be carried out until the Mexican section of the IBWC can identify proper measures that minimises or reduces the effects in Mexico of lining the AAC.

While surface water salinity is monitored and controlled in the U.S., and a desalinisation plant in Yuma, Arizona, was constructed to remove salt from water travelling to Mexico, groundwater does not currently face similar constraints and regulations, which makes groundwater regulation a complex matter for both sides of the border.

Pollution

The quality of water in the Colorado River Basin is a major component affecting the ecology and population, since heavy metals, arsenic, lead, pesticides, uranium, etc., have all been found in excessive levels in soils and source waters on the region. Due to significant public health and ecological impacts, the areas of high priority for control include the U.S. cities of Los Angeles, San Diego, Phoenix and the Mexican cities of Tijuana, Mexicali and Nogales. In addition to domestic and industrial wastes, run-off from agricultural practices contributes significant levels of toxic compounds and nutrient overload to already stressed ecosystems. The shortage of freshwater in the arid regions of the border often correlates with a lack of proper hygiene and sanitation practices.

Federal and State agencies are concerned of pollutants being transported by aqueducts (e.g. Colorado River Aqueduct) from reservoirs such as Lake Havasu to cities outside the drainage basin (e.g. Los Angeles, San Diego and Tijuana), since most of this water present high levels of contaminants (USDOI/BLM 2002).

Water quality in the Basin is generally satisfactory, although run-off from agricultural areas, abandoned mines, and naturally occurring saline groundwater discharges cause localised problems (USGS 2000):

- The Eagle River has metals contamination in some reaches;
- The Colorado River main stem and Gila River is subject to elevated salinity levels due to naturally occurring springs and agricultural drainage through saline deposits;
- The Gunnison River is subject to increased selenium levels;
- Previous mining activities have also impacted tributaries to the San Pedro, Gila, San Juan, White and Yampa Rivers.

Salinity above all other pollutants in the Colorado River Basin is considered as a continuous issue and historically significant to U.S.-Mexico relations since the early 1940s. The salinity of waters delivered to Mexico increased markedly in the winter of 1961-1962, from less than 1 000 mg/l in prior years to 2 600 mg/l. Mexico protested against the increase (Hundley 1966). In 1962, the presidents of the United States and Mexico agreed to find a mutually satisfactory solution. An agreement was reached and approved by the two Presidents in August 1973; the agreement was formalised as Minute 242 (IBWC 1973). As a result of Minute 242 a variety of salinity control programmes (e.g. Colorado River Basin Salinity Control Act, Clean Water Act and Colorado River Water Quality Program) have been implemented in the Colorado River Basin in response to Mexico's concerns over salinity and salinity standards within the U.S. states (MWD/USBR 1998).

Salinity varies from season to season in the Mexican borderland since water deliveries stipulated in the 1944 U.S.-Mexico water treaty are divided in two seasons (IBWC 1944):

- During the months of January, February, October, November and December the prescribed rate of delivery shall be not less than 19.1 m^3/s nor more than 113.3 m^3/s.
- During the remaining months of the year the prescribed rate of delivery shall be not less than 31.9 m^3/s nor more than 113.3 m^3/s. Should deliveries of water be made at a point on the land boundary near San Luis, Sonora, as provided for in Article 11, such deliveries shall be made under a sub-schedule to be formulated and furnished by the Mexican Section. The quantities and monthly rates of deliveries under such sub-schedule shall be in proportion to those specified for Schedule I, unless otherwise agreed upon by the Commission.

Due to high evaporation in the Lower Colorado Basin, the summer season tend to concentrate pollutants, leaving the winter season with better water quality standards (CNA 1999).

In an ecological context, one of the major threats in the Colorado River wetlands is selenium and pesticides (García-Hernández et al. 2001). Selenium can be bioaccumulated to levels toxic for wildlife and causes high rates of embryonic mortality and deformity. Selenium is a naturally occurring element originated from cretaceous formations in the Upper Colorado River and, due to its high solubility, is distributed along the Colorado River waters. Since the early 1970s, there have been concerns about the possibility of pesticide transport from the Mexicali Valley into the Upper Gulf of California. Pesticide levels have been found in organisms of the Mexicali Valley irrigation canals as well as the Upper Gulf of California (García-Hernández et al. 2001).

Environmental impacts

The Colorado River is considered as a major water pollutant distributor since it carries a considerable quantity of contaminants such as selenium, TDS, pesticides and the intensive contamination by chemical (perchlorate, chromium 6, and MTBE) and radionuclide wastes (thorium-230, radium-226 and radon-222) from industrial and agricultural activities.

Microbiological

The New River in south central California flows in from Mexico where it receives a variety of wastewater effluents. Each year Mexicali, a Mexican border city, discharges about 49 400 m^3 of effluent into the international boundary which flows north through Mexicali, crossing the border into California's Imperial Valley. About 70 km to the north, it empties into California's Salton Sea. Although some of Mexicali's effluent is treated, raw sewage and industrial waste often flow directly into the New River through storm drains and other outlets. The New River is considered one of the most polluted rivers in the United States (Lueck et al. 1999).

Semi-annual sampling of the New River at the Calexico gauge near the border by the California Regional Water Quality Control Board since 1994 shows consistently high levels of faecal coliform (130 000 to 2 200 000 per 100 ml) and TDS (>2 400 mg/l) and low concentrations of dissolved oxygen (Varady & Mack 1995). In short, the New River is not an acceptable raw water source for drinking water, but is likely used by for example Colonias (underdeveloped residential subdivisions), at least in Mexico, that are not currently served by a community water system (Mroz et al. 1996).

Eutrophication

The nutrient rich-inflows that reach the Salton Sea facilitate extremely high biomass production, but have also created eutrophic conditions (see Table 19). Eutrophication is responsible for the deaths of millions of fish in the Salton Sea, and may have created a vector for avian diseases (Setmire et al. 1993, USGS 1996, Costa-Pierce 1997, USBR 1997, USFWS 1997).

Chemical

Selenium and salinity are considered as the two major contributors to the regional water pollution. Extremely high concentrations of selenium, 1 300 µg/l, were found in water from shallow wells sampled in the upstream reaches of the Colorado and Uncompahgre River valleys, located in the extensive alluvium and residuum of the Cretaceous Mancos shale (Presser et al. 1994). The bioaccumulation of selenium has created toxicity problems for wildlife in the Ciénega de Santa Clara, in the east side of the Colorado River Delta (García-Hernández 1998) (Table 20).

Table 19 Annual phosphorus and nitrogen load of the Salton Sea.

Load	Phosphorus (mg/l)	Nitrogen (mg/l)
Permissible*	0.1	1.5
Dangerous*	0.2	3.0
Salton Sea	1.19	15.4

*Note: *According to Wetzel 1983. (Source: Primary data collection by CRWQCB 1980-1992. Data compiled by Richard Thiery, CVWD, in Cagle 1998)*

Table 20 Concentrations of selenium in biota in the Colorado River Delta.

Species	Selenium (ppm dry weight)
Double-breasted cormorant (*Phalocrocorax auritas*)	16.7
Cattle egret (*Bubulcus ibis*)	4.6
Red Winged blackbird (*Agelaius phoeniceus*)	5.1
Great-tailed grackle (*Quiscalus mexicanus*)	5.3
Mourning dove (*Zenaida macroura*)	2.3
Tilapia (*Tilapia zilii*)	6.8
Largemouth bass* (*Micropterus salmoides*)	5.1

*(Source: Mora & Anderson 1995, *García-Hernández 1998)*

Concentrations in water ranged from 5-19 mg/l, increasing along a salinity gradient. Although water levels of selenium exceeded EPA criterion (0.73 µg/g wet weight) for the protection of freshwater aquatic life, selenium levels in sediments (0.8-1.8 mg/g), plants (0-0.17 mg/g) and fish (2.5-6.4 mg/g) from the Ciénega de Santa Clara do not exceeded background levels found along the Lower Colorado River ecosystems.

In 1971, 230 tonnes of DDT was used in the Mexicali Valley, Mexico, which left residual concentrations of DDE in wildlife (García-Hernández et al. 2001). DDT was banned in Mexico for agricultural use in 1978 due to its persistence in the environment and to the rejection by other countries of DDT contaminated products (Canseco-González et al. 1997).

Even though such pesticides have been banned, DDE, DDT and DDD were detected in fish and invertebrate sampled from the delta wetlands. The DDE:DDT ratio was lower than 50, which is thought to indicate recent exposure to the parent compound (Mora 1997 in García-Hernández 2001). Nevertheless, under unknown exposure conditions, these ratios may not be indicative of recent DDT use but of long persistence and heavy use of DDT in the past, as pesticides, like selenium, tend to bioaccumulate. A pesticide study on cattle egrets (*Bubulcus ibis*) from the Mexicali Valley concluded that hatching success was not significantly affected by DDE or other organo chlorines (Mora 1997 in García-Hernández 2001). However, more studies are required to determine if organochlorine, organophosphates or carbamates pesticides as well as herbicides, are affecting the density of insects in the delta wetlands, which could potentially impact the habitat quality for insectivorous migratory birds.

The Atlas uranium mill near Moab, Utah, has leaked ammonia and other poisonous contaminants into the Colorado River for the past 40 years. The USGS (2000) study confirms that ammonia levels are far too high for the fish to survive. According to the report, ammonia levels in a stretch of the Colorado River about 4.8 km north of Moab are as high as 1 500 mg/l, greatly exceeding the 12 mg/l that the fish can tolerate. When researchers put experimental fish into the River below the waste site, most of them died in less than one hour. The same area has been designated as critical habitat for the recovery of the endangered Colorado pikeminnow (*Ptychocheilus lucius*), the Razorback sucker (*Xyrauchen texanus*), the Humpback chub (*Gila cypha*) and the Bonytail chub (*Gila elegans*).

Other sources of contamination in the Colorado waters such as perchlorate, uranium and methyl tertiary-butyl ether (MTBE) are becoming increasingly significant. MTBE is a fuel oxygenate added to gasoline to reduce pollution and increase octane ratings. However, MTBE is a highly toxic chemical, linked to cancer and neurological problems that spreads rapidly in groundwater (Squillace et al. 1996). The source of MTBE releases is mainly from leaking underground fuel tanks and it is a frequent and widespread contaminant in shallow groundwater from urban areas throughout California. A minimum estimate of the number of MTBE-impacted sites in California is greater than 10 000 (Happel et al. 1998).

Due to the combination of its elements (chlorine and oxygen) perchlorate (ClO_4^-) - a man made chemical that is used in the manufacture of rockets, missiles and fireworks, among other products - can persist for many decades under typical groundwater and surfacewater conditions, because of its resistance to reaction or degradation. In 1997, the state of California developed a method with detection of down to 4 µg/l. Much to the surprise of water officials, perchlorate was detected in numerous water systems including the entire Lower Colorado River, mostly in Lake Mead (EPA 1998, Batista et al. 2003).

The single largest source of contamination of perchlorate is a former Kerr-McGee Corp. rocket fuel plant outside Las Vegas. The site still leaches as much as 408 kg of perchlorate per day, which drains into the Colorado River. Across California, nearly 300 wells are contaminated. Most are in Los Angeles, Riverside and San Bernardino counties, where dozens of aerospace factories operated during the Cold War (Waldman 2002).

To date, the EPA has identified 75 perchlorate releases in 22 states, including Arizona, Texas, Nebraska, as well as California . The Colorado River, contains perchlorate at roughly 7 ppb, seven times the level that the EPA's National Centre for Environmental Assessment says is safe.

The leading cause of non-attainment on Colorado's waters is high concentrations of metals. The source of metals in the waters is from historic contamination contained within impounded sediments with the exception of mercury in fish tissue in lakes (e.g. Lake Powell). Acidic, metal rich discharges, originate from abandoned and inactive mines or run-off from old mining piles.

Solid waste

The solid waste issue was assessed as having a slight impact in the Basin. However, as the population in urban centres keeps on growing, the solid wastes pollution is becoming a principal issue for the Basin.

Radionuclide

Uranium ore was mined and milled in the Colorado River Basin beginning in the late 1940s and continued through the 1950s at an ever-increasing rate. When production finally reached its peak in 1958 nearly 8 960 tonnes of uranium ore were being milled each day in the Colorado Plateau. Waste left from the Atlas uranium mill near Moab, Utah, is threatening endangered fish that live in the Colorado River (USGS 2000). The USGS study conducted from August 1998 to February 2000 shows that 9.5 million tonnes of waste left from the mill are poisoning four endangered fish species in the Colorado River.

Concentrated in mill tailing piles are a number of heavy metals including arsenic, barium, cadmium, lead, vanadium and selenium. In addition to these contaminants the piles contain radioactive materials not removed in the production process. In fact, 85% of the radioactive material in ore remains after the milling process. Radionuclides concentrated in tailings piles include thorium-230, radium-226 and radon-222 (USGS 2000). The mining and milling wastes pose serious threats to groundwater from radionuclide contamination. High radium concentrations occur in shallow aquifers in Montrose County in association with uranium mining and milling operations. Many streams in the Basin tend to have higher pH values than in the state of Colorado, therefore strict un-ionised ammonia standards have been required of wastewater facilities in order to protect cold-water aquatic life (Driver 1994).

Table 21 Salinity impacts on crop yields.

TDS (mg/l)	Salinity damage to agriculture compared to full yield[1] (%)									
	Strawberry	Misc. vegetables	Nursery[2]	Cut flowers[2]	Citrus	Avocados	Vineyards	Pasture/Grains	Deciduous	Field
200	100	100	100	100	100	100	100	100	100	100
300	100	100	100	100	100	100	100	100	100	100
400	100	100	99.9	99.5	100	98.8	100	100	100	100
500	94.4	100	99.7	99.1	100	93.3	99.4	100	98.9	100
600	86.7	100	99.4	98.8	97.2	87.8	96.4	100	93.2	100
700	79.0	98.0	99.2	98.3	92.2	82.3	93.4	100	87.6	100
800	71.3	94.7	99.0	97.7	87.2	76.8	90.4	100	81.9	98.0
900	63.6	91.4	98.7	97.1	82.2	71.3	87.4	99.2	76.3	95.3
1 000	55.9	88.1	98.5	96.4	77.2	65.8	84.4	97.5	70.6	92.6
1 100	48.2	84.8	98.2	95.6	72.2	60.3	81.4	95.8	65.0	90.0
1 200	40.5	81.5	98.0	94.7	67.2	54.8	78.4	94.1	59.3	87.3
	Summary of agricultural value (USD/ha)									
Total value	40 620	12 860	105 700	46 860	9 260	10 850	3 840	660	6 250	2 610

Notes: [1]Prepared for use in Salinity Impact Model in Metropolitan's service area. Crops are grouped into the main categories in Metropolitan's service area. [2]Values adjusted to reflect costs to growers of using additional higher salinity waters for leaching to maximise yields. (Source: MWD/USBR 1998)

Socio-economic impacts

Economic impacts

The region faces considerable saline problems. The United States has invested more than 300 million USD in the prevention and restoration of saline soils and both Mexico and the U.S. require continuous investments to improve water quality (MWD/USBR 1998). The economic impact suffered on the regional sectors by the pollution of water sources is becoming a grave issue, particularly for agriculture (Table 21).

Industrial water users have different requirements for water quality depending upon the purpose for which the water will be used; process, boiler feed, cooling, or sanitation and irrigation. Process water makes up about 45% of industrial use and, in most cases, is used by industry as it is received. Impacts from increased salinity and hardness are minimal. Of the industrial water use, 12% require demineralisation and 12% some sort of softening (MWD/USBR 1998).

The cost of treating process water with reverse osmosis at a level of about 700 mg/l varies from about 570 USD/million m^3 to 810 USD/million m^3 for industries. Using 570 USD indicates that the cost of reducing salinity from 700 mg/l to 600 mg/l is 84 USD/million m^3, as only 14.7% of the water treated. Also, as additional water is lost because of a brine stream, an additional 20% of the treated water is required or 2.94% of the total. The estimated cost to obtain the additional water is about 570 USD/million m^3 (retail cost) and the disposal cost is about 490 USD/million m^3 resulting in a net cost increase of 31 USD/million m^3 of product water. Thus, the total unit cost of changing salinity from 700 mg/l to 600 mg/l is about 114 USD/million m^3 or 1.14 USD/million m^3 per mg/l increase in salinity (Table 22) (MWD/USBR 1998).

Table 22 Costs associated with treatment of process water.

Need of treatment	Water use for process (%)	Cost for 1 mg/l increase in salinity (USD/million m^3)
Demineralisation	12	1.14
Softening	12	0.47
No treatment	21	--
Total	45	0.44

(Source: MWD/USBR 1998)

Water, which is traditionally softened, will probably continue to be softened, as it costs less than demineralisation. Commercial units, including salt and operation and maintenance will cost 65 USD/million m^3 to 122 USD/million m^3, depending upon salinity and initial salinity of 600 mg/l, with a 200 mg/l reduction, apportioning the cost would indicate a cost of about 0.47 USD/million m^3 per mg/l change salinity (MWD/USBR 1998).

Many industries require water with very low salinity and treatment is required regardless of the salinity of the supplied water. These include pharmaceutical, biotech, electronics and microchip manufacturers. Salinity and hardness create additional problems including higher operating costs and capital equipment requirements such as an increase in the amount of water used in cooling systems.

For cooling water, increases in salinity result in decreased cycles of use and an increased requirement for make-up water. A major impact from higher salinity concentrations is the incremental costs of additional water, added chemicals, and further disposal requirements. The extra water required is approximately 0.0004 times the increase in salinity, 500 g/l to 600 mg/l. Thus, a 100 mg/l increase in salinity would represent a 4% increase in cooling water use. For a typical user, the cost per m^3 of added cooling water is about 1.18 USD (MWD/USBR 1998).

Problems related to siltation have occurred during the Gila River flood control releases of 1997-1999. Large amounts of sediment were moved to Morelos Dam and accumulated, impeding the operation of the diversion gates on both the U.S and Mexican sides (Table 23). Contracted dredging operations began in March 2000 to remove approximately 0.764 km^3 of material from in front of both diversion works and across the face of the overflow weir. The dredging operation was completed in June 2000.

Table 23 Volume of sediment and estimated cost of dredging operations 1997.

Section	Sediment (km^3)	Estimated cost (USD)
United States: Between the confluence of Gila and Colorado rivers and the Northerly International Boundary.	5.50	12 000 000
In Mexico: Northerly International Boundary (NIB) and Morelos Dam.	0.91	2 200 000
International section (NIB-SIB).	1.03	2 280 000
Irrigation District 14.	0.55	950 000
Southerly International Boundary (SIB) and the mouth of Colorado River.	4.50	6 820 000
Total	12.49	24 250 000

(Source: CNA 1999)

The New River has long been the subject of negotiations between the United States and Mexico regarding waste treatment. Recently, Mexico and the United States agreed to construct a bi-national wastewater treatment plant to be called Mexicali II. On completion in 2015, the plant will treat more than 1 645 l/s and serve a projected population of more than 0.5 million people (IBWC 1996).

However, the economic impact on local economies in the Salton Sea and Imperial Valley areas by the pollution of the New River has been quite severe. The Salton Sea area has a 76 million USD tourist industry. Bird watchers alone contribute 3.1 million USD to the local economy annually. The pollution generated by the farmers and the maquiladoras decreases the species diversity and abundance of the sea; as a result, its aesthetic value is adversely affected. For this reason, between 1986 and 1993, the number of tourists visiting the Salton Sea State Recreation Area dropped by 66% (Pauw 1994). In Imperial County, the unemployment rate was 30% as of March 1994, whereas, at that time, the nation as a whole was experiencing an economic boom.

Health impacts

Perchlorate (ClO_4^-) has migrated from disposal sites in Nevada into Lake Mead, and the Colorado River system, which supplies drinking water for about 20 million people in the Lower Colorado River Basin and has forced the shutdown of hundreds of wells in California. State and federal officials are still debating how much risk perchlorate poses when ingested and what limits should be set for the chemical, a process slowed partly by lawsuits filed by defence contractors such as Lockheed Martin Corp. that are concerned they may be liable for billions of dollars in clean-up costs (Waldman 2002).

When the Metropolitan Water District of Southern California found the chemical in taps in Los Angeles, scientists traced the plume 643 km up the Colorado River to Lake Mead, above Hoover Dam. From there, they tracked the plume 16 km westward, up a desert riverbed called the Las Vegas Wash, to Kerr-McGee Corp.'s giant ammonium perchlorate plant in Henderson, Nevada.

Kerr-McGee is spending roughly 70 million USD to extract perchlorate, but it is catching only about half the 408 kg per day seeping into the Las Vegas Wash, EPA officials say. The company, which has filed a lawsuit seeking Pentagon reimbursement for the clean-up costs, says it is adding new systems to capture much more of the perchlorate. Still, so much perchlorate has already entered Lake Mead that the levels below Hoover Dam - all the way out to Los Angeles - have hardly budged in five years, ranging from 5 to 10 ppb (EPA 2003).

Most communities that comprise the River Basin are serviced by large water systems. These residents receive high quality water for domestic use and are in no immediate health danger. But on the other hand the provision of safe drinking water is the most critical health issue in low-income areas along the U.S.-Mexico border that are still unserved or underserved by potable water and sewerage services. On Mexico's northern border, 30% of the residents do not have access to running water and sewerage services. The problem is not limited to Mexico, however. In the United States, the poorest residents of the border region live in underdeveloped residential subdivisions called Colonias which also lack water and/or wastewater services.

Colonias are home to many people who work in maquiladora industries that have developed along the border. High population densities combined with inadequate infrastructure result in deplorable living conditions. Colonia residents live in conditions that would be unacceptable anywhere else in the country, but residents are poor and have few options. Health problems in colonias are many and varied, but environmental contamination often permeates the developments.

Water supply contamination is an especially significant health risk. Inadequate wastewater treatment and improper disposal of solid and liquid wastes have contaminated many surface water and shallow groundwater supplies. Areas without drinking water systems are particularly vulnerable, but the potential for contamination threatens water sources for public water systems as well. Mroz et al. (1996) indicated that many Colonia residents get water from garden hoses or by truck delivery, but have "no electricity, sewer systems, garbage collection or waterlines."

A long-term solution to these problems will require the investment of billions of dollars to provide the necessary infrastructure for water delivery systems and for water and wastewater treatment plants. Until such services can be provided, intermediate steps can be taken to ensure that impacted populations have access to appropriate techniques that will make a difference to the quality of water consumed.

As it flows north from Mexico into California's Imperial Valley, the New River not only brings with it more than 75 700 m^3 of raw sewage daily, but also a human cargo of illegal immigrants that may host bacteria and pollutants that cause communicable diseases. Public health officials along the border worry about this toxic, infested river and the people who use it as a route into the United States.

A report by the federal Centers for Disease Control (Herrera et al. 1993) noted that California had double the rate of infections of two food-borne pathogens associated with human sewage, campylobacter and shigella, than any other state and it has been discussed if there are any connections between the immigrants and these diseases (Herrera et al. 1993, Hearn 1993).

Hayes et al. (1999) conducted a study in which sample results indicate there was not a widespread water quality or human health problem in the Lower Colorado River Basin. During the Gila River flood, levels of bacteria, total suspended solids (TSS) and nutrients increased significantly, but dropped quickly after the flooding had stopped. Faecal coliform bacteria counts of 200 colonies per 100 ml were found, compared to EPA standard levels of less than 10 colonies. However, testing showed that few of the samples that tested positive originated from human wastes. Of the 154 water wells and lake pump potable water samples taken, 64 tested positive for bacteria or showed elevated levels of total dissolved solids, total organic carbon or nitrates (CNA 2000a).

Pesticide contamination in the Lower Colorado has caused some localised health problems in the border region. An elevated prevalence of systemic lupus erythematosus (SLE) (an autoimmune disease) was reported several years ago (1996) in Nogales, Arizona and Rio Rico, a nearby community. The report showed that the prevalence of SLE in Nogales is higher than the reported prevalence in the U.S. population and that both cases and controls had past exposure to chlorinated pesticides and has ongoing exposure to organophosphates (Balluz et al. 2001).

From the sampled sites in the Colorado River Delta, García-Hernández et al. (2001) found that none of the edible fish (e.g. *Micropterus salmoides, Cyprinus carpio*, *Ictalurus punctatus*, *Mugil cephalus*, *Lepomis macrochirus* and *Tilapia zilli*) collected from the Colorado River Delta wetlands exceeded the selenium threshold level of 6.5 µg/g dry weight that warrants advisories by the U.S. Health Department, recommending limited fish consumption by humans (Scorupa et al. 1996).

Uranium is leaking from an abandoned uranium mill near Moab, Utah into the Colorado River at 530 times the federal radiation limit, threatening the drinking water of more than 25 million people, serving mainly people in Las Vegas, Los Angeles, Phoenix and Tucson.

Heavy metals and radioactive materials in tailings piles are introduced to human contact through a number of pathways. Continued radioactive decay through alpha and gamma particle emissions, inhalation of windblown particles, and inhalation of radon gas, a daughter product of radon-222, are all potential contaminant exposure pathways. These exposure pathways can be effectively mitigated and eradicated by capping the piles with a layer of impermeable material (USGS 2000).

The most threatening exposure pathway is contamination of ground and surface water with heavy metals and radionuclides. Preventing contamination of ground and surface water is a more complicated problem than mitigating the other exposure pathways. Mitigation of this pathway usually involves relocating the tailings to an offsite disposal cell. Due to the large volume of most tailings piles this procedure is both complicated and costly (USGS 2000).

The USGS (2000) study showed that the radiation and toxins are entering the River at 25.3 litres per minute from the Atlas uranium mill. The radiation already exceeds Utah standards and the state has called for an extensive study of groundwater.

According to Brechner et al. (2000), drinking water that has been contaminated with small amounts of perchlorate may be the reason behind higher-than-normal thyroid hormone levels being identified in some newborns in Arizona. The study found that mothers who drink water with detectable levels of perchlorate gave birth to babies with elevated levels of thyroid stimulating hormone (TSH), an indicator of the thyroid disorder known as hypothyroidism.

The drinking water from Lake Mead has perchlorate levels of 11 ppb, and the EPA currently recommends that drinking water contain no more than 18 ppb. No standards have been clearly established regarding safe levels of perchlorate exposure for humans. By late 2000, however, the EPA is expected to issue regulations regarding whether there are any acceptable levels of perchlorate in drinking water (Batista et al. 2003).

In addition to the direct effects of perchlorate in drinking water, there is also concern over harm to human health through foodstuffs. Across the Southwest, the Colorado River water irrigates 95% of America's winter lettuce crop, grown in Yuma, Arizona, and California's Imperial Valley. The EPA says it still does not know if lettuce and other vegetables accumulate perchlorate from irrigation water, but preliminary indications are not good. Tests on several vegetable samples from a perchlorate-contaminated farm in Redlands found the plants concentrated perchlorate from local irrigation water by an average factor of 65, according to calculations by Renee Sharp of the Environmental Working Group in Oakland, California, one of the few non-profit groups focused on perchlorate contamination. That means the perchlorate dose in the vegetables was 65 times the amount in the water (Waldman 2002).

Although health problems related to water pollution are considered to have moderate severity because of the characteristics of the cases known to date, the problem has been present for a long time, so it has a continuous impact on society. The severity and duration of impacts are extremely important not only from an environmental perspective but also from a social point of view, in order to call for government attention.

Other social and community impacts

Although the Colorado's river water is highly polluted, people accept the poor quality of water, since the River is to some the only reliable surface water source in the Basin (e.g. in Mexicali and San Luis Rio Colorado). Pollution of water sources for the purpose of human water consumption is of no threat, considering that 90% of the Basin employs purified water instead of potable water, which comes directly via municipal sources. Geographically, almost the entire region is affected by water quality issues, as well as the productive sectors (agriculture and industry). Despite the many people dependent on the Colorado River that are affected by poor quality water, radical changes have not been made to improve the situation.

Conclusions and future outlook

The GIWA Assessment considered pollution to have a moderate impact. The increasing salinisation of freshwater resources in the California River Basin is reducing the available water suitable for industrial and agricultural activities, and domestic water supply. Many sectors require water with very low salinity and treatment is required regardless of the salinity of the supplied water, and thus in the short-term all industries and sectors will be obligated to treat their waters within established regulations.

In general, industries prefer purveyor-supplied water for in-house potable supplies because it meets requirements under health codes. This implies direct consequences not only for the industry that will increase their costs, but also for the general public who will inevitably pay for the improved treated water they consume. Salts are commonly leached in agricultural lands, a reduction of water supplies to the agriculture and a lack of water recharge to the aquifers, would consequently lead to an increase in the salinity of the aquifer, making costs for soil recovery even higher.

In addition, aquifers have had salinity problems due to reduced surface water and as a result of groundwater recharge from imported water (e.g. Colorado River Aqueduct), recycled water as well as by incidental recharge from wastewater discharges (MWD/USBR 1998). This situation is particularly acute in southern California and northern Mexico.

Groundwater is one of Mexico's, California's and Arizona's greatest natural resources. In an average year, groundwater meets about 30% of California's urban and agricultural water demand. In drought years, this percentage increases to more than 40% (CDWR 1998). In 1995, an estimated 13 million Californians (nearly 43% of the state's population) used groundwater for at least a portion of their public-supply needs (Solley et al. 1998). In Arizona, 400 million m^3 of groundwater is removed annually which is about double the amount being replaced by recharge from rainfall (UNEP 2003), even though Arizona has become the first state to limit the pumping of groundwater (Wolman 1987).

Aquifer exploitation has increased in southwestern California and Mexico, following the reduction of California's water supply from the Colorado River. However, water pollution is expected to decrease in this region, due to the implementation of improved technologies and water treatments such as the Mexicali II wastewater treatment plant.

The impact of natural and non-natural pollution in the Basin will have a strong impact on the community's water culture. Diminishing water supplies and increasing demand for water will force society to become more conscientious regarding its use and quality. Conservation of this precious resource is essential and it is expected recycling will play an increasingly important role. Without appropriate mitigative and preventative measures population growth, urbanisation, and industrial development, will increase pollution and threaten available supplies of usable water.

IMPACT Habitat and community modification

Water management practices have caused dramatic changes in the Colorado River and resulted in a loss of nearly 76% of the historic wetland areas in the Colorado River Delta in the last century, with severe consequences for wildlife and local communities. The delta has shrunk to approximately 60 000 ha, 5% of its historic size. In the 1970s and 1980s no water from the River reached the Upper Gulf of California. From 1980 to 1998, total water releases to the delta have amounted to an estimated 20% of the Colorado's total flows (Lueck et al. 1999), permitting a partial revegetation of wetlands and riparian forests. Although most of the flows are either floodwater, which is extremely unreliable and irregular, or agricultural and municipal wastewater, which is high in salinity and pollutants, these waters are proving beneficial and have begun to restore some areas of the delta.

Up to the early 20th century, the delta region had a vegetation pattern clearly associated with the River. Plant communities in this area were probably similar to those currently found immediately north of the U.S.-Mexico border. Today, most of the vast riparian forests have disappeared, replaced by alien salt cedar (*Tamarix ramosissima*), although some patches and isolated trees remain.

The 150 km stretch of river in Mexico contains twice as much native riparian forest and wetland habitat as the upstream stretch in the U.S., as a result of flood and agricultural discharge waters over the past 20 years. However, even this modest regeneration of habitat is under treat from U.S. Bureau of Reclamation initiatives to eliminate this "slack" in the system and capture water flowing to Mexico for U.S. water users.

Environmental impacts

The modification and loss of habitat in the Basin is assessed as having a severe impact. Due to decades of dam construction and water diversions in the United States and Mexico along the Colorado River Basin, the Colorado River Delta's vast wetlands and riparian zones, has been greatly altered to a remnant system of small wetlands and brackish mudflats. Once the Colorado River Delta was lush with vegetation; it supported some 200-400 plant species, along with numerous birds, fish, and mammals (Glenn et al. 1992), of which many are native.

Many of these species are on the brink of extinction or are already extinct in the area, such as jaguars (*Felis onca*), Mule deer (*Odocoileus hemionus*) and otters (*Lutra canadensis*) (Mellink 1996). Much of the upper delta has been converted to irrigated farmland, and levees and channels have changed the physical delta significantly. Dam construction among other factors has provoked permanent changes to the natural ecosystems.

Prior to dam construction the Colorado River Delta covered 780 000 ha and supported plant, bird and marine life. The River's flow reaching the delta supplied freshwater, silt, and nutrients, which helped create a complex system of wetlands that provided feeding and nesting grounds for birds, and spawning habitat for fishes and crustaceans (Glenn et al. 1996).

In the 1970s and 1980s the delta was considered as a "dewatered" or "dead ecosystem" because the water from the River did not flow out to the ocean (Spamer 1990). Since 1981, the delta has been partially revegetated by the discharge of floodwaters (abnormal snow melts in the Upper Colorado River) and agricultural drainwater from the United States to Mexico. These current conditions have allowed wetlands and riparian vegetation to flourish on about 60 000 ha.

Although there exists a relative number and distribution of native species, non-native species have comprised the ecological health of much what remains of the delta wetlands. Increases in riverbank salinity and other alterations of the riparian zone have favoured the establishment of invasive, salt tolerant species (Glenn 1998). Along most of the River the native gallery forests of cottonwoods (*Populus fremonti*) and willow (*Salix goodingii*) have been replaced by the introduced shrub, salt cedar (*Tamarix ramosissima*), with a resulting loss in habitat for native fauna, occupying great extensions of modified habitat (USBR 2000b).

Salt cedar (Tamarisks) has four main impacts on the local environment once they become established: (i) increased soil salinity; (ii) increased water consumption; (iii) increased wildfire frequency; and (iv) increased frequency and intensity of flooding (Wiesenborn 1996). In general, as floodplains become more desiccated with age, salt cedar assumes a greater dominance due to its high drought tolerance compared with the native phraetophytes. This results in an ability to produce high density, monospecific stands (Cleverly et al. 1997).

Due to their high evapotranspiration rate tamarisks can dry out smaller water bodies, affecting fish such as the endangered Desert pupfish (*Cypranodon macularius*). Also, due to its aggressiveness, they out compete cottonwoods and willows, reducing the value of the habitat for several animals including the endangered Yuma clapper rail (*Ralus longirostris yumanensis*) (Mellink & Luevano 1998)

The drastic decline in native forest vegetation has reduced the habitat value of the riparian zone for the native species. The Southwestern willow flycatcher (*Empidonax traillii extimus*), as well as many other species, has become endangered in the U.S-Mexico border region due to the reduction of its habitat. The Willow flycatcher breeding area formerly included the Lower Colorado River and its delta. It now appears that the birds found in the delta were migrants (García-Hernández et al. 2001). Many species of native fauna have not been able to adapt to the actual conditions.

Recent studies indicate that populations of many neotropical migrant land bird species are in decline probably due to human development and land management practices along the Colorado River corridor. These human activities have modified or eliminated large amounts of potential stopover habitat for neotropical migrant land birds (Moore et al. 1995). At the continental scale, the delta plays an important ecological role, functioning as a rest area within the Pacific bird corridor used by 75% of North American migratory birds each year (Pitt et al. 2000). The delta presently plays a critical role because of the extensive loss of wetlands and riparian habitat throughout the southwest and northwest of America.

The introductions of invasive fishes to the hydrological system and the changes within the habitat conditions have resulted in a drastic reduction of native fish communities (Table 24). Four of the native "big river fish" of the Colorado River are now close to extinction (*Gila cypha*, *Gila elegans*, *Gila robusta* and *Ptychocheilus lucius*). Of these, only the Humpback chub (*Gila cypha*) has a sufficient population to reproduce successfully in the lower basin. In addition, marine fish species have been found with major frequency in the River (e.g. *Eleoteris picta*, *Mugil cephalus* and *Elops affinis*), due to the effects of tides from the Gulf of California, many of them turning into predators or competing with native fishes (USBR 2000b).

The damming of the Colorado River has modified the environment of the Upper Gulf of California. The reduction in freshwater flow has cut the influx of nutrients to the sea and reduced critical habitats for nursery grounds for many commercially important species: Totoaba (*Cynoscion macdonaldi*), Gulf curvina (*C. othonopterus*) and Brown shrimp (*Farfantepenaeus californiensis*) (Aragón-Noriega & Calderon-Aguilera 2000). The Upper Gulf is the nursery area for the Blue shrimp *Litopenaeus stylirostris*, the most profitable fishery in this region.

Table 24 Fishes of the Colorado River in the Grand Canyon, and their status.

Common name	Scientific name	Status*	Status of native species
Humpback chub	*Gila cypha*	N	Threatened with extinction; listed as endangered under the Endangered Species Act (ESA) in 1967; a reproducing population exists in the Little Colorado River.
Bonytail chub	*Gila elegans*	N	Threatened with extinction; listed as endangered under ESA in 1980; no natural reproduction; only a small number of older fish remain.
Roundtail chub	*Gila robusta*	N	Classified as a "species at risk" of being listed as endangered under ESA.
Colorado squawfish	*Ptychocheilus lucius*	N	Appears extirpated in lower Colorado; listed as endangered under ESA in 1967.
Speckled dace	*Rhinichthys osculus*	N	Classified as a "species at risk" of being listed as endangered under ESA.
Flannelmouth sucker	*Catostomus latipinnis*	N	Classified as a "species at risk" of being listed as endangered under ESA.
Bluehead sucker	*Catostomus discobolus*	N	Classified as a "species at risk" of being listed as endangered under ESA.
Razorback sucker	*Xyrauchen texanus*	N	Threatened with extinction; listed as endangered under ESA in 1967.
Common carp	*Cyprinus carpio*	I	
Red shiners	*Cyprinella lutrensis*	I	
Golden shiner	*Notemigonus crysoleucas*	I	
Fathead minnow	*Pimephales promelas*	I	
Redside shiner	*Richardsonius balteatus*	I	
Threadfin shad	*Dorsoma petenense*	I	
Apache trout	*Oncorhynchus apache*	I	
Cutthroat trout	*Oncorhynchus clarki*	I	
Silver salmon	*Oncorhynchus kisutch*	I	
Rainbow trout	*Oncorhynchus mykiss*	I	
Brown trout	*Salmo trutta*	I	
Brook trout	*Salvelinus fontinalis*	I	
Channel catfish	*Ictalurus punctatus*	I	
Mosquitofish	*Gambusia affinis*	I	
Green sunfish	*Lepomis cyanellus*	I	
Bluegill sunfish	*Lepomis macrochirus*	I	
Largemouth bass	*Micropterus salmoides*	I	
Striped bass	*Morone saxatilis*	I	

*Note: * N = Native, I = Introduced. (Source: Minckley 1991, Wigiington & Pontius 1995)*

The Gulf curvina is an endemic fish of the Gulf of California that annually migrates to the spawning and nursing grounds in the Upper Gulf of California and Colorado River Delta. Between 1917-1940 it was fished on a small-scale, along with Totoaba. The Gulf curvina apparently ceased its annual migration in the early 1960s, probably due to changes in habitat conditions, but its commercial harvest was reinitiated in the early 1990s

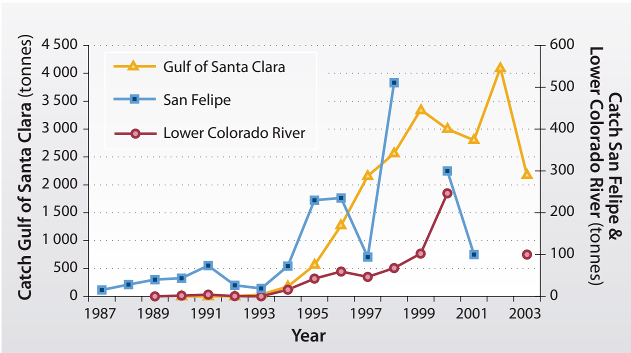

Figure 8 Re-initiation of the commercial harvest for the Gulf curvina (*Cynoscion othonopterus*) in the Upper Gulf of California.
(Source: Román-Rodríguez et al. 2003)

(Figure 8), coinciding with the presence of "surplus" water flows recently released into Mexico, which have reached the mouth of the Colorado River (Román-Rodríguez et al. 2003).

Socio-economic impacts

Economic impacts

It is important to mention that the economic value of natural resources has not been taken into account in this assessment. Without a prior establishment of environmental goods and services it is difficult to establish economical values on habitat modification. There is still an absence of an effective environmental valuation system to analyse, in cost-effective terms, habitat loss and ecosystem modification. Economic impacts of the Colorado River Basin have included costs from maintenance and restoration of river banks following increased bank erosion and siltation, control of alien species, recovery costs after the occurrence of floods, reduction of fisheries and loss of revenues from tourism.

Sediment deposits along the Colorado River in the Grand Canyon serve as campsites for rafting trips. Since the completion of Glen Canyon Dam in 1963, there has been a noticeable loss of suitable campsites, principally due to erosion, lack of sandbar replacement by incoming sediments, and vegetative succession. This is a concern because of intense rafting trip use (Figure 9). Over 22 000 river runners use the system each year (Kearsley et al. 1994), resulting in an annual regional economic impact in excess of 20 million USD (Bishop et al. 1989).

The total economic impact of commercial river rafting in the Colorado River was estimated to be approximately 70 million USD in 1991. This estimate is based on 410 000 user days with an average expense of 65.80 USD per day per user, using an economic multiplier of 2.56 (Colorado River Outfitters Association 1992).

In addition, the invasion of tamarisks has caused significant economic impacts from the costs incurred by control management, which requires a combination of herbicide, burning, and mechanical control techniques, One source claimed that tamarisk clearing costs from 750 to 1 300 USD per ha (Taylor & McDaniel 1998).

Livestock grazing results in the replacement of native grasses and forbs by Juniper (*Juniperus* spp.), Rabbit brush (*Chrysothamnus* spp.), Russian thistle (*Salsola kali*), and other shallow-rooted vegetation that are less adapted for soil stabilisation, thereby increasing sheet erosion. This erosion and the accompanying heavy and frequent flood events destroy trout habitat by filling pools with silt, uprooting trees and other riparian vegetation, widening and aggrading stream channels, and lowering water tables (Bock et al. 1992). The Glen Canyon rainbow trout fishery, located in the first 26 km downstream of Glen Canyon Dam, is one of only two blue-ribbon stream fisheries in Arizona and is used by over 19 000 anglers each year (NRC 1996), resulting in a regional economic impact in excess of 3 million USD (Bishop et al. 1989).

Health impacts

There are no known health impacts related to habitat and community modification.

Other social and community impacts

There has been a pervasive and systematic failure to assess and account for the range of negative social impacts from habitat modification on displaced and resettled people as well as on downstream communities. The livelihood of the indigenous people has been significantly affected, but there has been a failure to recognise associated impacts, and mitigation, compensation and resettlement programmes were often inadequate.

Further attention should be given to the effects on local communities (e.g. Cucapá) by the infestation of tamarisks along the Colorado River drainage basin, as many of them depend on riparian vegetation for their day-to-day activities. The tamarisks dry up springs, wetlands, and riparian areas by lowering water tables.

The natural hydrodynamics of the Colorado River Basin have been structurally modified to improve water conveyance and supply to cities including San Diego, Los Angeles, Tijuana and Mexicali. This water-related infrastructure constructed for electricity generation and irrigation expansion, has allowed the major urban areas of the region to expand. This associated urban development has caused habitat modification and ecosystem degradation, although these changes

Figure 9 Rafting in the Colorado River.
(Photo: Corbis)

have also provided social benefits related to economic growth and social prosperity.

The present trend is to gradually transfer water that was designated for agricultural activities to urban purposes. Since agriculture uses over 90% of water resources at a low cost, urban water transfers would allow greater revenues to be received from water resources, thus increasing its economic value. It is believed that the social implications of this would be a change in water culture and perceptions towards the conservation of water resources.

Conclusions and future outlook

Habitat modification has provided some positive economic benefits to the region's communities. It is expected that water infrastructure trends will continue to stimulate economic development. The U.S. Bureau of Reclamation has proposed new regulations and projects, including off stream storage of water and privatisation of the Wellton-Mohawk Irrigation District, which are likely to reduce flows to the Colorado River Delta, with consequences for delta ecosystems (USBR 1998).

The Yuma desalting plant is a 260 million USD water treatment plant built by the U.S. Bureau of Reclamation in Yuma, Arizona, about 32 km from the international border. The plant was built to treat agricultural drainage from the Wellton-Mohawk Irrigation District in Arizona. Under the original plan, this treated water would be delivered to Mexico as part of Minute 242. The plant was completed in 1992 but has never been operated. The USBR is analysing options for operating the plant and exploring possible markets, including California and the Middle East via super tanker. The city of Yuma has the right of first refusal on the water. A decision to operate the Yuma desalting plant and divert Wellton-Mohawk drain water from the Main Outlet Drain Extension (MODE) canal could have disastrous consequences for the Ciénega de Santa Clara wetland. The reduction in inflow would shrink the wetland by 40%, affecting both wildlife populations and the residents of the nearby farming community Johnson ejido. If water were diverted from this important wetland in the core zone of the biosphere reserve, the immediate effects would fall on two endangered species (Desert pupfish, *Cyprinodon macularius*; and Yuma clapper rail, *Rallus longirostris yumanensis*) that depend greatly on these wetlands for their survival.

In addition, the lining of the All American Canal would affect the 6 200 ha of wetlands along the border between Mexico and the United States, that was created by the infiltrations of the All American Canal. Hinojosa-Huerta et al. (2003), from studies of satellite images, detected six groups of wetlands in the dunes of the Mesa de Andrade, south of the All American Canal and suggest that these have possibly provided services to birds of the Pacific Corridor since 1940, and since 1901 when the Álamo Canal was completed. In these lagoons they identified the presence of 43 bird species, among which are species that are endangered and under special protection.

In positive terms, society will become more aware of the potential detrimental effects of water developments, and take into consideration environmental protection during planning and implementation of water projects. It is expected that water recycling in the future will figure more prominently as a conservation technique. The wastewater treatment employed for Mexicali (Mexicali II Project), has already demonstrated how new sources of water can be provided for the Colorado River Delta.

Unsustainable exploitation of fish and other living resources

Historically the Upper Gulf of California has supported numerous fisheries and commercially valuable species, providing important spawning and nursery habitat for shrimp, fish and other species in the Upper Gulf food chain. Various forms of human activity (shrimp trawls, pollution, and freshwater shortage) may be altering the ecosystem of the northern Gulf, which ultimately affect local fisheries, and the semi-enclosed nature of the Upper Gulf may serve to magnify the impact of these activities.

In the Upper Gulf, the once prolific Totoaba (*Cynoscion macdonaldi*), a highly prized commercial and sport fish (Figure 10), is nearly extinct, as is the Marine vaquita (*Phocoena sinus*), the world's smallest porpoise and most rare mammal. In the late 1980s and 1990s the shrimp catches dropped by over 50%, signalling a virtual collapse in the shrimp fishery. However, this activity noticeably improved when floodwaters reached the Gulf, such as in 1983-1988, when several km^3 of water spilled from upstream reservoirs and revitalised wetlands such as the Ciénega de Santa Clara. The Gila River floods in 1993 produced similar results.

Figure 10 Totoaba fishery in the late 1940s.

The Totoaba fishery declined dramatically since 1970 due to declining populations and to restrictions imposed (in 1975) when catch levels threatened the population. Despite closures, Totoaba gill net fisheries continue on a small-scale and they remain a threat to the Marine vaquita populations. Juvenile Totoaba have also been caught and killed in substantial numbers of shrimp trawls, which further endangers the Totoaba population.

Environmental impacts

Overexploitation

The overexploitation of fish resources is a considerable problem in the Colorado River Delta and the Upper Gulf of California. A large number of invertebrates (e.g. *Penaeus stylirostris* and *Penaeus californiensis*), mammals (e.g. *Tursiops truncatus*) and commercial species of fishes such as Totoaba (*Cynoscion macdonaldi*) and the Gulf curvina (*Cynoscion othonopterus*) are under critical conditions and some of them like the endemic porpoise (*Phocoena sinus*) are on the verge of extinction (there is a count of less than 600 vaquitas in the Upper Gulf of California) (Jaramillo-Legorreta et al. 1999).

Catches from the Upper Gulf shrimp fishery dropped off steeply during the late 1980s and early 1990s by over 50%, signalling a virtual collapse in the shrimp fishery. Although the damming of the Colorado River may have been the principle cause of the decline in the shrimp fishery, the escalation in the number of fishing vessels and fishing gear types could have also influenced its collapse (Figure 11). As stocks have declined in abundance, fishermen have moved to the use of more efficient gear (All 2002).

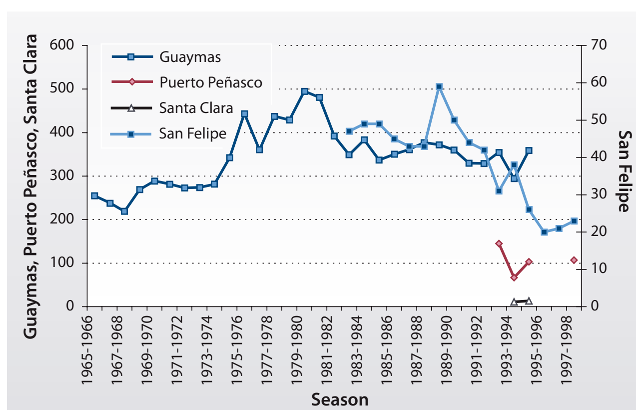

Figure 11 Escalation of fishing vessels for the shrimp industry in the Upper Gulf of California 1965-1998.
(Source: Román-Rodríguez et al. 2003)

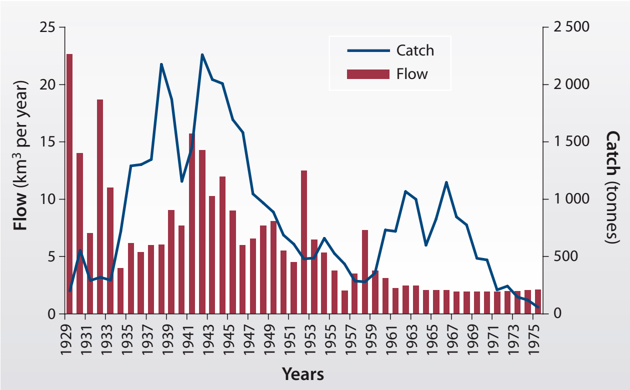

Figure 12 Totoaba fishery annual yield and Colorado River flows to Mexico 1930-1975.

(Source: Flanagan & Hendrickson 1976 with data obtained from Arvizu & Chavez 1974)

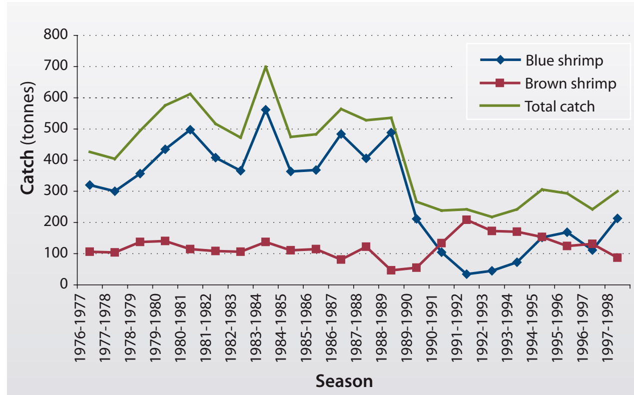

Figure 14 Specific and total catches of shrimp landed in the Port of San Felipe, Baja California, in the seasons from 1976/1977 to 1995/1996.

Note: Rosas-Cota et al. 1998 states that as of the 1996/1997 season, artisanal fishing reaches almost 50%. (Source: Rosas-Cota et al. 1996)

Some endemic species that reside in the Colorado River Delta have a commercially and environmental importance in the Colorado River Delta like the Totoaba. Although diverse studies suggest that overfishing had played the most significant role for the decline in Totoaba stock during the pre-1958 catch period (Flanagan & Hendrickson 1976). The reduction of annual flow to the Colorado River Delta could have been another strong factor in its decline, based on the fact that the alteration of its environment affected its area of spawning and nursery ground (Román-Rodríguez et al. 2003) (Figure 12).

Government policies have consistently encouraged the expansion of both the industrial and small-scale fishing sectors. Large artisanal fleets operating in the Gulf also contribute to overharvesting. In Sonora alone, there are an estimated 7 000 small boat fishers (pangas) (Figure 13) (Arizona Daily Star 2001). A recent survey by Conservation International Mexico (2003) estimated that there are 9 000 to 18 000 pangas active in the Gulf. In the three main communities of the Upper Gulf, the small-scale fishing fleet now exceeds 800 boats, which exploit over 70 species of fishes, molluscs, and crustaceans on a regular basis (Cudney-Bueno & Turk-Boyer 1998).

Figure 13 Pangas fishing in the Upper Gulf of California.

(Photo: G. Ybarra)

Fish populations in the Gulf are also influenced by annual catch rates that are related to the size of the fishing fleet; during the mid 1980s several years of extremely heavy fishing may have influenced the reductions in the shrimp population. Catch per unit effort has been declining for decades, while fuel and export subsidies artificially sustain overcapacity of industrial fishing fleets.

From the beginning to the mid-1970s, shrimp boats made 9 trips on average per season, each of which lasted from 17 to 20 days, with an average catch of 115 kg/day (Rodríguez de la Cruz 1981). The number of trips per season was maintained until the 1980s, and, on the other hand, the average duration of each increased to 23 days, whereas the average production decreased to 80 kg/day (Ehrhardt 1980). At the beginning of the 1990s, fishing trip length decreased to 20 days per season, with an average of 5 trips per boat; the average catch per vessel decreased from 52 and 35 kg/day in 1990 and 1991, respectively (Rodríguez de la Cruz & Chávez-Ortiz 1996). Shrimp catch in the Port of San Felipe is shown in Figure 14.

Excessive by-catch and discards

By-catch and discards was assessed as having a severe impact in the Upper Gulf of California. In the industrial shrimp fishery for example, Conservation International Mexico (2003) estimated that for each kg of shrimp, there are at least 10 kg of by-catch (Table 25). Of those 10 kg of

Table 25 Estimated by-catch in the Upper Gulf of California.

Catch	Volume (kg)	Relation Shrimp:Type of catch
Total	263	1:10
Shrimp	26	-
Fish	164	2:10
Invertebrate	72	4:10

(Source: Conservation International Mexico 2003)

Table 26 Trash species caught and discarded in the shrimp industry.

Common name	Scientific name
Longjaw	*Oligoplites altus*
Corvina	*Menticirrhus nasus*
Yellowfin croacker, chano	*Micropogon megalops*
Orangemouth corvina	*Cynoscion xanthulus*
Shortfin corvina	*Cynoscion parvipinnis*
Striped corvina	*Cynoscion reticulatus*
Blue crab	*Callinectes spp.*
Striped mullet	*Mugil cephalus*
Paloma pompano	*Trachinotus paitensis*
Roosterfish	*Nematistius pectorales*
Bonefish	*Albula vulpes*
Pacific sierra	*Scomberomorus sierra*
Gulf sierra	*Scomberomorus concolor*
Spanish mackerel	*Caranx hippos*
Sicklefin smoothhound	*Mustelus lunulatus*
Totoaba	*Totoaba macdonaldi*

(Source: Tapia-Landeros 2001b)

by-catch, there are juveniles of at least 16 species different to those of shrimp (Table 26). Only a few of these species have an economic value (e.g. *Mustelus lunulatus*, *Callinectes* spp.) as they are caught in their early stages of growth (Conservation International Mexico 2003).

In these operations, many species regarded as "trash" fish are killed and discarded, along with associated invertebrates. Furthermore, species like dolphins (*Tursiops truncatus*), turtles (*Dermochelys coracea*), rays (*Gymnura marmorata*), and vaquitas (*Phocoena sinus*) occasionally die in trawling and gill nets usually disposed for other target species.

SEMARNAP (1998) estimated the total value of by-catch as approximately 1.32 million USD for the Gulf of California region. These revenues earned from by-catch are very small when considering that the total value for the states of Baja California and Sonora in the same year for the shrimp fishery alone is 251 million USD. It is therefore argued that the ecological costs of by-catch far exceed the economic value of by-catch.

Destructive fishing practices

There have been drastic changes in benthic communities produced by the indiscriminate use of trawling nets (Mathews 1974), which for example in the Upper Gulf of California pass some areas more than 10 times per year. Most attention is given to the excessive by-catch and the destructive fishing practices because it is assumed that if fishing techniques can be improved and discards and by-catch levels can be reduced, the activity will become more sustainable.

Gill net fishing from pangas set for sharks, rays, mackerels (*Scomberomorus sierra* and *S. concolor*), Chano (*Micropogon megalops*) (a croaker), and shrimp (*Penaeus* spp.); and occasionally in commercial shrimp trawls, also incidentally captures the highly endangered Vaquita porpoise (*Phocoena sinus*) and sea turtles. Between March 1985 and January 1994, 76 vaquitas were confirmed to have been killed incidentally in Totoaba gill nets (D'Agrosa et al. 1995). Although mortality rates are apparently greatest in gill nets with large mesh (0.25-0.30 m), shrimp trawling may also impact the Vaquita through the direct depletion of an existing food source (shrimp) and by disrupting the benthos and associated food web.

The total estimated incidental mortality caused by the fleet of El Golfo de Santa Clara was 39 Vaquitas per year, over 17% of the most recent estimate of population size (D'Agrosa et al. 2000). All the porpoises taken in shrimp fisheries were referred to as "very small", probably calves or juveniles. The Vaquita population are counted to be of less than 600 (Jaramillo-Legorreta et al. 1999), therefore, considering normal replacement rates (maximum rate of population growth for cetaceans is of 10% per year), this incidental loss can not be sustained by the population.

Poaching of sea turtles is a problem throughout western Mexico, although turtle-excluder devices are mandatory (though commonly not employed) for industrial fishing vessels. Sea turtles have been essentially extirpated from the Upper Gulf.

Mathews (1974) estimated that an average shrimp net passed over every m^2 of the Mexican Pacific shrimp grounds about seven times each year. In the Upper Gulf this rate may be significantly greater than elsewhere. This constant bottom trawling damages fragile benthic habitats, although data to substantiate this contention are lacking. Silber (1990) counted more than 50 shrimp trawlers in a 6 km^2 area and several times over 80 boats were counted during a single visual scan of the horizon. It has been calculated that in a single shrimp season, the shrimp fleet had reached over 1 100 boats, these shrimp trawlers annually rake an area of sea floor equivalent to four times the total size of the Gulf (Brusca et al. 2001).

Impact on biological and genetic diversity

The alteration on biological and genetic diversity is considered the result of the introduction and release of alien species employed for commercial purposes like Catfish (*Ictalurus punctatus*) and Tilapia (*Tilapia zilli*), and in some cases by the introduction of laboratory stock trying to increase their natural population, as is the case of the Totoaba (*Cynoscion macdonaldi*). It is important to mention that the problem is more accentuated in the freshwater habitats than in the marine environment; most of the fishes of the Arizona Rivers for example, have been affected.

The pollution of water has affected various species (*Tilapia zilli*, *Micropterus salmoides*, *Mugil cephalus* and *Cyprinus carpio*) all along the Colorado River mostly due to an increase in selenium concentrations. In the marine area, species like the Blue shrimp (*Litopenaeus stylirostris*) and White shrimp (*Litopenaeus vannamei*) have presented viruses and species like Tilapia and other stocks have suffered impacts by polluted waters (García-Hernández et al. 2001).

Socio-economic impacts

Economic impacts

Three groups are exploiting the fishing resources in the Upper Gulf of California, all markedly different among each other: the industrial or major fleet sector; the artisan or minor fleet sector; and the national and foreign tourist sector. The former generally uses larger vessels for shrimp trawling and catching diverse fish species, whereas the second group, also known as the small-scale riparian or bay fishery sector, uses smaller boats or pangas. This sector is characterised by its low investment in equipment in comparison to the major fleet and its high dynamics. This type of fishing activity takes place in the ocean, the Santa Clara marsh and the area known as El Zanjon or main flow of the Colorado River. The riparian fleet exploits approximately 70 species. The tourist sector partakes in sports fishing activities, mainly provided by sports fishing service providers in Puerto Peñasco, San Felipe, to a limited degree in the Golfo de Santa Clara and the Ejido Luis Encinas Johnson, within the Santa Clara Marsh (Cudney-Bueno & Turk-Boyer 1998). To a lesser degree, but not of lesser importance, the artisan fishery sector catches molluscs, such as octopus, squids and collects some bivalves. In summary, in the case of the three communities that comprise the Upper Gulf of California, fishery has experienced growth, which, by itself can only be translated as a partial recovery of the former production levels existing prior to the great crisis observed at the end of the 1990s, before the establishment of the Biosphere Reserve.

The Upper Gulf of California is renowned for the volume of capture by its commercial fishing of sardine, pacific sierra, anchoveta and tuna fish, although there also exists minor tonnage fisheries with important economic revenue, such as the shrimp fishery (Table 27).

Table 27 Average annual catches by fishery 1994-2000.

Species	Volume (tonnes)
Sardine (*Sardinops sagax*)	46 021
Yellow fin tuna (*Thunnus albacares*)	21 166
Barrilete (*Katsuwonus pelamos*)	110 489
Anchoveta (*Cetengraulis mysticetus*)	7 803
Macarela (*Scomberomorus concolor*)	7 143
Blue fin tuna (*Thunnus maccoyii*)	1 560
Blue (*Litopenaeus stylirostris*) and Brown (Litopenaeus californiensis) shrimp	437

(Source: Secretaría de Desarrollo Económico 2000)

From the beginning of the 1930s to the 1960s, shrimp fishing grew exponentially in the area of the Upper Gulf of California. In the 1960s shrimp trawling fishery was the country's most important sector; Golfo de Santa Clara, Puerto Peñasco and San Felipe have been and still are the Upper Gulf's main fishing communities. During the 1970s, the sales price of shrimp increase considerably and a large portion of the population of San Felipe and Puerto Peñasco that was engaged in other activities (i.e. tourism), started getting involved in shrimp fishing. Simultaneously, there was a large migration from central Mexico to coastal communities in which shrimp were abundant. This was the age of the "pink gold" rush, as it is known locally.

Until the end of the 1980s, the shrimp industry generated the majority of revenues for the fisheries sector in this region. Besides increasing and industrialising the major fleet, shrimp engendered the growth and boom of the artisan or riparian fishing sector. Although other fisheries continued developing throughout the years, shrimp were the Basin's main fishery (Cudney-Bueno 2000).

When shrimp fishing in the Upper Gulf declined abruptly in the late 1980s to early 1990s, many cooperatives closed because of banks seizing boats due to fishers failing to make repayments on loans. In Puerto Peñasco alone, the trawler fleet decreased from 220 to 100 vessels (Cudney-Bueno & Turk-Boyer 1998). In view of this shrimp crisis, a good portion of the commercial sector of pangas (small skiffs powered by outboard motors) diversified activities, with some permanently engaged in sports fishing whilst others alternate between commercial and sports fishing, especially in San Felipe.

The adoption of sports fishing by some pangas fishers has proved profitable. For example, an average curvina weights 2 kg, at a price of 0.45 USD/kg; the curvina has a value price of 1.09 USD in the seafood market. Pangas charge between 80 USD and 100 USD per half day fishing trip to sport fishers, making the conversion to Mexican pesos, the equivalent is 900 MXN. It is quite common, that a single panga takes 4 sport fishers per trip, obtaining each an average of 4 to 5 curvinas. This way, the 20 curvinas caught during the trip generates a total income of 900 MXN to the fishing guide and divided into a total weight of 40 kg, gives an economic proficiency of 2.45 USD/kg of curvina obtained with a sport fish hook. Whereas, the curvinas captured with gillnet, would only have given an economic proficiency of 0.54 USD/kg, and in the best of cases a profit of 22 USD for the 20 curvinas (Tapia-Landeros 2001a). With this example it can be deduced that the curvina sport fishery is 78% more profitable than the commercial fishery of the same species. This example can be applied to the majority of the cases of species that use bait.

Due to the insufficient control of catches, some fishermen sell their product to purchasers who come to fishing camps. This generates an excess supply of the product, drastically decreasing prices. It is common to find during the first trimester of the year, piles of rotting curvinas on the outskirts of San Felipe, Baja California, as fishermen prefer to discard them, rather than settle for an unacceptably low price. Therefore, it is recommended to provide added value to the product, so that it may be feasible to catch a lesser number of individuals whilst obtaining a greater profit margin. Excess fishing has caused a decrease in the size of the fish that are being caught, which suggests that species such as the Sicklefin smoothhound (*Mustelus lunulatus*) are being overexploited (Table 28).

Table 28 Economic value and capture by species in Baja California and Sonora.

Species	Baja California			Sonora		
	Catch (tonnes)		**Value 1998** (USD)	**Catch** (tonnes)		**Value 1998** (USD)
	1993	**1998**		**1993**	**1998**	
Shrimp	290	900	4 580 000	4 566	6 299	103 289 000
Barrilete (*Katsuwonus* spp.)	9 669	4 665	4 225 000	ND	ND	91 000
Curvina (*Cynoscion* spp.)	124	422	441 000	195	2 496	2 386 000
Smoothhound (*Mustelus* spp.)	114	ND	213 000	682	94	121 000
Shark	1 226	884	ND	960	1 283	241 000
Sierra	162	3 372	188 000	1 090	1 976	1 704 000
By-catch	422	100	38 000	ND	ND	920 000

(Source: SEMARNAP 1998, INEGI 1999a)

Commercial fishing resources in the Upper Gulf are exploited by the industrial and artisan fleet sectors. The industrial fleet includes around 114 shrimp and/or scale boats at Puerto Peñasco and 16 shrimp boats at San Felipe. The remaining fleet of middle-size or large boats for sports fishing is 71 for Puerto Peñasco and 10 at San Felipe. There are also an undetermined and variable number of shrimp boats from other ports, such as Guaymas, La Paz, Yavaros or Topolobampo that work in the Upper Gulf for some time during the shrimp season. The distribution of fishing capture by economic importance is shown in Table 29.

Although certain species in the Upper Gulf of California and the Colorado River Basin are under threat from unsustainable exploitation by the fisheries sector (e.g. Smoothhound, shark, Totoaba, Gulf curvina and shrimp), in general this concern's impacts are not severe. The economic impact of a declining fishery is minor due to the dominance of the other productive sectors of the Basin's economy. However in specific localities, such as in the Upper Gulf where fishing is important to the local economy, this concern is persisting with considerable severity.

The shrimp fishery in Baja California has an average annual catch of 437 tonnes (average 1994-2000, in 1982 it reached a maximum catch of 1 800 tonnes), generating over 30 000 direct and indirect jobs and economic revenues of over 132 million USD per season.

Sonora ranks first in fishing production at the national level. At the state level, crustaceans rank second in production, shrimp ranking first

Table 29 Spatial distribution of fishing capture by economic importance in the Upper Gulf of California 1998.

Species	Value (USD)*	Volume (tonnes)	Vessels and fisherman employed	Fishing zone
Shrimp (*Litopenaeus* spp.)	258 846 000	39 822	1 133 vessels. Average of 6 fishermen per vessel and 3 fishermen in small-scale vessels.	Upper Gulf of California (Bahia San Jorge and Punta Radar) northeast of Isla Pajaros and south and west of Topolobampo.
Shark	6 306 000	5 842	ND	Baja California (west of Isla Cedros), Sonora (south of the Upper Gulf and Yavaros, north of Guaymas) Baja California Sur southeast of Los Cabos.
Mojarra (*Diplodus* spp.)	3 816 000	5 101	ND	Sinaloa (Topolobampo and El Castillo) and Sonora (Puerto Peñasco and Guaymas).
Corvina (*Cynoscion* spp.)	3 638 000	3 947	Fished by fin fishers and shrimpers.	Upper Gulf of California.
Sierra (*Scomberomorus* spp.)	2 632 000	3 275	15 vessels of 3 fishermen.	Upper Gulf of California and east to Huatabampo.
Berrugata (*Menticirrhus* spp.)	2 519 000	4 860	Fished by fin fishers and shrimpers.	South of the Upper Gulf and southeast and east of Topolobampo.
Baqueta (*Epinephelus* spp.)	2 505 000	1 201	Minor vessels of 3 fishermen.	Upper Gulf of California, between Guaymas and Huatabampo.
Bagre (*Ictalurus* spp.)	775 000	982	ND	South of P. Peñasco and east of El Novillero (Sinaloa).

*Note: *Prices of 1998. (Source: SEMARNAP 1998)* among crustaceans, with an average production of 12 000 tonnes from 1990 to 1999. In 1999, Sonora contributed 26.6% of all national catches, increasing its total income to 249 million USD dollars, considering only exported products (Ayala-Herrera 2001). The total population that works in shrimp fisheries amounts to 21 190 persons and, the shrimping sector alone employs 19 290 persons. With respect to the national total and that of the Pacific, the figures are 8.2 and 14.9% respectively, without considering the large amount of indirect jobs this activity generates (Ayala Herrera 2001). Over 60% of the Mexican production is exported to the United States through Ocean Garden, a marketing company.

Health impacts

In general terms, the existence of health issues related with unsustainable exploitation of fish is unknown.

Other social and community impacts

The number of people affected by the unsustainable exploitation of natural resources is limited and predominantly focused on the fishery. Social conflicts are related to the disputes for fishery resources between: the artisan and the industrial (commercial) fishermen; the environmental sector and the entire fishery sector; and the sport fishing and the artisan community. However, it is important to mention that due to the complexity and the permanent social problems generated in this activity, many people are looking for new economic alternatives in the Basin. The resurgence of the Gulf curvina (*Cynoscion othonopterus*) fishery has provoked several conflicts as most catches take place within the Biosphere Reserve's core zone (Román-Rodríguez et al. 2003). The main problem is that the existing landing points (Golfo de Santa Clara, San Felipe and Rio Colorado Camp) are considered as the most productive and important finfish artisanal fishery in both the Upper Gulf of California and Colorado River Delta Biosphere Reserve.

Conclusions and future outlook

At the end of the 1980s and beginning of the 1990s, the economic crisis, together with the low volume of catches, along with the overexploitation of certain species, resulted in a 50% decline in catch (Hernan 1997). Although there has been a partial recovery of the fishery sector, the overexploitation of natural resources is exhausting commercial stocks and in some cases making them economically unviable to fish (e.g. shark, smoothhound, and curvina fisheries).

The current efforts of national and international NGOs (e.g. Conservation International, PRONATURA, WWF, Sierra Madre) in cooperation with coastal communities and local and national authorities are yielding solid results in conserving the natural resources upon which a large number of people depend. Therefore, an improvement in the present trends is expected, enhancing the conditions of all marine habitats and ecosystems.

In 1993 the Mexican Government declared the Colorado River Delta and the Upper Gulf of California a Biosphere Reserve. A moderate positive change can be expected, if the fishery industry and local fisherman respect the close seasons, spawning and nursery grounds in the Biosphere Reserve and replace trawling nets for more efficient gear. It can be optimistically considered that the impact from the fishery sector will be reduced and the fishing communities will be become less dependent on these activities through diversification of the local economy. Examples include low impact oyster farms and non-intensive closed aquaculture, ecotourism, and the use of natural habitats for science education. These activities have been proved to be minimally destructive to the environment whilst still providing substantial economic benefits.

Estero Morua is a coastal lagoon near the town of Puerto Peñasco that is being developed as a model for sustainable wetland management. Since the 1980s, this lagoon has been used by a women's oyster farm cooperative, "Unica de Mujeres del Mar". Despite difficulties in acquiring capital to initiate the oyster farm, the operation has become a great success and has led to two additional oyster farms in Estero Morua, and others are being planned. Today several dozen families depend on this activity (Brusca et al. 2001).

If the fishing industry continues with its indiscriminating fishing practices, it has been suggested that funds from multilateral donors such as the Global Environment Facility (GEF) be used to buy out the older part of the shrimp fleet (Figure 15). The estimated cost to purchase 400 boats and fishing licenses would be about 60 million USD (Packard

Figure 15 Shrimp fleet in San Felipe.
(Photo: WWF/Gustavo Ybarra)

Box 1 Human impacts in the Gulf of California.

During the late 1950s, the Gulf of California began to show the first signs of deterioration by human activity, with the declining and almost extinction of the Totoaba (*Totoaba macdonaldi*) fishery. Annual yield began to increase rapidly in 1934 and catch peaked at 2 261 tonnes in 1942 (Arvizu & Chavez 1972). After 1942, despite intensified fishing effort and increased gear efficiency, the annual yield exhibited erratic fluctuation to the all time minimum catch of approximately 58 tonnes in 1975.

This endemic fish of the Gulf of California was initially exploited for the export of its dried air bladders (known as buche) to the Orient market as an ingredient of a gourmet soup (Conal 1993). Afterwards, its flesh was also highly commercialised mainly to the U.S. and Asian markets and used in international gourmets. The Totoaba was also very popular among sport fishers mainly coming from the south of California and northern Mexico.

Fishing pressure in the Gulf is extreme. The Basin's fisheries are operating under practically open-access conditions, existing fishing regulations are not enforced, federal subsidies support overcapacity in industrial fleets, the biology of commercial species is poorly known (or unknown), and monitoring programmes measuring the ecological impact of Mexico's fishing operations are almost non-existent.

The reduction of freshwater inflow, chemical pollution from agriculture and urban areas, and coastal habitat destruction have combined with overfishing, use of non-selective fishing gear, and lack of reliable scientific data to drive such high-visible species as the Totoaba and vaquita porpoise (*Phocoena sinus*) to near extinction, cause local extirpation of five species of sea turtles, and substantially reduces the Gulf's important commercial finfish and shrimp populations.

Cisneros-Mata et al. (1995) estimated that at least 120 800 juvenile Totoabas were killed by shrimp vessels every year (from 1979 to 1987). In a research taken place by the Autonomous University of Baja California (Siri-Chiesa & Moctezuma-Hernández 1989), it was reported that in a single catch, 267 juveniles of Totoaba were extracted from a shrimp vessel. This example helps to understand why the Totoaba is on the border of extinction.

Recent studies developed mainly by the U.S. have shown that a species of sea clam (*Mulinia coloradoensis*) of the Upper Gulf has demonstrated to be an excellent indicator of the decadence of life in these waters. Before the dams, the Colorado delta clam ranged as far as 60 km from the River's mouth and densities reached 46 individuals per m^2. Today, the species typically occurs within 30 km of the River's mouth and at densities of only 0.15 individuals per m^2 (Rodriguez et al. 2001). Life represented by this mollusc has been reduced to only 10% since the construction of dams in the U.S. portion of the Colorado River in 1935.

The dramatic decline of the Colorado delta clam since upstream diversion of freshwater is most likely the result of the increased salinity of its habitat (Rodriguez et al. 2001). Evidence for the importance of freshwater mixing in the clam's habitat comes from the isotopic geochemistry of the clam's shell. In addition, most, if not all, serranids are protogynous (female-first sequential hermaphrodites), and the sciaenids require estuarine habitats in the rapidly diminishing Colorado River Delta for spawning and nursery grounds.

Foundation 1999). International ecological organisations could also try to impose extreme measures such as the tuna embargoes.

Declines in shrimp landings, mainly *Litopenaeus stylirostris*, have been attributed to overexploitation and reductions of freshwater discharge in the Upper Gulf. The U.S. is responsible for 90% of the loss of freshwater flows to the delta and the Upper Gulf of California, but on the other hand overexploitation is due to inefficient enforcement of Mexican regulations over fishery resources. The restoration and conservation of the delta and Upper Gulf lies in both sides of the border. If the government could manage to contend the commercial fishery of these species during the months of February and April, for example, the fishes could reproduce, take care of the small fry's and return to the Middle Gulf to develop. These proposals are quite reasonable considering that the fishes with a commercial and sporting value are the ones of greater size, leaving the ones of small-size, of very little or no value.

The shrimp, commercial, and sport fisheries, that were once thriving, have steadily declined, but noticeably improved when floodwaters reached the Gulf, such as in 1983-1988 period. Although the amount of flow that would be needed to restore a small endangered species habitat such as the Colorado delta clam (*Mulinia coloradoensis*) at the mouth of the River would be very large (Rodriguez et al. 2001). Restoration of shrimp habitat would require a vastly larger volume (308 million m^3/year) of freshwater to double shrimp production in the Upper Gulf (Galindo-Bect et al. 2000) and this is not likely to be released with the current pressures upon southwestern water supplies. Glenn (1998) estimated that the minimum water requirements (annual maintenance flow + 4 year, overbank flood flow) to help restore the Colorado River Delta ecosystem, is calculated to be of 520 million m^3 over four years, or an average of 130 million m^3/year, which is much less than 1% of the annual base flow of the River (20 km^3/year).

The tremendous diversity of fishing activities taking place within the Upper Gulf of California, the cultural differences between communities, the complexity of the fishery, and the large-size of the Basin makes it a difficult area to manage. This is aggravated by the lack of sufficient resources for implementing and enforcing management decisions and federal laws, inadequate or lack of knowledge about the ecology of exploited species, and insufficient past efforts to actively involve fishing communities in management decision-making (Cudney-Bueno 2000).

IMPACT Global change

Several considerations were made regarding the impact from global climate changes. Due to the lack of data and references the concern was omitted. The GIWA assessment was reluctant to confuse normal cyclic variations with human induced global climate changes. Specific impacts from ENSO (El Niño Southern Oscillation) events were agreed upon, but it was felt that there was insufficient evidence to suggest that the intensity or frequency of these events in the Colorado River Basin and the Upper Gulf of California have been outside of normal fluctuations.

Priority concerns for further analysis

Based on the GIWA assessment, it was concluded that the most severe concern for the region was Freshwater shortage due to its linkages and synergies with all of the other concerns. The concerns were ranked in descending order of severity:

1. Freshwater shortage
2. Pollution
3. Habitat and community modification
4. Unsustainable exploitation of fish and other living resources
5. Global change

Freshwater shortage

The environmental issue of modification of stream flow was considered as the most important issue of the freshwater shortage concern.

The dispute over the distribution of the Colorado River embodies critical issues in the region: the over-appropriation of water and the rapidly changing face of southwestern United States and northern Mexico compounded by population growth and ecological needs. The water plan update for the Lower Colorado Basin presents two water supply and demand scenarios that best illustrate the overall demand and water supply availability. Currently the demands on the rivers water are by far greater in the Lower Basin, exceeding the 9.25 km^3 that the Colorado River Compact of 1922 apportions to the Lower Basin states. On the other hand, by some calculations, unquantified Indian water claims in Arizona alone could be as high as 3.8 km^3 per year – an amount exceeding the average annual surface flow of the state (2.8 km^3/year) and almost half of the state's 1990 total water demand (Eden & Wallace 1992). Shortages shown under present average flow conditions are chronic shortages indicating the need for additional long-term and short-term measures.

In addition, reductions of surplus water programmed by the U.S. Bureau of Reclamation (USBR 2000a) will result in negative impacts to the Colorado River Delta and Upper Gulf of California ecosystem. Most of the water that today enters the delta ecosystem is flood and wastewater. Surplus water in the Lower Colorado Basin has been proved to be beneficial for the environment and most economic sectors. As seen in the assessment, surplus water has had three main functions in the Lower Basin of the Colorado: (i) leach salts and pollutants from the Colorado River; (ii) revitalise wetlands and riparian vegetation along the river watershed and the Upper Gulf of California; and (iii) provide additional supplies of water to the agricultural and urban sectors.

The impacts on the regions ecosystem were some of the most important and potentially negative aspects of the analysis. Important environmental consequences of the modification of stream flow are the effects on riparian forests, anadromous fisheries, wetland and marsh area reductions, and substantial damage from elevated salinities in the Upper Gulf of California. The delta wetlands and marine ecosystems provide unique and valuable habitats to a large number of invertebrates, mammals, birds and commercial species of fishes that are under threat or on the verge of extinction (Alvarez-Borrego 1999).

There are those who believe market forces will solve the problem, for example, by allowing farmers, who have a legal right to the river water to sell water to cities. There are those who believe the answer lies in a continuation of the dam era, with bigger, bolder, more efficient water projects. And there are even those who believe the Colorado River should simply be set free, the Glen Canyon Dam torn down.

Pollution

Linked closely to the loss of freshwater flows, pollution is subject to further analysis, considering that freshwater shortage has increased pollution by diminishing the dilution capability of the water bodies. Although the main issue is salinity, the affects of pollutants such as selenium, methyl tertiary-butyl ether (MTBE), perchlorate and uranium, in the Colorado River Basin are expected to increase in severity in future years. Programmes that have undertaken extensive investigation and environmental analysis point out pollution (especially pollution of groundwater supplies) as an important concern.

Annual reductions in total water supply for urban and agricultural uses in southern California and northern Mexico could increase pollutants in the entire Basin. As a result of these shortages, groundwater recharge in most areas will be subject to detrimental hydrogeological changes, which result in increased salinity and pollution in most aquifers (Navarro 1998).

Recommended actions follow the implementation of a bi-national water quality control programme along the U.S.-Mexico border in order to improve the quality of water for the next 20 years. Implementation of these actions must be undertaken as part of a long-term water resource management program to restore the health of the Colorado River and Upper Gulf of California, while making our water supplies more reliable.

As population growth continues to escalate, pollution continues to increase in serenity, and will become a principal issue for urgent government attention. The New River has already been a subject of bi-national negotiations concerning pollution. The ecology of the Salton Sea has been seriously threatened, with mortality of aquatic species near discharges, as a consequence of agricultural, industrial and urban effluents entering the river system.

Choice of the Colorado River Delta for Causal chain and Policy options analysis

In the United States use of the Colorado River has had transboundary implications due to water abstraction and diversion reducing flows and increasing salinity before it reaches the Mexican border. As a consequence of the western water policy a series of distribution and pollution generated conflicts over the use of the Colorado River, has brought Mexico and the United States repeatedly to disputes over the rivers water resources. In addition, freshwater management plans during the last decade, which have emphasised the importance of controlling pollution, usually failed to address the increasingly important problem of freshwater resource depletion in the U.S.-Mexico border region.

The Colorado River Delta region is the subject of increasing bi-national attention. Much of this interest focuses on the wetland and riparian areas of the remnant delta, although the entire Colorado River border region are of interest, this area is the focus of water transfers, a quantification agreement, water conservation efforts, a proposed aqueduct and new turnout, channel modification, habitat conservation and restoration plans, and wastewater treatment efforts.

Conflicts and problems surrounding the delta region in Mexico have arisen following the reduction of stream flows to the delta region, as a result of unsustainable resource exploitation, inappropriate policies, poverty, population growth, and marginalisation of the local population. The Colorado River water flows are extremely important freshwater resources to the rivers delta, without such flows the riparian and wetland ecosystems would certainly disappear, affecting permanently the livelihood of the people surrounding the delta.

In 1993, the delta and the Upper Gulf were declared a Biosphere Reserve by the Mexican government giving it a special status to the international community. This designation, sanctioned by the United Nations, is designed to protect world-class ecosystems while encouraging continued sustainable economic activity in surrounding buffer areas. Since then public interest groups on both sides of the border have joined in partnership for the restoration of the delta and Upper Gulf of California.

In addition, the delta was recognised as part of the Western Hemisphere Shorebird Reserve Network in 1992. In 1994, Mexico joined the U.S. and Canada in the North American Waterfowl Management Plan, and listed the delta as continentally important habitat. In 1996, delta wetlands were listed as a Ramsar site when Mexico became a party to the Convention on Wetlands (also known as the Ramsar Convention) and thereby agreed to place a high priority on wetland conservation.

Delta ecosystems harbour migratory shorebirds travelling along the Pacific Flyway; serve as a breeding ground for marine species in the Gulf of California; provide habitat for a number of endangered species; improve the quality of water that flows in from various sources and out to the Gulf; deliver a steady flow of freshwater to near-shore marine (brackish) environments in the Gulf, improving breeding and nursery grounds for the endangered vaquita; and produce important vegetation to indigenous peoples. In addition to these environmental services, the delta historically has been a source of income for surrounding communities, supporting lucrative fisheries and ecotourism activities.

The Colorado River delta is clearly an international water system that is threatened by anthropogenic activities by both the U.S. and Mexico. Given the intertwined diverse issues and complexities that have all contributed to the environmental degradation of the Colorado River delta, as well as the interventions that have been initiated in order to address and mitigate the environmental degradation, the Colorado River delta stands out as prime choice for the Causal chain and Policy options analysis.

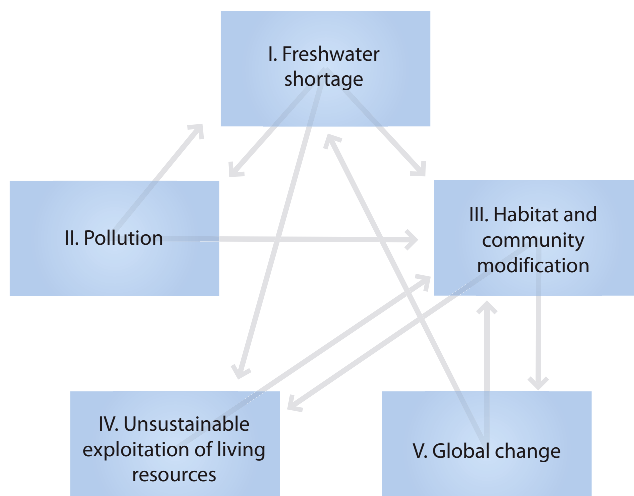

Figure 16 Linkages between the GIWA concerns.

Causal chain analysis

Arias, E., Becerra, M., Muñoz, C. and J. Saínz

This section aims to identify the root causes of the environmental and socio-economic impacts resulting from those issues and concerns that were prioritised during the assessment, so that appropriate policy interventions can be developed and focused where they will yield the greatest benefits for the region. In order to achieve this aim, the analysis involves a step-by-step process that identifies the most important causal links between the environmental and socio-economic impacts, their immediate causes, the human activities and economic sectors responsible and, finally, the root causes that determine the behaviour of those sectors. The GIWA Causal chain analysis also recognises that, within each region, there is often enormous variation in capacity and great social, cultural, political and environmental diversity. In order to ensure that the final outcomes of the GIWA are viable options for future remediation, the Causal chain analyses of the GIWA adopt relatively simple and practical analytical models and focus on specific sites within the region. For further details, please refer to the chapter describing the GIWA methodology.

Socio-economic forces drove many of the changes made throughout the 20th century in the Colorado River Basin region. In the past, the economics of the Colorado River Basin were dominated by mining and agriculture, and social attitudes were highly influenced by the developments and decisions related to these industries. The hydroelectric demands of the southern California metropolitan areas and the agricultural demands of California, Arizona, and Mexico have been the fundamental forces driving Colorado River water storage and release policies since the construction of Hoover Dam in the 1930s. These demands are consistently present and will continue to grow.

As the U.S. western state's population and need for water have grown, the Colorado's water priorities have shifted from being predominantly concerned with agricultural interests to urban and industrial requirements. California consumes about 1/6 of the Colorado River's water by way of the Colorado River Aqueduct. Lake Mead presently provides water for all uses for Las Vegas, and the Central Arizona Project aqueduct provides water for irrigating agriculture and human consumption for the Phoenix Metro/Maricopa County.

In addition maquiladoras[1] have thrived in cities like Tijuana, Mexicali and San Luis Rio Colorado, all of which are dependent on Colorado River water. Maquiladoras have priority over water intended for urban uses, and with their high profits these industries can afford to pay for water (Calbreath 1998). Some industries have even bought water from treatment plants in the U.S., while others are trying to buy agricultural water rights from the Mexicali Valley (Coronado 1999). These events mark the beginning of a new period where agricultural activities are being replaced by industrial activities on the border.

The management of water resources in the Colorado River Basin is strongly influenced by the 1922 Colorado River Compact and the 1948 Upper Colorado River Basin Compact. With the exception of the Mexican Water Treaty of 1944, Mexico was practically left out of the water equation in the Colorado River Basin, and have very limited powers over the management of the Colorado's water resources.

Already under the present water-use scenario, the Colorado River Basin's water resources have been over-allocated. During the last five years, water demands of the lower Colorado River Basin states have increased from the "normal" year supply of 9.2 km^3 to more than 10.1 km^3. Considering that the estimated total demand in the Colorado River budget is of 24.5 km^3/year and the average flow of the River between 1930-1998 was of 17.5 km^3/year (USGS 2004a), it is clearly that the situation is out of balance. There is not enough discharge to maintain present and most importantly future demands, without even

[1]Maquiladoras are in-process assembly plants owned by transnational corporations; they operate primarily for the export market.

considering water rights to U.S. Native Americans and the minimum water requirements to maintain the Colorado River's ecosystems.

At the time the Hoover and Glen Canyon dams were being constructed the negative externalities[2] that they would create were not recognised. In the United States as in the rest of the world the purpose of the dams was to improve human quality of life by providing drinking water and to support economic growth by diverting water for power, navigation, flood control, and irrigation. Water, like most other natural resources, was viewed solely as a resource for humans. Economic evaluations did not incorporate the potential costs of environmental degradation and, in turn, the costs would be borne by producers and consumers (Kenyon College 2002).

Among all the users of the Colorado River, the Colorado River Delta has had to contend with the highest economical and ecological costs. The River's delta once covered over 8 000 km^2 of riparian-wetland habitat, which supported over 400 species of plants and animals (Lueck et al. 1999). A sizable freshwater flow reached the mouth at the Upper Gulf, which replenished the delta with silt and delivered nutrients to fish and other marine life. Now only 10% of the flow reaches the border, and is completely consumed by municipal, industrial, or agricultural users in Mexico.

The creation of wetlands and the recovery of riparian forests in the delta throughout the last 25 years however have brought attention to the region. Together with important local efforts to exert control over resources, international conservation interventions in the area offer some hope of slowing the loss of reliable freshwater resources to the Colorado River Delta.

The following causal chain analysis will be focused on modification of stream flow in the Colorado River Delta.

System description

Physical characteristics

The Delta extends from the Cahuilla Mountains south to the Gulf of California, and west from the edge of the Imperial and Mexicali Valleys to the Wellton-Mohawk Valley. The delta ecosystem is located downstream of Morelos Dam and encompasses a land area of roughly 600 km^2 along the border of the Mexican states of Baja California and Sonora. It is characterised by low precipitation (52 mm/year) and high evaporation rates (2 058 mm/year) (CILA 2000). The Hardy

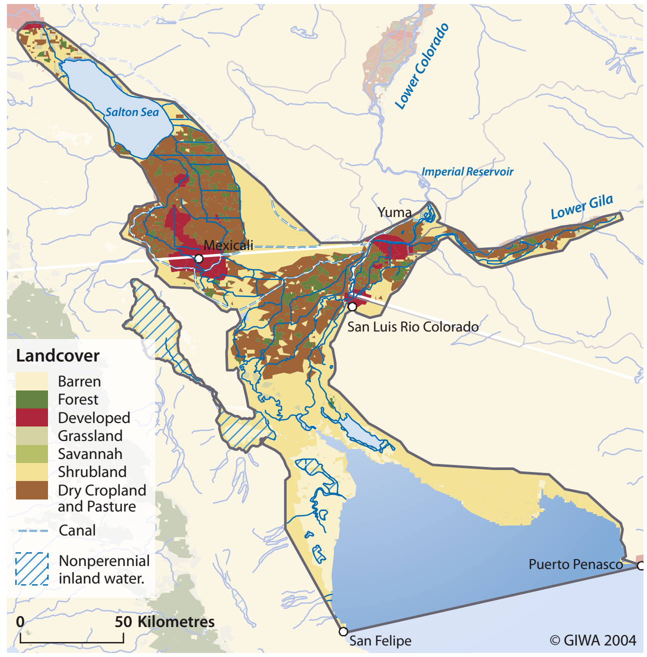

Figure 17 The Colorado River Delta.
(Source: based on USGS 2002b)

River wetlands are northwest of the levee on the right bank, and the Cienega de Santa Clara (4 200 ha) and El Indio (1 900 ha) and El Doctor (750 ha) wetlands are east of the levee on the left bank. The delta also commonly includes the intertidal zone along the final 19 km of the River, encompassing 440 ha (Lueck et al. 1999) (Figure 17)

Physiography and geology

Structurally the delta occupies the Salton Trough, a small section of the dynamic junction or 'crack' between the North American and Pacific tectonic plates. The kilometre-deep soils and sediments of the Coachella, Imperial and Mexicali valleys and the lower delta region represent materials ground out of the Rocky Mountains, the Grand Canyon, and elsewhere by the Colorado River and its tributaries and delivered into the tectonic crack. These are the delta deposits of the Colorado River. Their area is roughly 8 600 km^2, not including the underwater portion in the Gulf of California. The delta is not merely the few hundred square kilometres of plains along the lower river channel near the Gulf of California. The western boundary of the delta basin is marked by large normal faults that create an abrupt transition from the Sierra de Juarez of the Peninsular Ranges (a Mesozoic plutonic complex) to the basin floor. Three other mountain ranges of lesser importance extend into the basin. All of these ranges are located to the left or west of an imaginary dividing line up the centre of the Gulf of California.

[2] *Negative externalities are the costs of an action that accrue to someone other than the people directly involved in the action (Coase 1960).*

Hydrology

Hydrologically the region consists of two principal entities. One is the watershed of the Salton Sea, a terminal saline lake that receives inflows from an area that extends from Mount San Gorgonio in the north to the Mexicali valley in the south. The other is the watershed comprised of the southern, exclusively Mexican part of the delta and adjacent uplands and mountains. What little surface water flows there are in this region travel mostly via old channels of the Colorado to the Gulf of California. A third but much smaller watershed is that containing the terminal saline lake Laguna Macuata (Laguna Salada) and bounded by the Sierra de los Cocopah and the Sierra de Juarez.

Socio-economic characteristics

Population growth

The population growth in the Colorado River Delta region is shown in Table 30. On the eastern end of the California and Baja California border, Mexicali is a great urban area, but has numerous small populations dispersed throughout the fertile Mexicali Valley agricultural area. Across the border, the Imperial Valley is characterised by a number of rapidly growing communities, including the border town of Calexico (27 100), Imperial (7 600), Brawley (22 100), Holtville (5 600), and the centre of the county government, El Centro (37 800) (U.S. Census Bureau 2000).

Table 30 Population growth in the Colorado River Delta region.

District	1990	2000
Lower Coachella Valley	84 140	126 180
Imperial County	110 750	142 360
Mexicali	601 940	764 600
San Luis Rio Colorado	111 510	148 690
Yuma County	78 800	160 030
Total	875 630	1 341 860

(Sources: U.S. Census Bureau 2000, INEGI 2001)

The Yuma and San Luis Rio Colorado counties have experienced tremendous population growth associated with industrial development in the area, which has resulted in an increasing number and intensity of environmental problems related to wastewater pollution (Gerber et al 2002).

Economics

Imperial County is one of the poorest counties in the state of California. Contrary to what is probably common belief, its relative poverty cannot be attributed to agriculture and its large number of seasonal agricultural workers. Agriculture, taken as a whole and combining both farm income and farm worker income, actually generates above average incomes on a per capita basis. Since 1985, county employment growth has remained above the state level, but not by a sufficient margin to reduce the unemployment rate or to prevent a further divergence between county and state incomes.

During the last 30 years in Mexicali, the level of employment from agriculture, which had been the main employer, was reduced from 35.7% in 1969 to only 11.9% in 2000. Industrial employment, which includes mining, manufacturing, construction and utilities, increased its share from 22.3% to 35.0%, thanks largely to a rise in the maquiladora industry from 1980 to 2000. The trade and services sector however provided most of the employment opportunities, rising from 42.1% in 1969 to 53.1% in 2000.

Real wages during the last 30 years in Mexicali have behaved erratically. Daily minimum wages rose in dollar terms from 1970 to 1980, only to fall in 1990. The changes in minimum wages can be attributed to Mexico's economic instability during this period, which included high rates of inflation and devaluation.

The annual agricultural output of Yuma County reached 693 million USD in 1998 (Gerber et al. 2002). Just as the agricultural output of Yuma County dwarfs the production of farms in San Luis Rio Colorado, the manufacturing output of San Luis Rio Colorado surpasses that of Yuma by a wide margin. In neighbouring San Luis Rio Colorado, explosive growth in the manufacturing sector has far outpaced the growth of agriculture in recent years. Nevertheless, agricultural production still represents an important component of the economic output of the municipalities of both San Luis Rio Colorado and Mexicali (Gerber et al. 2002).

Key players

Agriculture

Major agricultural users of the Colorado River water are Coachella Valley Water District, Palo Verde Irrigation District, Imperial Irrigation District, Yuma Project (Reservation Division), and the Mexicali and San Luis Valleys.

In 1931 the U.S. Secretary of Interior asked California parties using Colorado River water draw up a priority agreement. Because agricultural users had been the first users and were continuing consumers, they were given first priorities to the water. The agreement is known as the Seven Party Water Agreement because of the participants: Palo Verde Irrigation District, Imperial Irrigation District, Coachella Valley Water

District, Metropolitan Water District of Southern California, City of San Diego, City of Los Angeles and the County of San Diego.

Coachella Valley Water District

The Coachella Valley Water District (CVWD) was formed in January 1918 under the state water code provisions of the County Water District Act. Nearly 259 008 ha are within the district boundaries. Most of this land is in Riverside County, but the district also extends into Imperial and San Diego counties. The district delivers approximately 0.345 km^3 of Colorado River water to Coachella Valley farms annually. The district is involved in six water-related fields of service: irrigation water, domestic water, stormwater protection, agricultural drainage, wastewater reclamation and water conservation. Recreation and generation of energy have become by-products of some of these services.

Imperial Irrigation District

The Imperial Irrigation District (IID), a community-owned utility, provides irrigation water and electric power to the lower southeastern portion of California's desert. IID interacts with many related water and power associations as well as provides many community services. The Imperial Irrigation District's canal and drainage system serves in excess of 202 350 ha of irrigated farm land within its district boundary. The Imperial Valley's region has an agriculture-based economy that produces nearly 1 billion USD in crops annually and provides over 1 000 jobs in the Imperial and Coachella Valleys (IID 2000).

Yuma Project

The Yuma Project provides water to irrigate 27 556 ha in the vicinity of the towns of Yuma, Somerton, and Gadsden in Arizona, and Bard and Winterhaven in California. The project is divided into the Reservation Division, which consists of 5 939 ha in California, and the Valley Division, which consists of 21 617 ha in Arizona. The Reservation Division is further subdivided into the 2 881 ha Bard Unit and the 3 057 ha Indian Unit. The original features of the project include Laguna Dam on the Colorado River, the Boundary Pumping Plant, one power plant, and a system of canals, laterals, and drains. Laguna Dam has not been used as a diversion structure since 1948.

Wellton-Mohawk Irrigation and Drainage District

The Wellton-Mohawk Irrigation and Drainage District (WMIDD) in Wellton, Arizona provides irrigation water, power, drainage and flood protection for the residents and lands in the Wellton-Mohawk Valley. WMIDD is part of the Gila Project authorised by U.S. Congress in 1947 to be built by the Bureau of Reclamation. The project was completed and transferred to WMIDD in 1951. Located along the Gila River in southwestern Arizona, approximately 48 km east of Yuma, operates and maintains the infrastructure necessary to provide Colorado River water to irrigate 25 293 ha of prime agricultural land. The fertile agricultural land is located along both sides of the Gila River for a distance of about 96 km.

Palo Verde Irrigation District

The Palo Verde Irrigation District (PVID) is a privately developed district located in Riverside and Imperial Counties, California. Water for irrigation is diverted from the Colorado River at the Palo Verde Diversion Dam and is conveyed through 407 km of main canals and laterals to serve approximately 36 423 ha of cultivated land. The irrigation return flows are collected in a 240 km drainage system and returned to the Colorado River.

Mexicali Irrigation District 14 (Distrito de Riego 14)

Mexicali Irrigation District 14 accounts a total water volume (including groundwater) of 2.75 km^3 per year. Water is distributed from Morelos Dam, through a complex system and channels and levees that provide water to the agricultural lands in Mexicali and San Luis. The Mexicali Irrigation District system serves in excess of 207 965 ha under cultivation each year (181 318 ha Mexicali and 26 647 San Luis).

Urban

Metropolitan Water District of southern California (MWD)

The Metropolitan Water District (MWD) of southern California is a consortium of 26 cities and water districts that provides drinking water to nearly 18 million people in parts of Los Angeles, Orange, San Diego, Riverside, San Bernardino and Ventura counties. MWD currently delivers an average of 6.4 million m^3 of water per day to a 13 468 km^2 service area.

Through the State Water Project it imports approximately half of all the water used from the Colorado River to northern California. The water is distributed wholesale to 27 members of agencies and more than 140 sub-agencies that delivers it to homes, business, and a few farms in the MWD's 13 468 km^2 service area (MWD 2002).

International agencies and actors

International Boundary and Water Commission

Since the International Boundary and Water Commission (IBWC) has authority to operate and invest capital on both sides of the border, the agency is often involved with domestic agencies dealing with transboundary sanitation issues. IBWC has limited its activities on border environmental matters to sewage related issues and water quality concerns. A variety of programmes and treaties have been implemented over the past 50 years to address border issues, but none have dealt specifically with the delta region. The Border XXI Program and North

American Free Trade Agreement are two examples of major bi-national agreements that include environmental provisions, but neither has the authority to allocate more Colorado River water for the delta.

National, Federal and State agencies

Many agencies of both federal governments are active in the border region, but in recent years the U.S. Environmental Protection Agency (EPA) and Mexico's Department of Environment and Natural Resources (SEMARNAT, Secretaría del Medio Ambiente y Recursos Naturales) have taken the lead for their respective country on border environmental issues.

U.S. federal agencies have duties that involve border environmental issues, including the Department of Commerce, the Department of the Interior, the Department of Housing and Urban Development, the Attorney General, the Department of the Treasury, the Department of Defence, the Department of Health and Human Services, the Department of Energy, and the Department of Agriculture.

On the Mexican side, entities such as the National Water Commission, the Secretariat of Health, the Secretariat of Agriculture, the Secretariat of Energy, and the Secretariat of the Treasury are all involved in some way with border environmental issues.

Water transfers

In 1963 the Coachella Valley Water District (CVW) and Desert Water Agency (DWA) entered into contracts with the state for entitlements to state project water. To avoid the estimated 150 million USD cost of constructing an aqueduct to bring state project water directly to the Coachella Valley, CVWD and DWA entered into an exchange agreement with the Metropolitan Water District of Southern California (MWD). MWD's Colorado River Aqueduct crosses Coachella Valley to carry water to serve MWD's 26 agencies along the southern California coast. MWD also is the major State Water Project contractor.

In April 1998, the IID and the San Diego County Water Authority signed a historic water transfer agreement. Due to this agreement, disputes have arisen between Coachella Valley Water District and the IID. The dispute has been long standing but has come to the forefront as the result of IID's proposed transfer of Colorado River water to the San Diego County Water Authority and Imperial Irrigation District over Colorado River water

Irrigation modules in Mexico

A new form of water and land management was created with the National Water Law in 1992 and the National Water Law Regulation in 1994. River Basin Councils (Consejos de Cuenca) began to be formed at the national level starting in 1992. The objective was to create irrigation districts with 5.8 million ha to be administered by users. The National Water Commission (CNA) gives administrative responsibility to users of irrigation districts because the districts were too expensive to manage.

An irrigation module is legally constituted as a civil association of agricultural growers. They give their water and land rights to managers of the association who administers the available resources for their partners benefit. Today, the Mexicali Valley has 22 irrigation modules. In Mexico, water rights are assigned directly to each producer.

Agricultural water use efficiency

Of the total water available in the valleys, most of it is used for agriculture. Some 90% of the water in Mexicali and 98% of the water in the Imperial Valley is used for agricultural purposes. Unfortunately, efficiency of water use in both cases is very low; only 50% in Mexicali and 55% in Imperial Valley (Roman & Ramirez 2003). In spite of high-tech agricultural developments in the Imperial Valley, agricultural use of water is the main cause of increasing soil salinity. Sprinkler irrigation systems are the most-often recommended solutions, however in most cases; these systems are used only in the first stage of cultivation. After that, gravity watering is used in an open furrow mode.

In the Mexicali Valley, gravity irrigation systems are used most often despite the variety of irrigation systems available. Only vegetable cultivation uses sprinkler and drip irrigation systems, and they do so over a minimal surface area. In both valleys the cost of water is lower than the other costs of the productive process, including seeds, fertilisers, machinery, and equipment. Cost use, and value of water differ significantly across the border (Table 31).

Table 31 Cost, use and value of water in the Imperial and Mexicali Valleys.

	Cost (USD/m^3)	Cultivated land (ha)	Water need (km^3)	Revenues (million USD)	Production coefficient (USD/m^3)
Imperial Valley	0.01	202 500	3.07	1 400	0.45
Mexicali Valley	0.01	208 000	2.55	4.25	0.16

(Source: Roman & Ramirez 2003)

Water in the in the Imperial Valley is priced at 0.01 USD per m^3. In Mexicali, water is sold by 24-hour rates. Farmers pay 6.35 MXN for every litre per second delivered during 24 hours, a total of 86.4 m^3 per day. The cost of this water translates into 0.007 USD per m^3. When comparing the cost of water to the revenues generated, it is clear that the water appreciates substantially in value based on its rate of return. Water

Box 2 Recently approved reforms to the Mexican Water Law.

On April 24 2003 the Mexican Congress approved important reforms to the National Water Law (NWL) (the reforms were approved on April 29, when the Chamber of Deputies voted the reforms previously proposed and approved by the Senate on April 24). These changes will improve the institutional framework of Mexico's existing water market and may lead to the provision of water toward environmental purposes (Comisión de Recursos Hidráulicos 2003). Mexican authorities have recognised that the main problem of water distribution in Mexico is institutional more than technical or geographic.

Under the previous water law National Water Commission (CNA) had most of the responsibilities in setting the national water policy. State and local governments and even regional representatives of CNA were unable to design specific policies to improve the efficiency of water use and management according to the specific needs, characteristics and resources of each region. Local proposals were required to go through a time-consuming approval process of central authorities, leaving state and local governments with just a marginal role. During the 1990s the federal government tried to decentralise CNA so states and local governments could manage water resources and find innovative solutions to water scarcity. However, opposition from CNA and farmers blocked the effort.

In 2000, a new federal administration identified that a more decentralised system could be an effective strategy to reduce water inefficiencies such as leaks, illegal diversions, and avoidance of payment in urban areas (CNA 2001). Under the new water law, CNA has greater autonomy to coordinate national policy while its regional representatives, renamed Regional Water Basin Organisations, are now the ones in charge of distributing, monitoring and charging for water in each state. State and local governments can also enter into new agreements with the federal government to administer the revenues from water fees coming from their own jurisdictions (Comisión de Recursos Hidráulicos 2003).

The recently approved water law establishes new rules to simplify the transfer of water rights and defines key terms and concepts that were previously subject to misinterpretations. Farmers and industries will receive incentives to implement technological improvements to reduce water consumption (CNA 2001). Moreover, the law guarantees farmers that they will continue to receive the same allocation of water they are currently receiving even if they reduce their overall consumption (Comisión de Recursos Hidráulicos 2003). With this guarantee, farmers will hopefully be motivated to reduce their total consumption of water and sell or lease their surpluses without the threat of losing their original allocation from CNA.

The new legal framework allows the President of Mexico to declare as a "disaster zone" a specific region where an ecosystem is threatened by natural or human modifications. In this case, the federal government would have special powers (e.g. condemnation, special funds) to solve the problem. More importantly, using water for environmental purposes will be considered a "beneficial use" of water. Following domestic and urban use of water, which has the highest priority, fisheries and environment, are the second in line for water allocations (Comisión de Recursos Hidráulicos 2003). This represents a fundamental reordering of beneficial use priorities.

profitability in the Imperial Valley is 45 times the cost of water because a farmer is able to generate 0.45 USD for every 0.01 USD spent per m^3. Although less extreme than in the Imperial Valley, water profitability in Mexicali is also high at 22 times the cost of water. Mexicali farmers generate revenues of 0.16 USD for every 0.007 USD spent per m^3 of water. Thus the ratio of water productivity of Imperial County to Mexicali is 0.45 USD to 0.16 USD or 2.8:1 for each cubic metre (Roman & Ramirez 2003). Under these circumstances, it is clear that agricultural water use in the region, when compared with domestic and industrial uses, has an extremely low index of economic productivity.

Subsidies

United States

The Bureau of Reclamation supplies water to agricultural water districts with which it has long-term contracts. The contracts specify subsidised prices and fixed water allotments. The Bureau determines water prices based on a complicated formula for allocating the costs of building and financing a water project among the various groups of users. In so doing, the Bureau must determine both the percentage of the costs attributable to each use and then, given the allocation of the total costs, the actual amount it will charge each user group. Both calculations tend to be highly favourable to agriculture (Weinberg 1997).

For multipurpose projects; those whose purposes may include flood control, recreation, hydropower production, and municipal and industrial uses in addition to agriculture, the Reclamation Projects Act of 1939 directs the Secretary of the Interior to allocate costs to each of the uses based on the proportion of the benefits each use receives from the project. However, it is rarely clear exactly what portion of a project's costs or benefits is attributable to a given use, and the ultimate calculation is somewhat subjective (Weinberg 1997).

Thus, even if agriculture receives 90% of the water developed by that project, its share of the costs may be much smaller. Project costs associated with public purposes are not allocated to any user group; the government pays the costs. Such uses include flood control, recreation, fish and wildlife, and Native American uses.

The formula for allocating the costs of financing construction also benefits agriculture. The government pays the interest charges on the portion of costs allocated to irrigation, but electricity users and urban water users must pay interest charges on their portion of the cost of constructing the project. In addition, all users benefit from being able to spread repayment over a long period. The terms of that financing typically allow 40 years to repay the project's costs, and they delay the start of the repayment period up to 10 years from the date the project is completed. For farmers, that is analogous to a 50-year interest-free loan for building irrigation projects (Weinberg 1997).

Finally, in addition to being relieved of the obligation to pay interest charges, farmers may be obligated to reimburse the federal government for only a portion of their share of a project's construction costs. If the Bureau determines that the portion of costs allocated to farmers will result in a price that exceeds the farmers' ability to pay, that is, the amount farmers can pay and still realise a minimal profit, the repayment obligation is reduced to the amount the Bureau calculates that farmers can pay. Electric power users must pay the difference between the amount of project costs allocated to agricultural uses and the amount that agriculture will pay (based on the reduced repayment obligation) (Wahl 1989).

Substantial federal subsidies for irrigation-related construction costs arose from that combination of pricing policies. The present value of federal outlays made between 1902 and 1986 for such projects was 22 billion to 23 billion USD (in 1986 dollars) (Wahl 1989). The present value of the money repaid by irrigators over that same period was 2 billion USD. The repayment figure may ultimately increase by another 1 billion USD, based on existing contracts. Thus, the federal government's contribution to the cost of constructing and financing irrigation projects amounts to about 85% to 90% of the total cost allocated to irrigation.

Mexico

The four main types of social assistance programmes currently used by the Mexico government include food subsidy programmes, generating programmes, credit programmes, cash transfer programmes and electrical subsidies.

Agriculture in this part of the region mainly employs cash and electrical subsidies. The Program for Direct Assistance in Agriculture (PROCAMPO) is a cash transfer programme that the federal government confers through the Secretariat of Agriculture, Livestock, Rural development, Fisheries and Food (SAGARPA). The primary objective of cash transfer programmes like PROCAMPO is to raise income (SAGARPA 1998). The programme consists of cash payments to farmers based on their historical production; to receive payments, farmers must farm the land, or put it into an environmental reserve. Transfers are on a per-hectare basis, decoupled from current land use, and fixed across the whole country. PROCAMPO payments are about 85 USD per ha, and were 128 million USD in 2001 covering and average of 14 million ha per year (OECD 2002).

In accordance to the Diario Oficial de la Federacion (DOF 2003), the agreement over the modification of electrical water rates establishes two types of electrical tariffs (Tarifa 9-CU and Tarifa 9-N) for pumping water for agricultural uses in low and medium tension. It has been estimated that the real price per kWh consumption in electrical costs for pumping water is around 1.15 USD. Under present applicable rates price per kWh is in 0.15 USD (Table 32), although tariffs are established in two-hour rate periods (diurnal and nocturnal) varying in costs. The tariff establishes two hour rate periods applicable from Monday to Sunday.

Table 32 Electrical costs for pumping water for agricultural uses.

Year	Diurnal time (USD/kWh)	Nocturnal time (USD/kWh)
2003	0.15	0.30
2004	0.16	0.32
2005	0.17	0.33
2006	0.18	0.34

(Source: DOF 2003)

Causal chain analysis

Immediate causes

Water use in the region over the last 50 years has significantly reduced the flows of water in the Colorado River. Increased diversion, reduced peak flows and changes in return flow were identified as the immediate causes for the modification of stream flow (Table 33).

Increased diversion

The hydrology of the Colorado River has been altered through a system of dams and diversions (Table 34) that deliver water for agriculture, urban use and hydroelectric power. Increased diversions by the various states for inter-basin water transfers, urbanisation, and agriculture have all diminished the supply of water to the delta. The network of reservoirs supply cities including Phoenix, Salt Lake City, Denver, Albuquerque, San Diego, Rock Springs, Las Vegas, Los Angeles and many others, which are all experiencing rapid growth (Table 35).

Reduced peak flows

Prior to the construction of Glen Canyon Dam, between 4.9 and 7.4 km^3 of Colorado River water still inundated Mexico's wetlands

Table 33 Freshwater shortage in the Colorado River Delta: percentage contribution of issues and immediate causes of the impacts.

Issue	%	Immediate cause	%
Modification of stream flow	70	Increased diversion	70
		Reduced peak flows	20
		Changes in return flow	10
Pollution of existing supplies	15	Agricultural run-off	70
		Evaporation induced concentration	30
Changes in the water table	15	Excessive pumping	40
		Reduced recharge	60

Table 34 Major dams in the Lower Colorado Basin and Mexico.

Dam	River	Country	Reservoir capacity (km^3)	Elevation (m above sea level)	Operation date
Morelos	Colorado	Mexico	Diverter	33	1950
Imperial	Colorado	U.S.	Diverter	55	1938
Parker	Colorado	U.S.	0.80	138	1938
Davis	Colorado	U.S.	2.24	197	1952
Hoover	Colorado	U.S.	35.20	372	1935
Glen Canyon	Colorado	U.S.	34.54	1 131	1963
Painted Rock	Colorado	U.S.	5.96	212	1959
Roosevelt	Gila	U.S.	1.71	651	1911
Total			80.45		

(Source: CNA 1999)

Table 35 Annual water use in the Lower Colorado Basin 1990-1996.

State	Apportionment (km³)	Water use (km³)						
		1990	1991	1992	1993	1994	1995	1996
Arizona	3.45	2.78	2.29	2.35	2.77	2.65	2.73	3.33
California	5.43	6.43	6.17	5.60	5.96	6.45	6.07	6.55
Nevada	0.370	0.219	0.222	.219	0.251	0.281	0.267	0.307
Mexico	1.85	2.02	2.04	2.07	6.48	2.03	2.26	
Unmeasured returns[1]		0.287	0.263	0.249	0.272	0.313	0.349	0.328

Notes: [1]Estimates of unmeasured return flows are for the Colorado River diversions portions of Las Vegas Wash (Nevada) surface water discharge of Lake Mead, as found in decree accounting. Total unmeasured return flows in 1991-1993 for Arizona and California are estimated to be 0.246 km³ and were proportioned on the basis of irrigated agriculture diversions.
(Source: Harkins 1997)

in a normal water year. The peak flow rate before its completion would normally be around 2 410 m³/s for the month of June (Collier et al. 1996). The peak flow rate through the Grand Canyon after construction of the dam was reduced to 1 420 m³/s on rare occasions and is normally around 850 m³/s (USGS 2004a). Today, flows only reach the delta in very wet years. El Niño created a succession of these wet years between 1983-1987, allowing the reinundation of the delta and floodplains, dispersing tree and plant seeds, and submerging land for the first time in nearly two decades (Figure 18).

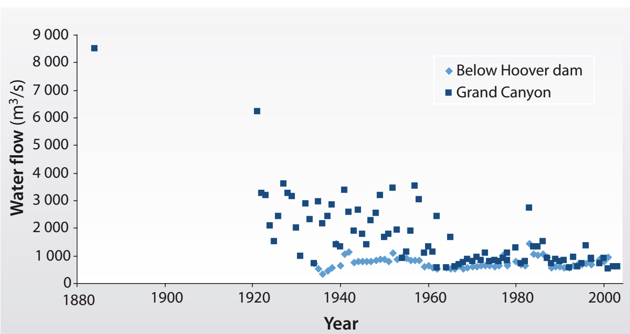

Figure 18 Peak flows of the Colorado River near Grand Canyon.
(Source: USGS 2004b)

The peak flows of the Colorado River at Lee's Ferry typically occur in May or June and have a broadly based shape. Statistical analysis revealed that the 100-year peak flows are about 4 390 m³/s, the 20-year peak flows are about 3 540 m³/s, and the average peak flows are about 1 840 m³/s. This means that the river bypass tunnels probably could pass all but about 10% of the flows in all years. Only years such as 1952, 1957, 1983, and 1984 would there be more water than the tunnels could pass. In those cases, there would be some filling (3 to 6 m) of the reservoir, creating some head on the tunnel resulting in river flows of about 3 400 to 3 680 m³/s.

Changes in return flows

The extensive use of the Colorado River water has led to a considerable reduction in return flows to the river and provoked consternation from downstream users dependent on these flows. Since 1970, augmentation plans have been required to replace water withdrawn by wells to satisfy senior, downstream water rights holders (Mumme 1988). Augmentation replaces the water extracted by irrigation wells.

Substantial quantities of water diverted from the lower Colorado River in the Yuma area, Arizona and California, return to a reach of the river as groundwater flow. The average annual return flow for 1975-1978 was estimated to be 54.2 km³ from lands on the Arizona side of the river and 46.8 km³ from lands on the Californian side (Loeltz & Leake 1983). At Parker Valley, Arizona the annual return flow that discharged directly to the Colorado River in 1981 resulted in an estimate of 19 km³ of groundwater (Leake 1984).

Presently all return flows in the Lower Colorado River are mainly wastewater and agricultural run-offs. From 1990-1996 return flows have accounted to be higher than the apportionment given to the State of Nevada in the Lower Colorado River (Table 35). Eventually these return flows have been important sources of water to the delta, the Salton Sea and the aquifers of the region, although these changes have had localised negative effects on the water quality of the River (García-Hernández 2001).

Sector activities

Freshwater loss around the Colorado River Delta region is driven primarily by the construction of dams, withdrawal of water for agricultural purposes and the heavy reliance of urban centers on natural resources, particularly of freshwater resources. Underlying these driving factors is the failure to resolve the problems surrounding the water administration of the region. Population growth in the delta region is attributed to the economical attractions of the region, considering that the southwestern part of the U.S. and northern portion of Mexico is the most dynamic region in the U.S.-Mexico frontier.

The sector activities that influenced the modification of stream flow in order of importance were:

1. Agriculture
2. Urbanisation
3. Industry
4. Energy production

However, the analysis is only focused on the agricultural sector, since from a historic point of view many of the changes made throughout the 19th century were influenced by agriculture, both in the U.S. and Mexico (Worster 1985).

Agriculture

In 1936, the Mexican president Cardenas stressed the need to develop the resources of Baja California. Central to this was the exploitation of water from the Colorado River. Finally, Cardenas wanted to increase the population in Baja California and construct highways and railways between the peninsula and central Mexico as a defence against American economic and political hegemony through the implementation of federal and local initiatives (Muñoz 1976). The unparalleled success of these objectives contributed to the rapid depletion of water resources in the Mexican Delta and the concomitant decline of ecological conditions in the region.

Extensive irrigation projects carried out in the 1940s and 1950s greatly expanded Mexico's cropland, especially in the north (Betanzos 1988). The government created areas of intensive irrigated agriculture by constructing storage dams across the Imperial and Mexicali Valleys by controlling the Lower Colorado River, and by tapping the regions aquifers. These water-control projects allowed Mexico and the U.S. to expand rapidly its total land area under cultivation. Between 1950 and 1965, the total area of irrigated land in Mexico more than doubled, from 1.5 million to 3.5 million ha (Betanzos 1988).

In an effort to resolve Mexico's long-standing conflict between promoting agricultural production for export and for domestic consumption, the government followed a dual strategy between 1940 and 1965; it promoted large-scale commercial agriculture while redistributing land to the rural poor (Hewitt de Alcantara 1978). Government policy favoured large producers because export agriculture provided foreign exchange needed to finance industrialisation. Extensive public investment in irrigation projects primarily benefited northern areas (Benítez 1978).

Root causes

Demographic

The root causes identified begin with the demographic aspects, which refer to migration policies and incentives carried out during the 1940s in the U.S. Western states and Mexicali. The 1940 to 1960 period marked the beginning of extensive spontaneous and planned immigration to the region. Offices of the agrarian reform agency actively promoted migration to the delta area (Table 36) (Gamboa 1990).

Table 36 Average annual population growth rates, Imperial Valley and Mexicali, 1940-1995.

	Annual growth rate (%)					
	1940-1950	**1950-1960**	**1960-1970**	**1970-1980**	**1980-1990**	**1990-1995**
Imperial Valley	0.53	1.36	0.31	2.2	1.78	5.09
Mexicali	10.85	8.51	3.49	2.57	1.66	2.94

(Source: U.S. Census Bureau 2000, INEGI 1995)

The two nationalistic economic revolutions that collided in the Colorado River Delta not only created agricultural strains on the water supply, but also encouraged large-scale immigration to the region. Viewed as an economic frontier by people of all classes throughout both nations, farmers, labourers, and their families descended on the region in a chaotic frenzy. Immigration was heaviest in the Mexican Delta, clearly reflecting the asymmetric politic-economic relationship between the two nations. With the decline of agribusiness growth in the region during the 1960s (Lorey 1999), the maquiladora factories renewed U.S. corporate and Mexican working-class interest in heading to the delta.

Presently two features characterise the local population dynamics in the Colorado River Delta: rapid population growth, due to high fertility rates and migration, and rapid turnover of the population. To date the annual population growth rate for the main cities is calculated at about 4%, implying that there are more inhabitants in the area, increasing the demand over water resources in the region.

Technological

Increased development in irrigation technology throughout the Colorado River Basin in the United States, as well as in the delta area, influenced Mexican efforts to develop the Mexicali Valley in the early 1930s (López-Zamora 1977). The construction and operation of the All American Canal and Boulder, Parker, and Imperial dams during the 1930s and 1940s boosted food production, but greatly disrupted the natural flow regimes of the Colorado River downstream. Instead of being controlled primarily by precipitation and natural run-off, the river was regulated by American dams upstream. Depending on the

Figure 19 Hoover Dam.
(Photo: Corbis)

needs of users and power companies throughout the American West, USBR engineers either increased or decreased releases from these dams (Dowd 1951).

Economic

Concerning economic aspects, the existence of historical agricultural subsidies and the lack of economic valuation of water encouraged its use. Agriculture in the U.S. and Mexico has received extensive support from state and federal agencies. The local agricultural cooperatives in Mexico have provided important assistance to producers , but still suffer from management and marketing problems. Through the 1970s, government policy in Mexico aimed for self-sufficiency in agricultural production (Aguirre-Avellaneda 1976). Under the recent liberalisation programme, much of the support for domestic agriculture has been reformed. The aim of current policy is to promote the competitiveness and productivity of the sector (Fritscher 1993). Until recently, staple crops were supported by guaranteed prices. This system has been replaced with the Program of Direct Rural Support or PROCAMPO programme, which was intended to cushion the impact of the removal of trade barriers and price subsidies. The stated purpose of the PROCAMPO programme is to induce more market-based decision-making among small farmers: they are expected to move from traditional crops to more profitable forms of land use (SAGARPA 1998).

Farmers not only receive subsidies in electricity in order to pump out groundwater (DOF 2003), but the use of water for agriculture is essentially free of charge (Oritiz et al. 1997). These two elements provide an incentive to overconsume water and they also create asymmetries in water transfers. The obstacles to local resource management and successful participation in markets are the result not only of legal arrangements, but also of institutional arrangements that foster poor access to markets, enforcement failures, corruption, and political manoeuvring. Economic instruments, such as charging for water, have not been implemented in the delta. This has encouraged the inefficient use of water.

The lack of real economic alternatives to using land for agriculture is equally important in shaping resource use. The political and economic marginalisation of the Colorado River Delta has made it difficult to improve local socio-economic conditions of the native population (Cucapá) or support resource use. Recent far-reaching changes in laws and policies that shape markets and land tenure may have important effects on the region in the long-term, but for the moment have limited influence on local resource use patterns.

Socio-cultural

Regarding socio-cultural aspects, agricultural development in the Lower Colorado was induced by the need to produce food and other agricultural products in semi-desert and desert zones. Through the years the idiosyncratic differences molded the institutions and laws in different ways between the two nations.

Legal

The Legal framework at both the national and international level is inappropriate for the current water use scenario and is inadequate in addressing freshwater shortage issues, due to a lack of effective legal instruments. The Law of the River has resulted in a very rigid system of water rights allocation in the U.S. and Mexico. Nearly every drop of water is accounted for in this allocation.

The Law of the River has two inherent problems. The 1922 Colorado River Compact, while successful in its time, is antiquated by today's standards and usage. The Compact and the 1944 Water Treaty allocates at least 18.5 km^3 from the River. However, when the Compact was signed in 1922, the annual flow of the River past Lee's Ferry was estimated at 22.2 km^3, based on flows from 1914-1923. Another study

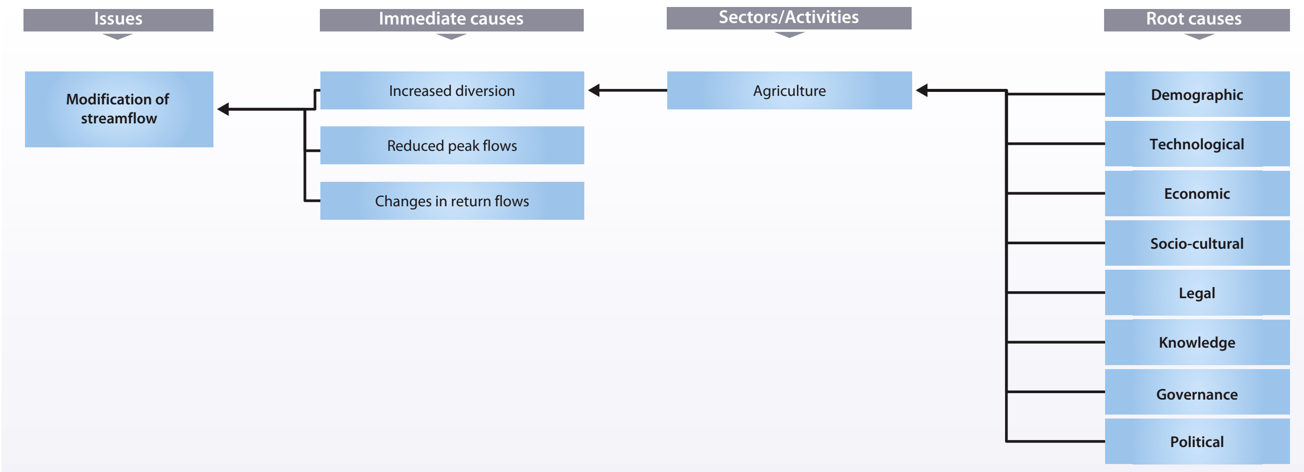

Figure 20 Causal chain diagram illustrating the causal links of Freshwater shortage in the Colorado River Delta.

based on 1930 to 1998 calculated average flows of 17.5 km^3, and flows over the past 400 years averaged only 15.2 km^3 (USGS 2004a). Thus, the River is over allocated by almost 30%.

Comprehensive reform in the management of the Colorado River is urgently needed. Getting California to live within its allotment, which it has regularly exceeded for decades, is the first step toward sustainable and equitable use of this vital international river.

Another problem with the Law of the River framework is that when the 1944 Water Treaty was signed, the delta ecosystem was not considered as a beneficial user of the water. Because the Law of the River stipulates, "use it or lose it", people are encouraged to overconsume the water. Article 3 of the Treaty outlines the following beneficial uses of water in order of preference (IBWC 1944):

- Domestic and municipal uses;
- Agriculture and stock rearing;
- Electric power;
- Other industrial uses;
- Navigation;
- Fishing and hunting;
- Any other beneficial use determined by IBWC.

Knowledge

There are considerable gaps in information, data, and knowledge about the quantity, quality and temporality of water flows needed to maintain the delta ecosystem. At the same time, the lack of information about the conditions of groundwater represents a problem in both countries (USBR 1995a). One aspect that concerns both countries in the decision making process is that studies and investigations are not ratified by the governments, which makes these reports unofficial and therefore discarded. On the other hand there are also restrictions to access official public information, although this improved after 2002 when the Mexican Federal Government approved the Law of Administrative Transparency and Access to Public Information (DOF 2002). The lack of public awareness of the necessities, benefits and opportunities from conserving the Colorado's River Delta can be attributed, in part, to these knowledge deficiencies.

Governance

The U.S. and Mexican governments continue to promote the overexploitation of water resources through the provision of subsidies for water use (e.g. PROCAMPO), rather than incentives to conserve water. It has been demonstrated that regular subsidies have not been effective in enabling efficient use of the resource. On the contrary, they have been counter-productive in terms of conservation, as they have created a situation where water essentially has no price in agriculture, allowing farmers to use as much water as they desire.

Another important aspect concerning governance is the inadequate consideration of environmental services, which can be conserved through a payment for environmental services.

Finally, the lack of efficiency occurs for several reasons: (i) lack of suitable resources assigned to public, state and federal institutions; (ii) economic power of some stakeholders; and (iii) low commitment from River Basin Councils to fulfil the recommendations that are discussed at their meetings.

Political

Ongoing disputes between the United States and Mexico over the allocation of Colorado River water have lasted for almost a century rendering it difficult for the two countries to agree on any amendments to the 1944 Treaty. Within Mexico and the U.S., farmers are a politically powerful lobby. In the past 40 years their interests have dominated the allocation of water to the detriment of the delta's ecosystem (Cortez & Whiteford 1996).

Presently about 80-90% of water is used by agriculture in both the United States and Mexico (Pontius 1997). Farmers use the water essentially free of charge (El caso del agua dulce en Mexico 2003). The only cost to farmers is that of pumping the water to their farmlands, which in the Mexican case is also highly subsidised (Tarifa 09 and Tarifa 09-cu) (DOF 2003). This has encouraged farmers to grow water intensive crops, such as alfalfa and asparagus in an arid climate.

Conclusions

It is very unlikely that any surplus water from the Colorado River is to be used for riparian restoration projects in the Colorado River Delta, due to the exceedingly high demand of water in the U.S. western states. Although the Colorado River Delta is maintained by the discharge of floodwaters and agricultural drain water from the United States to Mexico, it is known that even this source of water is to be questioned.

The U.S. Bureau of Reclamation has proposed new regulations and projects, including off stream storage of water and privatisation of the Wellton-Mohawk Irrigation District which are likely to reduce such flows, without considering the impact on the delta ecosystems (USBR 1998).

The Department of Interior, and the states of California, Nevada and Arizona have developed along the Colorado River from Lee's Ferry in Arizona to the southerly international boundary, a multispecies conservation programme, with the purpose to remediate some of the damage to the riparian zone in the United States portion of the River. Yet no official recognition is given to the delta ecosystems in Mexico.

Even if it were determined that more water should be given for the delta, state interests and the United States government may remain cautious about supplying more water to Mexico. "We don't have any jurisdiction over how Colorado River water is used once it crosses over the border into Mexico" said Robert Johnson, regional director for the Bureau's Lower Colorado Region (Newcom 1999). The question still remains, as to how to increase allocations to Mexico without revising the Law of the River, which is considered by many to be a major undertaking and one that could involve massive litigation.

Morrison et al. (1996) in their report "The Sustainable Use of Water in the Colorado River Basin" indicates that the Mexicali Valley is suffering from a groundwater overdraft of roughly 118 million m^3 per year. The overdraft could become even greater with the added lining of the All American Canal north of the border; a source of groundwater recharge for Mexico.

Seepage from the All American Canal has created a series of wetlands totalling over 6 200 ha along the U.S.-Mexico border. Over half of these are in Mexico, east of the portion of the canal that is proposed for lining, and will therefore be impacted by lack of further seepage. The Andrade Mesa Wetlands are extensive and provide high-quality bird habitat in an isolated part of the northern Colorado River Delta where replacement habitat is non-existent. The loss of this critical habitat should be considered in assessing the potential environmental impacts of the canal-lining project (Hinojosa-Huerta et al. 2003)

Mexico has a considerable interest in insuring that additional flows reach the delta. This has given rise to fears that increased flows to Mexico would be used to recharge groundwater overdraft or to irrigate fields in Mexico instead of as in stream flows for the environment. These concerns may be incorrect for a least two reasons. The first is that Mexico currently lacks the capacity to divert and store additional flows, and second a Minute would obligate Mexico, under international law, to release increased flows to the delta. The fact is that Mexico actively wants additional Colorado River water for the delta, not for other municipal or agricultural uses in the Mexicali region.

The Colorado River provides water for agriculture, municipal and industrial needs as well as electricity generation in the Lower Colorado Basin. Major issues such as water rights to Native Americans, ecological and urban water resources, as well as the question of how to allocate the shortage between actual flows and 21.5 km^3 in allocations, have not been addressed.

Policy options

Arias, E., Boone, A., Chia, D., Vargas, A., Gao, J., Becerra, M., Muñoz, C. and J. Saínz

This section aims to identify feasible policy options that target key components identified in the Causal chain analysis in order to minimise future impacts on the transboundary aquatic environment. Recommended policy options were identified through a pragmatic process that evaluated a wide range of potential policy options proposed by regional experts and key political actors according to a number of criteria that were appropriate for the institutional context, such as political and social acceptability, costs and benefits and capacity for implementation. The policy options presented in the report require additional detailed analysis that is beyond the scope of the GIWA and, as a consequence, they are not formal recommendations to governments but rather contributions to broader policy processes in the region.

This report recommends four options to secure at least a portion of the annual flow requirements for the delta ecosystem. The options have been categorised into short-term (less than 5 years), medium-term (5-10 years), and long-term (greater than 10 years) periods. The short-term option is to lease water rights from farmers in the Mexicali or San Luis Rio Colorado Valleys (District 14). Since existing Mexican laws and regulations allow for the lease and transfer of water rights for conservation purposes, this is the most expedient method to secure a guaranteed water supply for the delta.

The medium-term proposal is to buy or lease water rights in the United States and transfer the water to the delta. Since significant legal barriers (e.g. the 1944 U.S.-Mexico Treaty) exist to prevent the transfer of this water to Mexico, it may not be feasible to implement this option in the near-term. However, there are serious equity concerns regarding the exclusive purchase and leasing of water in Mexico, therefore the amendment of a Minute to the 1944 Water Treaty is recommended.

Finally, for the long-term, the implementation of water markets to increase the efficiencies of water use in Mexico is proposed, and the elimination of electricity subsidies to farmers in order to motivate them to use less water, thereby "freeing up" water potentially available for the delta. At the same time, farmers would benefit from these changes by being able to market their water savings. Deep-seated institutional and political obstacles may very likely challenge any attempt to push these options forward. Thus, a long-term horizon is an appropriate way to frame their potential implementation.

Any solution to secure a guaranteed flow of water for the delta must come from existing users in the United States and Mexico. This is due to the fact that the River is already over-allocated; there is simply no more water to allocate. However, getting this water will undoubtedly be challenging considering the fact that agricultural interests, the largest users of water, are powerful and politically well connected, as are municipal users. Moreover, since existing users are not likely to voluntarily give up water for the good of the delta, any non-voluntary effort must involve a reallocation of water under the auspices of the Law of the River, an effort that is almost certainly doomed to fail.

Moreover, it is strongly emphasised that any strategy to obtain a guaranteed source of water must be bi-national; that is, both countries should bear the ultimate responsibility of restoring the delta ecosystem. As eloquently stated by Glennon and Culp (2002):

"The historical context must inform any solution to the Delta problem. Mexico has seen one of its largest rivers, wealthiest agricultural districts, and most important fisheries dried up, or salted up, by U.S. development upstream. From a Mexican perspective, the Mexico-U.S. Water Treaty--negotiated during a period of U.S. dominance and relative Mexican weakness--was substantively unfair. In the intervening years, the U.S. has consistently denied responsibility for the harsh environmental,

Figure 21 Colorado River Delta and the Upper Gulf of California.
Irrigation and urban sprawl now prevent the River from reaching the Gulf, which can be seen in solid blue at the lower right hand corner of the image. (Photo: NASA)

social, and economic impacts to Mexico of its development policies on the Colorado…Of the 17.5 maf of Colorado River water that is allocated…the U.S. claims 16 maf--around 92 percent…To use only Mexico's apportionment to save what little is left of the Delta heaps insult upon injury. Equity requires that the burden of water needed for restoration be shared between the two countries."

Consistent with this perspective, options that can be implemented in both Mexico and the U.S. are proposed. Below each option is described and general steps to implement each option are further discussed.

Short-term policy options

Lease water rights in the Mexicali and San Luis Rio Colorado Valleys and transfer associated water to delta ecosystem

This option involves the leasing of water rights in District 14 as the primary mechanism in Mexico to secure a guaranteed annual water source for the delta. This option can be implemented immediately as existing Mexican laws currently allow water transfers for conservation purposes. Other mechanisms to secure water include permanently purchasing water rights or land with associated water rights. However, as explained below, at this point, the most expedient and economical option is to lease water rights since farmers are reportedly opposed to selling their land and by extension, their water rights. This section briefly describes the legal basis for leasing and transferring water rights and the steps that generally should be taken to implement this option.

Legal basis for leasing water rights

Essentially all the water available in District 14 is defined as national waters, falling under the jurisdiction of the Mexican Water Commission (Comisión Nacional de Aguas, CNA). The Mexican government first allocated water rights in this district in 1938 (Clark et al. 2001). These rights are tied to the land and allocated commensurate with the size of the parcel. In most cases, a water rights holder receives enough water to irrigate a 20 ha parcel. However, depending on the availability of water, this amount can vary from year to year (IBWC 1944).

In 1992, the Mexican government passed a National Water Law (NWL) to legalise the purchase or lease of water between private parties. Water rights may be converted from an agricultural use to other uses (e.g. ecological purposes) as long as CNA approves the change and law permits the new use. When approved, a water (or irrigation) right is converted into a concession title and is valid for a period of 5 to 50 years. The concession title must then be registered in the Public Registry of Water Rights, created by the NWL as a way of legally proving the existence and status of a title. As of May 2001, CNA has never been requested to approve the transfer of water for ecological purposes. However, Clark et al. (2001), and Carrillo (2002) report that CNA officials in Mexicali generally would approve such transfers assuming the requirements of all laws and regulations are fulfilled.

The Mexican National Water Commission

Mexico's National Water Law (NWL) serves as the basis for the management of national waters. The National Water Commission (CNA) is the federal agency designated to implement the policies of the NWL and develop associated regulations. To manage water allocations, CNA has divided water management districts into geographic modules. Each module is governed by a local government entity that is responsible for the management, operation, and maintenance of the module's water distribution canals. Each module submits its water order to CNA who then delivers the order to the external boundary of each module. The module employs zanjeros (ditch riders) who make the final delivery of water to individual parcels. In District 14, CNA allocates water rights based on the assignment of regional and national cropping patterns. Thus, if a farmer grows a more water-intensive crop, he receives a greater amount of water.

This system reportedly operates effectively while minimising illegal water diversions (Carrillo 2002). However, Clark et al. (2001) recommends: "If the CNA canal system and delivery ditches within the modules are to be used to deliver water to the Delta ecosystem, it is imperative that an advocate for delivery of the Delta water be an active participant in the governance of the participating module or modules".

Step 1: Inventory available water

Initially, it is recommend that an inventory of available water supplies for lease in District 14 should be conducted. The Sonoran Institute of Arizona is currently carrying out this task by focusing on those parcels that have not been under production for three to five years (Zamora-Arroyo pers. comm.). According to the Institute, if farmers do not use their land or water rights for agricultural purposes for four consecutive years, they may lose their water rights. Therefore, the above timeframe should provide a rough estimate of the total amount of water potentially available for lease.

Step 2: Lease water rights from willing farmers

After this inventory is available, individual farmers can then be approached to gauge their interest in leasing all or some of their water allotment. Alternatively, where appropriate, advertisements could be placed in newspapers or in the offices of CNA or modules. The price of water may be determined through three methods: (i) a standing offer; (ii) individually negotiated contracts; or (iii) through an auction (Pitt et al. 2002).

Carrillo (2002) surveyed farmers within and outside District 14 to assess their attitudes and willingness to lease their water rights or retire their land for delta conservation purposes. For this reason, the survey was limited to farmers owning land adjacent to the River or its levees; that is, land which is the most suitable for riparian or wetland restoration. The results of the survey indicated that 87% of the farmers surveyed with water rights are willing to lease them for purposes of maintaining and enhancing native riparian vegetation. Of 663 ha of irrigated land owned by these farmers, the water rights associated with about 214 ha could be available for leasing. This amount of water is approximately 2.14 km^3 and the cost to lease this water is between 54 and 271 USD/ha/year or approximately between 8 210 and 41 400 USD/m^3/year. Thus, using these figures, the cost to secure an annual flow of 39 million m^3 of water would range between 213 100 and 1 073 600 USD.

Purchasing water rights or land with water rights attached is another option to secure water for the delta. Based on preliminary estimates, the cost to permanently purchase water rights in District 14 is approximately 1 000 USD/ha or 152 000 USD/m^3 (Zamora-Arroyo pers. comm.). Thus, the total cost to purchase 39 million m^3 of water would be 3 950 700 USD. While a significantly greater upfront payment is necessary, purchasing water rights would be the most cost-effective approach as benefits can be permanently guaranteed. Compared to leasing water rights, one would break-even by purchasing water rights after approximately the fourth year of leasing (using the upper end of leasing costs). However, according to the survey by Carrillo (2002), almost all farmers contacted (96%) would be unwilling to sell their land "…because it is the only legacy they could leave to their children" (Carrillo 2002). With this in mind, high resistance to purchasing water rights may also be encountered assuming farmers wish to leave a legacy that involves the use of water. Nonetheless, because of it is more cost-effective than leasing water rights; this option should not be dismissed, as some farmers may be willing to sell their water rights.

Further steps

With adequate funding from the Global Environmental Facility (GEF), a NGO could implement a water rights leasing programme in Mexico. As discussed above, the Sonoran Institute is initiating such a programme by inventorying available agricultural water supplies in District 14. After leasing water rights, the NGO is expected to monitor the delivery of leased water to the delta through the local CNA office, the responsible entity for delivering water to the delta. As recommended by Clark et al. (2001), representatives of the NGO should also establish relationships with the leaders of the module(s) in which the water rights were leased (Clark et al. 2001). Considering the precedent-setting nature of such a programme, it is important that the NGO gain the trust of the leaders of the module and the community at large.

Unresolved concerns

Assuming the actual amount of water available for lease in District 14 is consistent with that which Carrillo (2002) identified (2 million m^3); this amount represents only 5% of the estimated 39 million m^3 in annual flow needs. In order to meet this need, the balance would have to be made up from U.S. or other sources. Nonetheless, even limited guaranteed flows to the delta could benefit existing riparian or wetland habitat during periods of drought (Carrillo 2002).

Although this report does not address the potential economic effects of this option, they should not be ignored. It is expected that farmers would participate in a water-leasing programme if they expect to receive greater economic benefits than those received from farming. Farmers with water rights that are currently not farming would likely be most interested in participating. However, to the extent that the programme offers a leasing price high enough to encourage farmers to stop farming, there could be adverse economic consequences.

Moreover, this option does not address the documented need for periodic flood flows in order to inundate the floodplain and produce responses in native riparian vegetation. Zamora et al. (2001) recommend that when surpluses arrive in the River, they be delivered as flood flows to the delta. The U.S. Department of Interior (Bureau of Reclamation) and the International Boundary and Water Commission (IBWC) would likely be the most appropriate entities capable of addressing this need. More specifically, new surplus criteria should be developed to allow environmental considerations to be taken into account when deciding how annual surplus flows are allocated.

The results of Carrillo's (2002) survey indicate that Mexican farmers realise the importance of in-stream flows and are willing to participate in water leasing or land retirement programmes that would provide these flows to the delta ecosystem. In addition to financial gain, farmers also understand that healthy riparian forests minimise the loss of farmland to erosion during flood events by providing stabilising riverbanks. Other farmers acknowledge that by converting their land to wetland or marsh habitat, they could, with expert advice, also explore other uses of their land such as small-scale aquaculture operations or ecotourism activities such as bird watching and camping (Carrillo 2002). This willingness holds much potential for a water leasing or land retirement programmes that could ultimately be expanded to a greater level with community, NGO, and government support and funding. At the same time, efforts to assist farmers in developing economically viable alternatives to farming should also be encouraged.

Sub-category: Grant subsidies to farmers in the U.S. and Mexico for implementing water conservation measures

In exchange for subsidies farmers could dedicate rights to water saved. This water could be diverted into the delta.

Mexico is experiencing a serious problem of water waste, especially in the agricultural sector. According to CNA (2001) 83% of the water in Mexico is dedicated to the agricultural sector. Of this, water loss fluctuates between 30% and 50%. One of the explanations for this water waste is the lack of resources to implement conservation measures. This is one of the reasons farmers get less water for their production activities, especially in areas where scarcity prevails. Implementing water conservation measures could help increase the quantity of water received in the agricultural sector, and thus farmers could divert water into the delta for conservation purposes.

Figure 22 Irrigation system, California, U.S.
(Photo: Corbis)

Potential for water conservation in the agricultural sector

According to Pontius (1997), water conservation is the most effective tool in demand management and often the cheapest source of new water supplies. Water conservation measures are one of the least expensive methods to provide water for growth and to assure an adequate supply for the future. Evidence suggests that there is much potential in the Lower Colorado River Basin (U.S. and Mexico) for effective water conservation in the agricultural sector. Farmers would also save money from reduced water pumping costs.

Payment of environmental services

PROCAMPO operates through direct payments to communities that participate in the conservation of the environment. That is not to say that every subsidy produce negative effects. Subsidies could be a good government option if they cover three criteria: (i) increase income levels of poor people (equity); (ii) do not distort the market (efficiency); and (iii) incentive environment protection. These three aspects could be covered under a scheme of Payment for Environmental Services (PES), where farmers get a payment if they follow the conservation practices stipulated in a contract. This programme has been used mainly to provide incentives for forest conservation, oriented to the production of environmental services such as improvement of water quality, and biodiversity conservation or carbon capture (SAGARPA 1998). Other subsidies of this kind would be payment in exchange of PES, where individuals voluntarily refrain from certain uses that impact the environment in his property.

The importance of technological measures

It is very important to balance available water resources between users, especially if the demand for water is increasing. The technological methods that can be used to improve the conservation of water in the agricultural sector are as follow: better maintenance of existing irrigation systems, information management techniques, altered tillage and soil management, or changes in cropping patterns (e.g. reduce acreage, switch to less water intensive crops).

The structural methods for the same purpose are: replacing open ditches with underground pipe, lining ditches, use of gated pipe, fitting gated pipe systems with surge-flow devices, conversion from furrow to sprinkler irrigation or drip irrigation, upgrading existing sprinkler systems, and installation of tail water recovery systems.

Morrison et al. (1996) suggested that approximately 1.73 km^3 of water savings could be achieved by the agricultural sector by investment in irrigation efficiency and retiring marginal land. The California State Water Resources Control Board found that the Imperial Irrigation District could save up to 0.49 km^3/year with irrigation efficiency improvements.

Water transfers

Water transfers of this kind are becoming more common in California including a proposed agreement by the San Diego County Water Authority and Imperial Irrigation District to "free up" 620 million m^3 of water. However, in order to transfer water to Mexico, a Minute to the 1944 Mexico- US Treaty would have to be executed.

Political feasibility

In order for the farmers to dedicate water to the delta and not keep the water for their own use, they have to have the right incentives. As previously discussed, the leasing of water rights is an incentive to save water. For example, the IBWC (2003) through Minute 309, has given approval for the technification project of Delicias Irrigation District in Mexico, which is presently under way to transfer volumes of water saved (396 million m^3/year) that will eventually be incorporated waters down of the Rio Conchos to Delicias Irrigation District and afterwards sent to the Rio Bravo in the U.S. (COCEF 2002).

Medium-term policy options

Purchase or lease water rights in the United States in order to use the water for ecological purposes in the Colorado River Delta

Water transfers, or the purchase or lease of water, are an important and successful tool to redistribute water between geographic areas or between user groups. Water transfers such as those between the Central Arizona Project and other southwestern states have allowed for the redistribution of water that would have otherwise not been feasible because of the rigidity of the Law of the River. The purchase or lease of water rights in the U.S. may provide a significant portion of the annual flow needs of the delta, although there exists legal challenges to transfer the water between the Lower and Upper River basins and between the U.S. and Mexico. Because agricultural production in this region is of low value and uses water inefficiently, the purchase or lease of water represents an economically feasible way to ensure water for the delta.

Legal basis and needed changes for the purchase or lease of water in the U.S.

Existing law establishes a strong foundation for this policy option. Under current U.S. law, water rights may be purchased or leased without buying the property to which the rights are assigned. However, property owners who have weak or junior water rights (those which have legal standing after water allocation to senior rights holders have been fulfilled) may be at a disadvantage to those with more secure rights and may receive a lower price for their water.

Despite this foundation, there are legal challenges to the transfer of water between the Upper and Lower Basin states and between the U.S. and Mexico. The Colorado River Compact of 1922 allocates 9.25 km^3 of water to both the Upper (Colorado, Wyoming, Utah, and New Mexico) and Lower Basin states (Nevada, Arizona and California). If water is to be transferred from the Upper Basin for restoration of the delta, the Compact may need to be amended in order to overcome political opposition from Lower Basin states.

Lease or purchase rights from willing farmers

Agricultural production in the Colorado River Basin is often of low value and consists of water intensive crops such as wheat and upland cotton which return approximately 35 USD and 40 USD per million m^3 of water, respectively (Pitt et al. 2002). A recent report has estimated the cost of leasing water in the Wellton-Mohawk Irrigation and Drainage District in Arizona as 53 USD per million m^3 plus an incentive payment. It would cost approximately 2 million USD per year to provide the delta with an estimated annual flow of 39 million m^3 (Lueck et al. 1999). The cost for purchasing water in the Wellton-Mohawk is estimated to be about 10 times the cost of leasing it or about 530 USD per million m^3, excluding incentive payments (Pitt pers. comm.). Therefore, the estimated cost to purchase water rights equivalent to 39 million m^3 would be 17 million USD. It is believed that securing permanent water rights will be significantly more difficult than leasing because it limits the options for agricultural production on the property.

Institutional capabilities

With adequate funding a non-profit or governmental entity could be charged with identifying available water to purchase or lease in the U.S. This entity would purchase/lease, hold, and monitor the delivery of the water to the delta. The proper price of water may be determined through three methods: (i) a standing offer; (ii) individually negotiated contracts; or (iii) auctioning (Pitt et al. 2002)

In the Upper Basin, it is impossible to quantify how much water each farmer uses because of a lack of gauging stations at individual parcels. The use of water is determined by comparing historic outflows (as a proxy of current inflows) to present-day outflows. Overall, Upper Basin usage is determined by what is used downstream, severely limiting the extent to which water rights purchased in the Upper Basin may be enforced.

At the Mexican border, the IBWC would be responsible for ensuring that the purchased amount of water reaches the delta. A stream gauge station should be located near or at the delta to aid in monitoring. The IBWC has recently asserted its interests in ecological issues through Minute 306, passed in 2000 (IBWC 2000), that provides a framework for bi-national cooperation in carrying out scientific research on the delta ecosystems. The Minute establishes a "framework for cooperation" to address ecological concerns of the delta and suggest possible alternatives for restoring the delta. The process would include the "formulation of recommendations for cooperative projects" (IBWC 2000). The Minute represents a substantial leap forward towards the restoration of the delta.

The entity holding the water rights must have the institutional capability to ensure, by checking stream gauge readings and water records, that IBWC is delivering the appropriate amount of water to the delta. In addition, experts believe that independent observers may be necessary to ensure unbiased monitoring (El caso del agua dulce en Mexico 2003).

Political feasibility

Despite the fact that the water transfers are voluntary and economically feasible, there may be political opposition to this policy option because of the enormous pressure on the Colorado River's resources. The Upper Basin states may oppose water transfers because it would signal that they are not using their entire allocation of water for "beneficial consumption", opening up the possibility of a reallocation between basins. In addition, the Lower Basin states may oppose the transfer because they currently benefit from water that the Upper Basin does not use and therefore flows into their states. Water transfers would effectively mean that the Lower Basin states would have to pay for the water they are now receiving for free (Culp 2001). However, it is conceivable that water transfers for ecological purposes, as public goods, would not cause the political opposition that other water transfers may provoke.

On the other hand Glennon and Culp (2002) note that, while individual farmers within the Wellton-Mohawk Irrigation District might be interested in selling water, the District itself is on record as opposing the sale or lease of its water and, under Arizona law, it has a veto power over sales by individual farmers to parties outside the district.

Despite the political and legal barriers to voluntary water transfers from the U.S. to the delta, this policy option represents a way in which water can be transferred to the delta without the need to renegotiate the Law of the River. Due to inefficiencies in agricultural production in the Colorado River Basin and the opportunity for farmers to benefit financially, a water transfer programme could address the needs of the delta ecosystem and water interests in both countries.

Sub-category: Amendment of a Minute to the 1944 Water Treaty for ecological purposes

Minute 242 to the 1944 Water Treaty already addresses the problem of salinity, while Minutes such as 261, 264, 270, 273, 295 and 298 already deal with various border sanitation issues. What is needed, more specifically, is an ecological Minute to the 1944 Treaty that addresses the full water cycle of the Lower Colorado River Basin as it relates to the native flora and fauna of this massive riparian ecosystem.

Legal basis for amending a Minute for ecological purposes

The U.S. National Environmental Policy Act (NEPA) requires all federal agencies to prepare an environmental impact statement (EIS) for all actions that significantly affect the environment.

The U.S. Fish and Wildlife Service (FWS) and all other federal agencies must ensure that their actions do not jeopardise the continued existence of or adversely modify the critical habitat of all listed species under the U.S. Endangered Species Act (ESA).

Particularly relevant to Mexico is the ESA requirement that federal action agencies such as the U.S. Bureau of Reclamation must consult with the FWS on any action that might jeopardise a listed species; the Totoaba, Vaquita porpoise, Desert pupfish, Yuma clapper rail, and Southwestern willow flycatcher are among the Mexican resident or migratory species listed under the U.S. Endangered Species Act.

In addition, the Colorado River is governed by the Law of the River; Mexico is an integral component of the Law of the River itself, through the 1944 U.S.-Mexico Water Treaty. In this way Mexico, entitled user of the Colorado River under International Law, has the right to negotiate over water resources of the Colorado River if the upper riparian state (U.S.) affects in any way the natural resources of the lower basin state (Mexico), in which case the construction of dams in the U.S. has affected the natural conditions of the Colorado River Delta and its ecosystem.

The Treaty of 1944 would need to be amended through a Minute of the IBWC to allow water to flow from the U.S. into Mexico in excess of the 1.85 km^3 currently provided through the Treaty. For example, the Treaty of 1944 could be amended through a "congressional-executive" agreement that would accomplish the same results as a full-fledged amendment to the Treaty of 1944. However, it would be more politically feasible as it only requires a majority of both the U.S. House and Senate rather than a two-thirds vote required of the Senate for a treaty amendment. The minute will be able to overcome legal challenges raised by individual states because it is an executive agreement and as such, supersedes any conflicting state laws.

Political feasibility

Although many states will oppose the amending of a Minute to the Water Treaty regarding additional supplies of water for ecological purposes, it is quite comprehensible that actions to restore the delta consist of cooperation between both countries. In this way the U.S. in part should proportion part of the solution that is needed for restoration and maintenance of the delta.

Salinity increases as possible alternatives to increase water flows to the delta

Glennon and Culp (2002) considered that salinity increases in the Lower Colorado Region could be a factor of new negotiations of water deliveries in the short-term, due to the adoption of the new Colorado River Surplus Criteria. The Environmental Impact Statement of the USBR regarding Colorado River Surplus Criteria, completely ignored the salinity effects on Mexican water users, and failed to provide an estimate of increased river salinity below Imperial Dam. Because Minute 242 requires an exact proportion between the levels at Imperial and Morelos dams (a difference of no more than 115 ppm ±30 ppm), the salinity levels at Morelos are far more significant than the levels at Imperial Dam. The Basin states alternative would increase the flows that reach Imperial Dam but reduce them below the dam. Therefore, the salinity levels at Imperial and Morelos will likely diverge, which could easily result in violations of Minute 242.

On this basis, if salinity exceeds the salinity levels stipulated in Minute 242, the USBR may be forced to re-open the Yuma Desalting plant facility. Due to elevated operational costs, Glennon and Culp (2002) suggest that Mexico offer the U.S. an alternative and cheaper means of reducing salinity to an acceptable level based on increasing the flow of the River, thereby generating water for the delta as an incidental by-product (Glennon & Culp 2002).

Comparative water transfer costs

The cost of permanently acquiring water rights in the U.S. is expensive, ranging from 10 to 20 times the price of leasing water rights. The cost of leasing water in Mexico will become more expensive than permanently purchasing water rights after 3-18 years, based upon the range of leasing prices. In the U.S. the cost of leasing will exceed the cost of permanently purchasing rights after 10 years. However, one must consider that leasing costs will decrease in the future due to discounting.

In addition, the cost of leasing water in the Wellton-Mohawk district is two to seven times the price of leasing water in Mexicali and San Luis Rio Colorado. The cost of purchasing water in Wellton-Mohawk is roughly 4.3 times the price to purchase water rights in Mexicali and San Luis Rio Colorado (Table 37).

Table 38 analyses the cost of providing one-half (19.5 million m^3), three-fourths (29 million m^3) and the full amount of annual flows (39 million m^3) needed for the delta based on preliminary estimates. In addition, it analyses the difference between providing the amount of water exclusively within Mexico, exclusively within the U.S., and shared equally between the two countries.

The lowest cost option for leasing or purchasing water over all amounts is to obtain the water from the Mexicali/San Luis Rio Colorado district.

Table 37 Price of leasing compared to purchasing rights .

	Location			
	Mexicali and San Luis Río Colorado, Mexico		Wellton-Mohawk, Arizona, U.S.	
	Price (USD/ million m^3)	Total cost (USD)[1]	Price (USD /million m^3)	Total cost (USD)[1]
Lease	6.66-33.55	213 120-1 073 600[2]	53	1 696 000[2]
Purchase	123.46	3 950 720	530	16 960 000

Note: [1] Total cost to provide 39 million m^3. [2] Total cost per year.
(Source: With data from Pitt et al. 2002, Carrillo 2002, Zamora-Arroyo pers. comm.)

Table 38 Sensitivity analysis of purchase/lease allocation in the Wellton-Mohawk and Mexicali/San Luis Rio Colorado districts.

Location of purchase	Amount of water (km^3)	100% lease (USD)	50% lease/ 50% purchase (USD)	100% purchase (USD)
100% Mexico	19.5	342 000	1 220 000	2 099 000
	29	503 000	1 795 000	3 087 000
	39	643 000	2 297 000	3 951 000
50% Mexico/ 50% U.S.	19.5	621 000	3 088 000	5 554 000
	29	914 000	4 541 000	8 168 000
	39	1 170 000	5 813 000	10 455 000
100% U.S.	19.5	901 000	4 956 000	9 010 000
	29	1 325 000	7 288 000	13 250 000
	39	1 696 000	9 328 000	16 960 000

(Source: With data from Pitt et al. 2002, Carrillo 2002, Zamora-Arroyo pers. comm.)

However, the exclusive purchase and leasing of water in Mexico has serious equity concerns. It is frequently asserted that Mexico lacked bargaining power during the 1944 Treaty negotiations and thus, was under-allocated its fair share of water (Culp 2001). Therefore it is recommended that the U.S. and Mexico share purchase or lease of water rights to some degree.

Long-term policy options

Institutionalise the market for water in Mexico and convert electricity subsidies

This policy option aims at institutionalise the market for water in Mexico, convert the electricity subsidy in the agricultural sector through a cash subsidy or decoupled subsidy in order to approximate to the real price of water, as well as eliminating the price subsidies of domestic users of water.

Currently, farmers receive water at a highly subsidised rate - essentially it is free. Not only does this provide an incentive to overconsume water, but it also distorts the water market. The estimate of the real price of water could be useful to reduce information asymmetries in water transfers. The different prices of water that have been negotiated by farmers do not always reflect the "real" cost of water; in economic terms, the market price does not equal the marginal cost of providing it. Authorities estimate that most transactions are below the marginal cost. Currently water rights sold in the Mexicali Valley range between 700 and 1 200 USD per ha. The "real" costs of water are estimated between 3 000 and 4 000 USD (Oyarzabal pers. comm.).

Farmers currently receive subsidies in the price of electricity to pump out groundwater. These subsidies give farmers the incentive to overexploit this source of water. Though eliminating this subsidy may not be politically feasible, converting it into a cash subsidy could lead to greater efficiencies in use. Currently, most farmers receive cash subsidies to compensate price subsidies elimination in agricultural inputs (e.g. seeds, fertiliser) through the Program for Direct Assistance in Agriculture (PROCAMPO). With a cash subsidy, farmers could choose if they prefer to consume other goods and reduce or eliminate their consumption of underground water. In other words, farmers may be able to find cheaper sources of water thereby reducing or eliminating their consumption of groundwater while using the money they save for other purposes. Therefore, this policy can lead to the reduction of market distortions, overexploitation of groundwater, and save public resources without harming the interests of farmers.

In addition, according to the OECD (2002), "Decoupling refers to the effects of a measure, or a set of measures", a policy is decoupled if it has no or only very small effects on production and trade. A decoupled policy should not affect either production or consumption decisions (OECD 2002). Contrary to the decoupled subsidies, ordinary subsidies do not necessarily contribute to a more efficient way of production. They lack the incentives to use efficient ways of production, and the misuse of resources such as water or electricity is greater. It has been demonstrated that decoupled subsidies work better because there is compensation to the price increase, in which it is calculated how much payment is needed in order to raise the price of electricity for instance.

As discussed above, it is natural to believe that there will be opposition coming from the agricultural sector, especially because water price has not been an issue in their production decisions. However, with a decoupled subsidy this burden can be diminished. In the European Union one of the most important forms of support to the agricultural sector has been cash payment. Experts argue that these payments are more secure than a price support system, with a better guarantee behind them (Frawley & Keeney 2000). This option may be politically feasible if the cash payments can indeed improve production in the agricultural sector. Therefore, this option would be more feasible in the long-term, giving an opportunity to the farmers to adjust to the idea that water has a price.

As far as water price is concerned, it is proposed that the elimination of price subsidies to domestic users of water. Subsidies to export-oriented crops are difficult to modify given the possible reduction in competitiveness for agricultural products in the international markets. Similarly, modifying water subsidies for industry can affect the competitiveness of Mexico as a main recipient of foreign investment.

In order to minimise political opposition to this proposal the government can lower taxes to the general population and increase cash subsidies to the low-income population. Currently the low-income population is very well identified through a cash subsidy programme called OPORTUNIDADES. This programme targets the poorest families in the country offering cash grants if they met certain conditions (e.g. sending their children to school, go to clinics for regular check ups) (SEDESOL 2003). To meet these conditions without enhancing current disparities in water distribution, a parallel increase of water distribution to underserved areas would be necessary. The recently approved changes obligate CNA and local and state governments to expand the distribution of water to underserved areas and increase price subsidies for low-income groups. Approximately, 10% of urban population does not have access to water. Most of this population lives in poverty or extreme poverty in Mexico. However, they are forced to pay the highest prices for water, which they purchase from mobile tanks (Roemer 1993).

However, this increase in price subsidies might be the wrong strategy to follow because it generates incentives for overconsumption and would probably represent an expensive burden to public finances. Like the farmers using groundwater, low-income groups might prefer increased cash subsidies to buy other goods while at the same time being able to cover their water needs by paying the "real" price of water.

Sub-category: Volumetric allocation

Volumetric allocation is the quantity of water per hectare that corresponds to each user registered in the user's census (Padron de usuarios). Each association is responsible for determining the quantity; on basis of the irrigated surface rights of their associates and the volume of water that corresponds to its release point, deducing loss from canal seepage and dividing surplus volumes among the irrigated surface of all the users that conform the (Guillen et al. 1999).

Potential for water conservation in the agricultural sector

As have been described above, one of the main problems of highly subsidised water prices is that subsidies give farmers the incentive to waste large amounts of water due to a lack of control of federal agencies (CNA). A possible way to reduce water waste from agricultural use, without reducing the farmer's share of water or changing crop patterns, is to allocate water portions volumetrically. This way every farmer or consumptive user gets a quantified measure of water and uses it efficiently, relying on the fact that they won't be able to acquire any more water than that designated or at least at a low cost, unless they buy water rights from another stakeholder.

Political feasibility

Despite the fact that there may be political opposition to this policy option because of the enormous pressure of farmers who already have "stipulated" quantities of water, on the other hand there are new demands to give new concessions of water of an already over-apportioned river. The only way of obtaining more water for agricultural purposes is to reduce wastewater and make distribution more efficient. This could be a solution, although many farmers may oppose to volumetric allotments because it would signal that they are not using their entire allocation of water for "beneficial consumption".

If a price is placed on water used in agriculture, farmers will begin to question the economic viability of growing water intensive crops, which may lead to a change in crop types.

Identification of the recommended policy options

This report addressed the following problem: too little water is being allocated towards ecosystem maintenance or restoration in the Colorado River Delta. In fact, neither the United States nor Mexico officially allocates any water to the delta. As a result, it has suffered considerable environmental degradation and affected the lives that depend on it for survival. Though it still supports diverse plant and animal life, including threatened and endangered species, its expanse has shrunk from approximately 7 770 km^2 to only 600 km^2; and only 5% of its original wetlands still remain (Lueck et al. 1999).

Therefore, the short-term policy option: Lease water rights in the Mexicali and San Luis Rio Colorado Valleys and transfer associated water to the delta ecosystem, and the long-term policy option: Institutionalise the market for water in Mexico and convert electricity subsidies, are proposed as preliminary measures to assure minimal flows of freshwater into the delta. Additionally, also proposed are the long-term policy option that attempts to increase the efficiencies of water use in Mexico through market mechanisms, thereby "freeing up" water potentially available for the delta, and the medium-term policy option: Amendment of a Minute to the 1944 Water Treaty in which it specifically stipulates water deliveries for the delta as a bi-national solution to compensate for freshwater loss to the delta ecosystem. The recommendations are in priority order:

- Lease water rights in the Mexicali and San Luis Rio Colorado Valleys and transfer associated water to the delta ecosystem. In addition, grant subsidies to farmers in Mexico for implementing water conservation measures.
- Convert electricity subsidies for Mexican farmers to cash subsidies, and eliminate price subsidies to municipal water users in Mexico.
- Increase the water use efficiency in Mexico through market mechanisms, thereby potentially "freeing up" water for the delta.
- Amend a Minute to the U.S.-Mexico Water Treaty, to stipulates minimum flow rates for the delta.

Analysing the future tendencies of water use in the Lower and Upper Basin of the Colorado River, the most viable way to obtain surplus water for ecological purposes is to change agricultural water use patterns without affecting present deliveries to water stakeholders and farmers in the Mexican part of the delta. This implies changes in the actual Mexican National Water Law, regarding the time and quantity of deliveries of water for agricultural purposes.

Although there are alternatives to water surplus deliveries like the Mexicali II Project, the implication of this alternative has negative impacts for the U.S. portion of the Colorado River Delta. Each year Mexicali discharges about 49 million m^3 of effluent into the International Boundary Drain, which empties in the New River. The New River originates 35 km, south of the international boundary and flows north through Mexicali, crossing the border into California's Imperial Valley. About 70 km to the north, it empties into California's Salton Sea, a closed basin, where evaporation tends to concentrate pollutants.

To reduce pollutants that are diverted to the New River and eventually the Salton Sea, the U.S. and Mexico, agreed to build a bi-national wastewater treatment plant to be called Mexicali II. The projects objective is to treat more than 1 645 litres per second and serve a population of more than 0.5 million people (IBWC 1996). The negative implication to the U.S. is a change in the plants design, since it could discharge in the New River (U.S.) or in the Hardy River (Mexico).

If the treated water is discharged to the New River, this could possibly improve water quality conditions in the Salton Sea. But if the treated water were to be emptied in the Hardy River Basin, a considerable amount of water would no longer reach the Salton Sea, creating more environmental problems than it already has. On the other hand disposal in the Hardy River wetlands would help maintain important ecosystems in the Colorado River Delta.

Conclusions

Under international law individual states are endowed with the right to control territorial resources. Consensus, however, is difficult to reach on what constitutes an equitable and reasonable utilisation and when another state is adversely affected by such utilisation.

Although the two countries cooperate as good neighbours in developing the vital water resources of the shared river in which each has an equitable interest, there is the obligation to notify projects related to transboundary water, considering that any change in the water balance affects both sides of the border. Presently the Colorado River Delta and the Upper Gulf ecosystems only receive flows of freshwater whenever a surplus of water exists in the River in excess of the amount of water necessary to supply the U.S. Base flows and periodic flows should be consistent to the delta despite the 1944 Treaty stipulations, due that the rivers ecosystem survival does not depend on treaties or political factors.

The long-term problem for the delta is the decline in stream flow of the River and its flooding regime. Changing the patterns of controlled flooding will not always solve this problem. In order to implement effective conservation programmes more water flowing directly into the delta is needed. However, economic and technical support from the United States will be necessary, and realistically, the Lower Colorado River Basin states will probably not agree to allow more water to reach Mexico.

Therefore the preservation of the Colorado River Delta ecosystems will remain a complex task. To maintain sufficient stream flows in the River, the alignment of numerous institutions, agreements, and organisations will be required. As a transboundary representative, the International Boundary and Water Commission (IBWC) still remains as the most eligible institution to achieve this goal in the long-term, although it remains cautious in its jurisdiction over environmental problems relating to the Colorado River Delta; therefore the criticism of the way it operates and manages problems concerning to the environment.

Mexico has actively attempted to conserve the delta region through initiatives such as the Upper Gulf of California and Colorado River Delta Biosphere Reserve (Reserva de la Biosfera Alto Golfo de California y Delta del Rio Colorado). This has demonstrated the federal government's commitment to conserving this vital ecosystem..

Considering the transboundary implications of the Colorado River Delta as a shared watershed, the responsibility for its protection relies on both riparian states. To date, both Mexico and U.S. state and federal government agencies have resisted active bi-national cooperation to restore the health of the Colorado River Delta ecosystem. These agencies instead point to the absence of any formal agreement between the federal governments of the United States and Mexico regarding allocation of Colorado River water for delta conservation.

There is extensive legal precedent for protection of the delta region. There exists between Mexico and the United States a significant history of cooperation in the conservation of shared natural resources, including water, vegetation and wildlife. As evidenced by a substantial number of organisations, there exists broad international support for restoration and long-term protection of Mexico's Colorado River Delta region.

It is believed that the restoration of the Colorado River Delta comes down to all water consumptive users in the Colorado River Basin. There must be a continuity of public participation in policy and management decisions and recommends coordination among the various involved organisations to ensure that efforts are not duplicated.

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Annexes

Annex I
List of contributing authors

Name	Institutional affiliation	Country	Field of Work
Edgar Arias	World Wildlife Fund (WWF) Mexico	Mexico	Environmental assessment and policy analysis
Amy Boone	University of California, Berkeley	United States	Policy analysis
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Daniel A. Chia	University of California, Berkeley	United States	Policy analysis
Jaime Sainz	Instituto Nacional de Ecología (INE)	Mexico	Environmental policy analysis
Mariana Becerra	Instituto Nacional de Ecología (INE)	Mexico	Environmental Policy analysis
Carlos Muñoz Piña	Instituto Nacional de Ecología (INE)	Mexico	Environmental policy analysis
Ivan Parra	World Wildlife Fund (WWF) Mexico	Mexico	Terrestrial Ecology and Coastal Zone management
Mary Albar	World Wildlife Fund (WWF) Mexico	Mexico	Natural Protected Areas and marine and coastal conservation

Annex II
Detailed scoring tables

I: Freshwater shortage

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
1. Modification of stream flow	3	70	Freshwater shortage	2.6
2. Pollution of existing supplies	1	15		
3. Changes in the water table	2	15		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small – Very large (0 1 2 3)	2	40
Degree of impact (cost, output changes etc.)	Minimum – Severe (0 1 2 3)	2	40
Frequency/Duration	Occasion/Short – Continuous (0 1 2 3)	1	20
Weight average score for Economic impacts		**1.8**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small – Very large (0 1 2 3)	1	30
Degree of severity	Minimum – Severe (0 1 2 3)	1	40
Frequency/Duration	Occasion/Short – Continuous (0 1 2 3)	1	30
Weight average score for Health impacts		**1.0**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small – Very large (0 1 2 3)	1	10
Degree of severity	Minimum – Severe (0 1 2 3)	2	50
Frequency/Duration	Occasion/Short – Continuous (0 1 2 3)	3	40
Weight average score for Other social and community impacts		**2.3**	

II: Pollution

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
4. Microbiological	1	10	Pollution	1.1
5. Eutrophication	1	10		
6. Chemical	2	20		
7. Suspended solids	1	20		
8. Solid wastes	1	10		
9. Thermal	0	10		
10. Radionuclide	1	10		
11. Spills	1	10		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small – Very large (0 1 2 3)	2	30
Degree of impact (cost, output changes etc.)	Minimum – Severe (0 1 2 3)	2	40
Frequency/Duration	Occasion/Short – Continuous (0 1 2 3)	3	30
Weight average score for Economic impacts		**2.3**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small – Very large (0 1 2 3)	1	20
Degree of severity	Minimum – Severe (0 1 2 3)	2	40
Frequency/Duration	Occasion/Short – Continuous (0 1 2 3)	3	40
Weight average score for Health impacts		**2.2**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small – Very large (0 1 2 3)	3	20
Degree of severity	Minimum – Severe (0 1 2 3)	1	30
Frequency/Duration	Occasion/Short – Continuous (0 1 2 3)	3	50
Weight average score for Other social and community impacts		**2.4**	

III: Habitat and community modification

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
12. Loss of ecosystems	3	60	Habitat and community modification	3.0
13.Modification of ecosystems or ecotones, including community structure and/or species composition	3	40		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small 0 1 2 3 Very large	1	20
Degree of impact (cost, output changes etc.)	Minimum 0 1 2 3 Severe	1	40
Frequency/Duration	Occasion/Short 0 1 2 3 Continuous	2	40
Weight average score for Economic impacts		**1.8**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small 0 1 2 3 Very large	0	34
Degree of severity	Minimum 0 1 2 3 Severe	0	33
Frequency/Duration	Occasion/Short 0 1 2 3 Continuous	0	33
Weight average score for Health impacts		**0**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small 0 1 2 3 Very large	2	20
Degree of severity	Minimum 0 1 2 3 Severe	1	40
Frequency/Duration	Occasion/Short 0 1 2 3 Continuous	2	40
Weight average score for Other social and community impacts		**1.6**	

IV: Unsustainable exploitation of fish and other living resources

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
14. Overexploitation	3	15	Unsustainable exploitation of fish	2.9
15. Excessive by-catch and discards	3	30		
16. Destructive fishing practices	3	30		
17. Decreased viability of stock through pollution and disease	2	5		
18. Impact on biological and genetic diversity	3	20		

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small 0 1 2 3 Very large	1	40
Degree of impact (cost, output changes etc.)	Minimum 0 1 2 3 Severe	1	40
Frequency/Duration	Occasion/Short 0 1 2 3 Continuous	3	20
Weight average score for Economic impacts		**1.4**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small 0 1 2 3 Very large	0	34
Degree of severity	Minimum 0 1 2 3 Severe	0	33
Frequency/Duration	Occasion/Short 0 1 2 3 Continuous	0	33
Weight average score for Health impacts		**0**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small 0 1 2 3 Very large	1	40
Degree of severity	Minimum 0 1 2 3 Severe	2	30
Frequency/Duration	Occasion/Short 0 1 2 3 Continuous	2	30
Weight average score for Other social and community impacts		**1.6**	

V: Global change

Environmental issues	Score	Weight %	Environmental concern	Weight averaged score
19. Changes in the hydrological cycle	0		Global change	0
20. Sea level change	0			
21. Increased UV-B radiation as a result of ozone depletion	0			
22. Changes in ocean CO_2 source/sink function	0			

Criteria for Economic impacts	Raw score	Score	Weight %
Size of economic or public sectors affected	Very small 0 1 2 3 Very large	0	
Degree of impact (cost, output changes etc.)	Minimum 0 1 2 3 Severe	0	
Frequency/Duration	Occasion/Short 0 1 2 3 Continuous	0	
Weight average score for Economic impacts		**0**	
Criteria for Health impacts	**Raw score**	**Score**	**Weight %**
Number of people affected	Very small 0 1 2 3 Very large	0	
Degree of severity	Minimum 0 1 2 3 Severe	0	
Frequency/Duration	Occasion/Short 0 1 2 3 Continuous	0	
Weight average score for Health impacts		**0**	
Criteria for Other social and community impacts	**Raw score**	**Score**	**Weight %**
Number and/or size of community affected	Very small 0 1 2 3 Very large	0	
Degree of severity	Minimum 0 1 2 3 Severe	0	
Frequency/Duration	Occasion/Short 0 1 2 3 Continuous	0	
Weight average score for Other social and community impacts		**0**	

Comparative environmental and socio-economic impacts of each GIWA concern

Concern	Types of impacts								Overall score	Priority
	Environmental score		Economic score		Human health score		Social and community score			
	Present (a)	Future (b)	Present (c)	Future (d)	Present (e)	Future (f)	Present (g)	Future (h)		
Freshwater shortage	2.6	2.4	1.8	2.3	1	1	2.3	2.7	**2.0**	**1**
Pollution	1.1	1.2	2.3	2.5	2.2	2.0	2.4	2.6	**2.0**	**2**
Habitat and community modification	3.0	2.5	1.8	1.6	0	0	1.6	1.4	**1.5**	**3**
Unsustainable exploitation of fish and other living resources	2.9	2.0	1.4	1.2	0	0	1.6	1.6	**1.3**	**4**
Global change	0	0	0	0	0	0	0	0	**0**	**5**

Annex III
List of important water-related programmes in the region

Binational Programmes

1889 International Boundary and Water Commission

1944 Water Utilization Treaty

1983 The United States-Mexico Border Environmental Cooperation Agreement (The la Paz Agreement)

1994 The Border Environment Cooperation Commission (BECC)

1994 North American Development Bank (NADbank)

United States

Programmes

The Colorado River Basin Salinity Act

The Federal Clean Water Act

The National Environmental Policy Act (NEPA)

The Safe Drinking Water Act

The Federal Endangered Species Act

The Fish And Wildlife Coordination Act

The Wild and Scenic Rivers Act

The Pacific Northwest Power Planning and Conservation Act

Institutional Framework

Environmental Protection Agency (EPA)

Council of Environmental Quality (CEQ)

Department of Agriculture (USDA)

Department of Energy (DOE)

Department of the Interior (DOI)

US Coast Guard

Interstate Compact Commissions

Colorado River Commission

Native American Government

Mexico

Programmes

National Water Act

Institutional Framework

Secretaria del Medio Ambiente y Recursos Naturales (SEMARNAT)

Comisión Nacional del Agua (CNA)

Annex IV
List of conventions and specific laws that affects water use in the region

Major components of the Law of the River

The River and Harbor Act, March 3, 1889.

The Reclamation Act of June 17, 1902.

Reclamation of Indian Lands in Yuma, Colorado River, and Pyramid Lake Indian Reservations Act of April 21, 1904.

Yuma Project authorised by the Secretary of the Interior on May 10, 1904, pursuant to section 4 of the reclamation Act of June 17, 1902.

Protection of Property Along the Colorado River Act of June 25, 1910.

Warren Act of February 21, 1910.

Patents and Water-Right Certificates Acts of August 9, 1912 and August 26, 1912.

Yuma Auxiliary Project Act of January 25, 1917.

Availability of Money for Yuma Auxiliary Project Act of February 11.

Sale of Water for Miscellaneous Purposes Act of February 25, 1920.

Federal Power Act of June 10, 1920.

The Colorado River Compact of Santa Fe, 1922.

The Colorado River Front Work and Levee System Acts of March 3, 1925; June 21, 1927.

The Boulder Canyon Project Act of December 21, 1928.

The California Limitation Act of March 4, 1929.

The California Seven Party Agreement of August 18, 1931.

The Rivers and Harbors Act of August 30, 1935.

The Parker Dam Power Project Appropriation Act of May 2, 1939.

The Reclamation Project Act of August 4, 1939.

The Boulder Canyon Project Adjustment Act of July 19, 1940.

The Mexican Water Treaty, February 3, 1944.

Gila Project Act of July 30, 1947.

The Upper Colorado River Basin Compact of October 11, 1948.

Consolidate Parker Dam Power Project and Davis Dam Project Act of May 28, 1954.

Palo Verde Diversion Dam Act of August 31, 1954.

Change Boundaries, Yuma Auxiliary Project Act of February 15, 1956.

The Colorado River Storage Project Act of April 11, 1956.

Water Supply Act of July 3, 1958.

Boulder City Act of September 2, 1958.

Report of the Special Master, Simon H. Rifkind, Arizona v. California, et al,. December 5, 1960.

United States Supreme Court Decree, Arizona vs. California, March 9, 1964.

International Flood Control Measures, Lower Colorado River Act of August 10, 1964.

Southern Nevada (Robert B. Griffith) Water Project Act of October 22, 1965.

The Colorado River Basin Act of September 30, 1968.

The National Environmental Policy Act of 1969.

Criteria for the Coordinated Long Range Operation of the Colorado River Reservoirs, June 8, 1970.

Supplemental Irrigation Facilities, Yuma Division, Act of September 25, 1970.

Minutes 218, March 22, 1965; 241, July 14, 1972 (replaced 218); and 242, August 30, 1973, (replaced 241) of the International Boundary and Water Commission, Pursuant to the Mexican Water Treaty.

The Endangered Species Act of 1973.

The Colorado River Basin Salinity Act of June 24 1974.

The Federal Water Pollution Control Act, as amended by the Clean Water Act of 1977.

United States Supreme Court Supplemental Decrees, Arizona vs. California, January 9, 1979, and April 16, 1984.

Hoover Power Plant Act of August 17, 1984 (98 Stat. 1333).

The Grand Canyon Protection Act of 1992

The Numerous Colorado River Water Delivery and Project Repayment Contracts with the States of Arizona and Nevada, cities, water districts, and individuals.

Hoover and Parker-Davis Power Marketing Contracts.

The Global International Waters Assessment

This report presents the results of the Global International Waters Assessment (GIWA) of the transboundary waters of the Gulf of California/Colorado River Basin. This and the subsequent chapter offer a background that describes the impetus behind the establishment of GIWA, its objectives and how the GIWA was implemented.

The need for a global international waters assessment

Globally, people are becoming increasingly aware of the degradation of the world's water bodies. Disasters from floods and droughts, frequently reported in the media, are considered to be linked with ongoing global climate change (IPCC 2001), accidents involving large ships pollute public beaches and threaten marine life and almost every commercial fish stock is exploited beyond sustainable limits - it is estimated that the global stocks of large predatory fish have declined to less that 10% of pre-industrial fishing levels (Myers & Worm 2003). Further, more than 1 billion people worldwide lack access to safe drinking water and 2 billion people lack proper sanitation which causes approximately 4 billion cases of diarrhoea each year and results in the death of 2.2 million people, mostly children younger than five (WHO-UNICEF 2002). Moreover, freshwater and marine habitats are destroyed by infrastructure developments, dams, roads, ports and human settlements (Brinson & Malvárez 2002, Kennish 2002). As a consequence, there is growing public concern regarding the declining quality and quantity of the world's aquatic resources because of human activities, which has resulted in mounting pressure on governments and decision makers to institute new and innovative policies to manage those resources in a sustainable way ensuring their availability for future generations.

Adequately managing the world's aquatic resources for the benefit of all is, for a variety of reasons, a very complex task. The liquid state of the most of the world's water means that, without the construction of reservoirs, dams and canals it is free to flow wherever the laws of nature dictate. Water is, therefore, a vector transporting not only a wide variety of valuable resources but also problems from one area to another. The effluents emanating from environmentally destructive activities in upstream drainage areas are propagated downstream and can affect other areas considerable distances away. In the case of transboundary river basins, such as the Nile, Amazon and Niger, the impacts are transported across national borders and can be observed in the numerous countries situated within their catchments. In the case of large oceanic currents, the impacts can even be propagated between continents (AMAP 1998). Therefore, the inextricable linkages within and between both freshwater and marine environments dictates that management of aquatic resources ought to be implemented through a drainage basin approach.

In addition, there is growing appreciation of the incongruence between the transboundary nature of many aquatic resources and the traditional introspective nationally focused approaches to managing those resources. Water, unlike laws and management plans, does not respect national borders and, as a consequence, if future management of water and aquatic resources is to be successful, then a shift in focus towards international cooperation and intergovernmental agreements is required (UN 1972). Furthermore, the complexity of managing the world's water resources is exacerbated by the dependence of a great variety of domestic and industrial activities on those resources. As a consequence, cross-sectoral multidisciplinary approaches that integrate environmental, socio-economic and development aspects into management must be adopted. Unfortunately however, the scientific information or capacity within each discipline is often not available or is inadequately translated for use by managers, decision makers and policy developers. These inadequacies constitute a serious impediment to the implementation of urgently needed innovative policies.

Continual assessment of the prevailing and future threats to aquatic ecosystems and their implications for human populations is essential if governments and decision makers are going to be able to make strategic policy and management decisions that promote the sustainable use of those resources and respond to the growing concerns of the general public. Although many assessments of aquatic resources are being conducted by local, national, regional and international bodies, past assessments have often concentrated on specific themes, such as biodiversity or persistent toxic substances, or have focused only on marine or freshwaters. A globally coherent, drainage basin based assessment that embraces the inextricable links between transboundary freshwater and marine systems, and between environmental and societal issues, has never been conducted previously.

International call for action

The need for a holistic assessment of transboundary waters in order to respond to growing public concerns and provide advice to governments and decision makers regarding the management of aquatic resources was recognised by several international bodies focusing on the global environment. In particular, the Global Environment Facility (GEF) observed that the International Waters (IW) component of the GEF suffered from the lack of a global assessment which made it difficult to prioritise international water projects, particularly considering the inadequate understanding of the nature and root causes of environmental problems. In 1996, at its fourth meeting in Nairobi, the GEF Scientific and Technical Advisory Panel (STAP), noted that: *"Lack of an International Waters Assessment comparable with that of the IPCC, the Global Biodiversity Assessment, and the Stratospheric Ozone Assessment, was a unique and serious impediment to the implementation of the International Waters Component of the GEF"*.

The urgent need for an assessment of the causes of environmental degradation was also highlighted at the UN Special Session on the Environment (UNGASS) in 1997, where commitments were made regarding the work of the UN Commission on Sustainable Development (UNCSD) on freshwater in 1998 and seas in 1999. Also in 1997, two international Declarations, the Potomac Declaration: Towards enhanced ocean security into the third millennium, and the Stockholm Statement on interaction of land activities, freshwater and enclosed seas, specifically emphasised the need for an investigation of the root causes of degradation of the transboundary aquatic environment and options for addressing them. These processes led to the development of the Global International Waters Assessment (GIWA) that would be implemented by the United Nations Environment Programme (UNEP) in conjunction with the University of Kalmar, Sweden, on behalf of the GEF. The GIWA was inaugurated in Kalmar in October 1999 by the Executive Director of UNEP, Dr. Klaus Töpfer, and the late Swedish Minister of the Environment, Kjell Larsson. On this occasion Dr. Töpfer stated: *"GIWA is the framework of UNEP´s global water assessment strategy and will enable us to record and report on critical water resources for the planet for consideration of sustainable development management practices as part of our responsibilities under Agenda 21 agreements of the Rio conference"*.

The importance of the GIWA has been further underpinned by the UN Millennium Development Goals adopted by the UN General Assembly in 2000 and the Declaration from the World Summit on Sustainable

The Global Environment Facility (GEF)

The Global Environment Facility forges international co-operation and finances actions to address six critical threats to the global environment: biodiversity loss, climate change, degradation of international waters, ozone depletion, land degradation, and persistent organic pollutants (POPs).

The overall strategic thrust of GEF-funded international waters activities is to meet the incremental costs of: (a) assisting groups of countries to better understand the environmental concerns of their international waters and work collaboratively to address them; (b) building the capacity of existing institutions to utilise a more comprehensive approach for addressing transboundary water-related environmental concerns; and (c) implementing measures that address the priority transboundary environmental concerns. The goal is to assist countries to utilise the full range of technical, economic, financial, regulatory, and institutional measures needed to operationalise sustainable development strategies for international waters.

United Nations Environment Programme (UNEP)

United Nations Environment Programme, established in 1972, is the voice for the environment within the United Nations system. The mission of UNEP is to provide leadership and encourage partnership in caring for the environment by inspiring, informing, and enabling nations and peoples to improve their quality of life without compromising that of future generations.

UNEP work encompasses:

- Assessing global, regional and national environmental conditions and trends;
- Developing international and national environmental instruments;
- Strengthening institutions for the wise management of the environment;
- Facilitating the transfer of knowledge and technology for sustainable development;
- Encouraging new partnerships and mind-sets within civil society and the private sector.

University of Kalmar

University of Kalmar hosts the GIWA Co-ordination Office and provides scientific advice and administrative and technical assistance to GIWA. University of Kalmar is situated on the coast of the Baltic Sea. The city has a long tradition of higher education; teachers and marine officers have been educated in Kalmar since the middle of the 19th century. Today, natural science is a priority area which gives Kalmar a unique educational and research profile compared with other smaller universities in Sweden. Of particular relevance for GIWA is the established research in aquatic and environmental science. Issues linked to the concept of sustainable development are implemented by the research programme Natural Resources Management and Agenda 21 Research School.

Since its establishment GIWA has grown to become an integral part of University activities. The GIWA Co-ordination office and GIWA Core team are located at the Kalmarsund Laboratory, the university centre for water-related research. Senior scientists appointed by the University are actively involved in the GIWA peer-review and steering groups. As a result of the cooperation the University can offer courses and seminars related to GIWA objectives and international water issues.

Development in 2002. The development goals aimed to halve the proportion of people without access to safe drinking water and basic sanitation by the year 2015 (United Nations Millennium Declaration 2000). The WSSD also calls for integrated management of land, water and living resources (WSSD 2002) and, by 2010, the Reykjavik Declaration on Responsible Fisheries in the Marine Ecosystem should be implemented by all countries that are party to the declaration (FAO 2001).

The conceptual framework and objectives

Considering the general decline in the condition of the world's aquatic resources and the internationally recognised need for a globally coherent assessment of transboundary waters, the primary objectives of the GIWA are:

- To provide a prioritising mechanism that allows the GEF to focus their resources so that they are used in the most cost effective manner to achieve significant environmental benefits, at national, regional and global levels; and
- To highlight areas in which governments can develop and implement strategic policies to reduce environmental degradation and improve the management of aquatic resources.

In order to meet these objectives and address some of the current inadequacies in international aquatic resources management, the GIWA has incorporated four essential elements into its design:

- A broad transboundary approach that generates a truly regional perspective through the incorporation of expertise and existing information from all nations in the region and the assessment of all factors that influence the aquatic resources of the region;
- A drainage basin approach integrating freshwater and marine systems;
- A multidisciplinary approach integrating environmental and socio-economic information and expertise; and
- A coherent assessment that enables global comparison of the results.

The GIWA builds on previous assessments implemented within the GEF International Waters portfolio but has developed and adopted a broader definition of transboundary waters to include factors that influence the quality and quantity of global aquatic resources. For example, due to globalisation and international trade, the market for penaeid shrimps has widened and the prices soared. This, in turn, has encouraged entrepreneurs in South East Asia to expand aquaculture resulting in the large-scale deforestation of mangroves for ponds (Primavera 1997). Within the GIWA, these "non-hydrological" factors constitute as large a transboundary influence as more traditionally recognised problems, such as the construction of dams that regulate the flow of water into a neighbouring country, and are considered equally important. In addition, the GIWA recognises the importance of hydrological units that would not normally be considered transboundary but exert a significant influence on transboundary waters, such as the Yangtze River in China which discharges into the East China Sea (Daoji & Daler 2004) and the Volga River in Russia which is largely responsible for the condition of the Caspian Sea (Barannik et al. 2004). Furthermore, the GIWA is a truly regional assessment that has incorporated data from a wide range of sources and included expert knowledge and information from a wide range of sectors and from each country in the region. Therefore, the transboundary concept adopted by the GIWA extends to include impacts caused by globalisation, international trade, demographic changes and technological advances and recognises the need for international cooperation to address them.

International waters and transboundary issues

The term "international waters", as used for the purposes of the GEF Operational Strategy, includes the oceans, large marine ecosystems, enclosed or semi-enclosed seas and estuaries, as well as rivers, lakes, groundwater systems, and wetlands with transboundary drainage basins or common borders. The water-related ecosystems associated with these waters are considered integral parts of the systems.

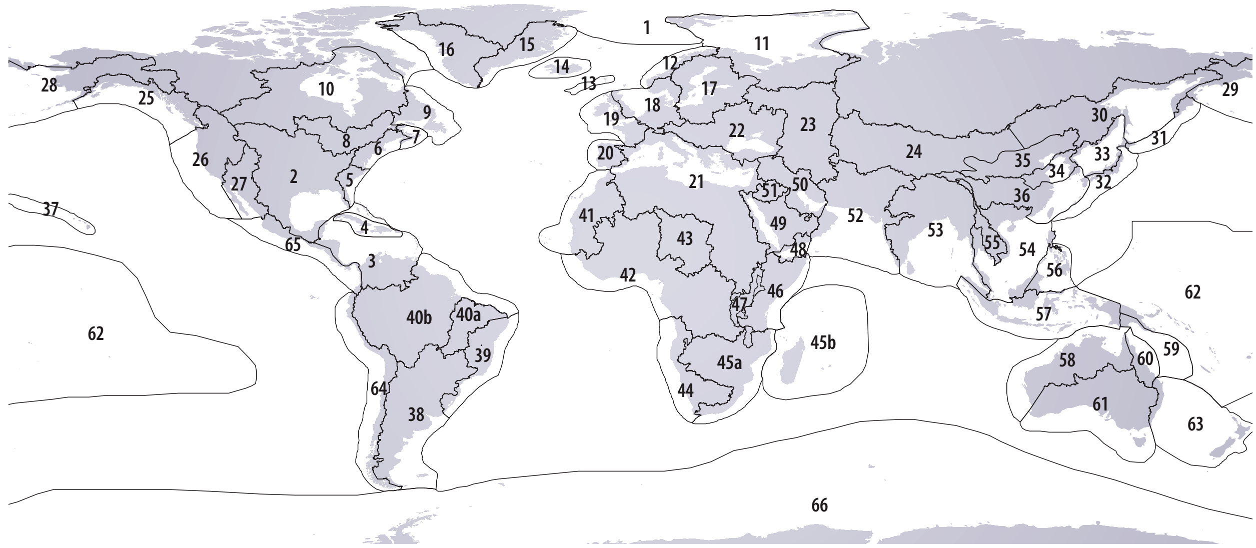
The term "transboundary issues" is used to describe the threats to the aquatic environment linked to globalisation, international trade, demographic changes and technological advancement, threats that are additional to those created through transboundary movement of water. Single country policies and actions are inadequate in order to cope with these challenges and this makes them transboundary in nature.

The international waters area includes numerous international conventions, treaties, and agreements. The architecture of marine agreements is especially complex, and a large number of bilateral and multilateral agreements exist for transboundary freshwater basins. Related conventions and agreements in other areas increase the complexity. These initiatives provide a new opportunity for cooperating nations to link many different programmes and instruments into regional comprehensive approaches to address international waters.

The organisational structure and implementation of the GIWA

The scale of the assessment

Initially, the scope of the GIWA was confined to transboundary waters in areas that included countries eligible to receive funds from the GEF. However, it was recognised that a truly global perspective would only be achieved if industrialised, GEF-ineligible regions of the world were also assessed. Financial resources to assess the GEF-eligible countries were obtained primarily from the GEF (68%), the Swedish International Development Cooperation Agency (Sida) (18%), and the Finnish Department for International Development Cooperation (FINNIDA)



1 *Arctic*
2 *Gulf of Mexico (LME)*
3 *Caribbean Sea (LME)*
4 *Caribbean Islands*
5 *Southeast Shelf (LME)*
6 *Northeast Shelf (LME)*
7 *Scotian Shelf (LME)*
8 *Gulf of St Lawrence*
9 *Newfoundland Shelf (LME)*
10 *Baffin Bay, Labrador Sea, Canadian Archipelago*
11 *Barents Sea (LME)*
12 *Norwegian Sea (LME)*
13 *Faroe plateau*
14 *Iceland Shelf (LME)*
15 *East Greenland Shelf (LME)*
16 *West Greenland Shelf (LME)*
17 *Baltic Sea (LME)*
18 *North Sea (LME)*
19 *Celtic-Biscay Shelf (LME)*
20 *Iberian Coastal (LME)*
21 *Mediterranean Sea (LME)*
22 *Black Sea (LME)*
23 *Caspian Sea*
24 *Aral Sea*
25 *Gulf of Alaska (LME)*
26 *California Current (LME)*
27 *Gulf of California (LME)*
28 *East Bering Sea (LME)*
29 *West Bering Sea (LME)*
30 *Sea of Okhotsk (LME)*
31 *Oyashio Current (LME)*
32 *Kuroshio Current (LME)*
33 *Sea of Japan/East Sea (LME)*
34 *Yellow Sea (LME)*
35 *Bohai Sea*
36 *East-China Sea (LME)*
37 *Hawaiian Archipelago (LME)*
38 *Patagonian Shelf (LME)*
39 *Brazil Current (LME)*
40a *Brazilian Northeast (LME)*
40b *Amazon*
41 *Canary Current (LME)*
42 *Guinea Current (LME)*
43 *Lake Chad*
44 *Benguela Current (LME)*
45a *Agulhas Current (LME)*
45b *Indian Ocean Islands*
46 *Somali Coastal Current (LME)*
47 *East African Rift Valley Lakes*
48 *Gulf of Aden*
49 *Red Sea (LME)*
50 *The Gulf*
51 *Jordan*
52 *Arabian Sea (LME)*
53 *Bay of Bengal S.E.*
54 *South China Sea (LME)*
55 *Mekong River*
56 *Sulu-Celebes Sea (LME)*
57 *Indonesian Seas (LME)*
58 *North Australian Shelf (LME)*
59 *Coral Sea Basin*
60 *Great Barrier Reef (LME)*
61 *Great Australian Bight*
62 *Small Island States*
63 *Tasman Sea*
64 *Humboldt Current (LME)*
65 *Eastern Equatorial Pacific*
66 *Antarctic (LME)*

Figure 1 The 66 transboundary regions assessed within the GIWA project.

(10%). Other contributions were made by Kalmar Municipality, the University of Kalmar and the Norwegian Government. The assessment of regions ineligible for GEF funds was conducted by various international and national organisations as in-kind contributions to the GIWA.

In order to be consistent with the transboundary nature of many of the world's aquatic resources and the focus of the GIWA, the geographical units being assessed have been designed according to the watersheds of discrete hydrographic systems rather than political borders (Figure 1). The geographic units of the assessment were determined during the preparatory phase of the project and resulted in the division of the world into 66 regions defined by the entire area of one or more catchments areas that drains into a single designated marine system. These marine systems often correspond to Large Marine Ecosystems (LMEs) (Sherman 1994, IOC 2002).

Large Marine Ecocsystems (LMEs)

Large Marine Ecosystems (LMEs) are regions of ocean space encompassing coastal areas from river basins and estuaries to the seaward boundaries of continental shelves and the outer margin of the major current systems. They are relatively large regions on the order of 200 000 km^2 or greater, characterised by distinct: (1) bathymetry, (2) hydrography, (3) productivity, and (4) trophically dependent populations.

The Large Marine Ecosystems strategy is a global effort for the assessment and management of international coastal waters. It developed in direct response to a declaration at the 1992 Rio Summit. As part of the strategy, the World Conservation Union (IUCN) and National Oceanic and Atmospheric Administration (NOAA) have joined in an action program to assist developing countries in planning and implementing an ecosystem-based strategy that is focused on LMEs as the principal assessment and management units for coastal ocean resources. The LME concept is also adopted by GEF that recommends the use of LMEs and their contributing freshwater basins as the geographic area for integrating changes in sectoral economic activities.

Considering the objectives of the GIWA and the elements incorporated into its design, a new methodology for the implementation of the assessment was developed during the initial phase of the project. The methodology focuses on five major environmental concerns which constitute the foundation of the GIWA assessment; Freshwater shortage, Pollution, Habitat and community modification, Overexploitation of fish and other living resources, and Global change. The GIWA methodology is outlined in the following chapter.

The global network

In each of the 66 regions, the assessment is conducted by a team of local experts that is headed by a Focal Point (Figure 2). The Focal Point can be an individual, institution or organisation that has been selected on the basis of their scientific reputation and experience implementing international assessment projects. The Focal Point is responsible for assembling members of the team and ensuring that it has the necessary expertise and experience in a variety of environmental and socio-economic disciplines to successfully conduct the regional assessment. The selection of team members is one of the most critical elements for the success of GIWA and, in order to ensure that the most relevant information is incorporated into the assessment, team members were selected from a wide variety of institutions such as universities, research institutes, government agencies, and the private sector. In addition, in order to ensure that the assessment produces a truly regional perspective, the teams should include representatives from each country that shares the region.

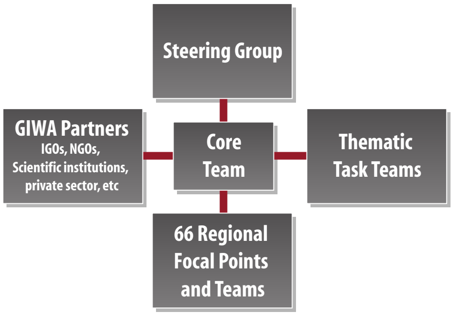


Figure 2 The organisation of the GIWA project.

In total, more than 1 000 experts have contributed to the implementation of the GIWA illustrating that the GIWA is a participatory exercise that relies on regional expertise. This participatory approach is essential because it instils a sense of local ownership of the project, which ensures the credibility of the findings and moreover, it has created a global network of experts and institutions that can collaborate and exchange experiences and expertise to help mitigate the continued degradation of the world's aquatic resources.

GIWA Regional reports

The GIWA was established in response to growing concern among the general public regarding the quality of the world's aquatic resources and the recognition of governments and the international community concerning the absence of a globally coherent international waters assessment. However, because a holistic, region-by-region, assessment of the condition of the world's transboundary water resources had never been undertaken, a methodology guiding the implementation of such an assessment did not exist. Therefore, in order to implement the GIWA, a new methodology that adopted a multidisciplinary, multi-sectoral, multi-national approach was developed and is now available for the implementation of future international assessments of aquatic resources.

UNEP Water Policy and Strategy

The primary goals of the UNEP water policy and strategy are:

(a) Achieving greater global understanding of freshwater, coastal and marine environments by conducting environmental assessments in priority areas;

(b) Raising awareness of the importance and consequences of unsustainable water use;

(c) Supporting the efforts of Governments in the preparation and implementation of integrated management of freshwater systems and their related coastal and marine environments;

(d) Providing support for the preparation of integrated management plans and programmes for aquatic environmental hot spots, based on the assessment results;

(e) Promoting the application by stakeholders of precautionary, preventive and anticipatory approaches.

The GIWA is comprised of a logical sequence of four integrated components. The first stage of the GIWA is called Scaling and is a process by which the geographic area examined in the assessment is defined and all the transboundary waters within that area are identified. Once the geographic scale of the assessment has been defined, the assessment teams conduct a process known as Scoping in which the magnitude of environmental and associated socio-economic impacts of Freshwater shortage, Pollution, Habitat and community modification, Unsustainable exploitation of fish and other living resources, and Global change is assessed in order to identify and prioritise the concerns that require the most urgent intervention. The assessment of these predefined concerns incorporates the best available information and the knowledge and experience of the multidisciplinary, multi-national assessment teams formed in each region. Once the priority concerns have been identified, the root causes of these concerns are identified during the third component of the GIWA, Causal chain analysis. The root causes are determined through a sequential process that identifies, in turn, the most significant immediate causes followed by the economic sectors that are primarily responsible for the immediate causes and finally, the societal root causes. At each stage in the Causal chain analysis, the most significant contributors are identified through an analysis of the best available information which is augmented by the expertise of the assessment team. The final component of the GIWA is the development of Policy options that focus on mitigating the impacts of the root causes identified by the Causal chain analysis.

The results of the GIWA assessment in each region are reported in regional reports that are published by UNEP. These reports are designed to provide a brief physical and socio-economic description of the most important features of the region against which the results of the assessment can be cast. The remaining sections of the report present the results of each stage of the assessment in an easily digestible form. Each regional report is reviewed by at least two independent external reviewers in order to ensure the scientific validity and applicability of each report. The 66 regional assessments of the GIWA will serve UNEP as an essential complement to the UNEP Water Policy and Strategy and UNEP's activities in the hydrosphere.

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The GIWA methodology

The specific objectives of the GIWA were to conduct a holistic and globally comparable assessment of the world's transboundary aquatic resources that incorporated both environmental and socio-economic factors and recognised the inextricable links between freshwater and marine environments, in order to enable the GEF to focus their resources and to provide guidance and advice to governments and decision makers. The coalition of all these elements into a single coherent methodology that produces an assessment that achieves each of these objectives had not previously been done and posed a significant challenge.

The integration of each of these elements into the GIWA methodology was achieved through an iterative process guided by a specially convened Methods task team that was comprised of a number of international assessment and water experts. Before the final version of the methodology was adopted, preliminary versions underwent an extensive external peer review and were subjected to preliminary testing in selected regions. Advice obtained from the Methods task team and other international experts and the lessons learnt from preliminary testing were incorporated into the final version that was used to conduct each of the GIWA regional assessments.

Considering the enormous differences between regions in terms of the quality, quantity and availability of data, socio-economic setting and environmental conditions, the achievement of global comparability required an innovative approach. This was facilitated by focusing the assessment on the impacts of five pre-defined concerns namely; Freshwater shortage, Pollution, Habitat and community modification, Unsustainable exploitation of fish and other living resources and Global change, in transboundary waters. Considering the diverse range of elements encompassed by each concern, assessing the magnitude of the impacts caused by these concerns was facilitated by evaluating the impacts of 22 specific issues that were grouped within these concerns (see Table 1).

The assessment integrates environmental and socio-economic data from each country in the region to determine the severity of the impacts of each of the five concerns and their constituent issues on the entire region. The integration of this information was facilitated by implementing the assessment during two participatory workshops that typically involved 10 to 15 environmental and socio-economic experts from each country in the region. During these workshops, the regional teams performed preliminary analyses based on the collective knowledge and experience of these local experts. The results of these analyses were substantiated with the best available information to be presented in a regional report.

Table 1 Pre-defined GIWA concerns and their constituent issues addressed within the assessment.

Environmental issues	Major concerns
1. Modification of stream flow 2. Pollution of existing supplies 3. Changes in the water table	**I Freshwater shortage**
4. Microbiological 5. Eutrophication 6. Chemical 7. Suspended solids 8. Solid wastes 9. Thermal 10. Radionuclide 11. Spills	**II Pollution**
12. Loss of ecosystems 13. Modification of ecosystems or ecotones, including community structure and/or species composition	**III Habitat and community modification**
14. Overexploitation 15. Excessive by-catch and discards 16. Destructive fishing practices 17. Decreased viability of stock through pollution and disease 18. Impact on biological and genetic diversity	**IV Unsustainable exploitation of fish and other living resources**
19. Changes in hydrological cycle 20. Sea level change 21. Increased uv-b radiation as a result of ozone depletion 22. Changes in ocean CO_2 source/sink function	**V Global change**

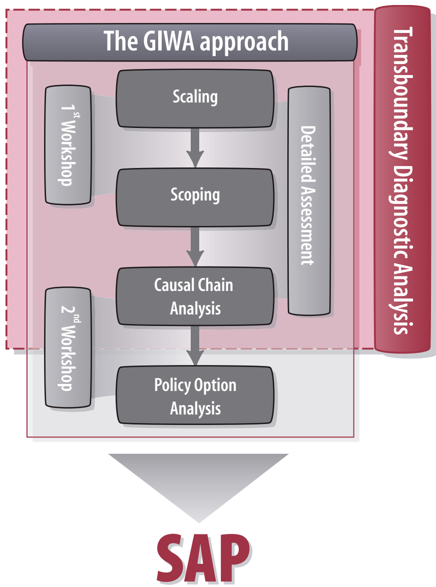

Figure 1 Illustration of the relationship between the GIWA approach and other projects implemented within the GEF International Waters (IW) portfolio.

The GIWA is a logical contiguous process that defines the geographic region to be assessed, identifies and prioritises particularly problems based on the magnitude of their impacts on the environment and human societies in the region, determines the root causes of those problems and, finally, assesses various policy options that addresses those root causes in order to reverse negative trends in the condition of the aquatic environment. These four steps, referred to as Scaling, Scoping, Causal chain analysis and Policy options analysis, are summarised below and are described in their entirety in two volumes: *GIWA Methodology Stage 1: Scaling and Scoping*; and *GIWA Methodology: Detailed Assessment, Causal Chain Analysis and Policy Options Analysis*. Generally, the components of the GIWA methodology are aligned with the framework adopted by the GEF for Transboundary Diagnostic Analyses (TDAs) and Strategic Action Programmes (SAPs) (Figure 1) and assume a broad spectrum of transboundary influences in addition to those associated with the physical movement of water across national borders.

Scaling – Defining the geographic extent of the region

Scaling is the first stage of the assessment and is the process by which the geographic scale of the assessment is defined. In order to facilitate the implementation of the GIWA, the globe was divided during the design phase of the project into 66 contiguous regions. Considering the transboundary nature of many aquatic resources and the transboundary focus of the GIWA, the boundaries of the regions did not comply with political boundaries but were instead, generally defined by a large but discrete drainage basin that also included the coastal marine waters into which the basin discharges. In many cases, the marine areas examined during the assessment coincided with the Large Marine Ecosystems (LMEs) defined by the US National Atmospheric and Oceanographic Administration (NOAA). As a consequence, scaling should be a relatively straight-forward task that involves the inspection of the boundaries that were proposed for the region during the preparatory phase of GIWA to ensure that they are appropriate and that there are no important overlaps or gaps with neighbouring regions. When the proposed boundaries were found to be inadequate, the boundaries of the region were revised according to the recommendations of experts from both within the region and from adjacent regions so as to ensure that any changes did not result in the exclusion of areas from the GIWA. Once the regional boundary was defined, regional teams identified all the transboundary elements of the aquatic environment within the region and determined if these elements could be assessed as a single coherent aquatic system or if there were two or more independent systems that should be assessed separately.

Scoping – Assessing the GIWA concerns

Scoping is an assessment of the severity of environmental and socio-economic impacts caused by each of the five pre-defined GIWA concerns and their constituent issues (Table 1). It is not designed to provide an exhaustive review of water-related problems that exist within each region, but rather it is a mechanism to identify the most urgent problems in the region and prioritise those for remedial actions. The priorities determined by Scoping are therefore one of the main outputs of the GIWA project.

Focusing the assessment on pre-defined concerns and issues ensured the comparability of the results between different regions. In addition, to ensure the long-term applicability of the options that are developed to mitigate these problems, Scoping not only assesses the current impacts of these concerns and issues but also the probable future impacts according to the "most likely scenario" which considered demographic, economic, technological and other relevant changes that will potentially influence the aquatic environment within the region by 2020.

The magnitude of the impacts caused by each issue on the environment and socio-economic indicators was assessed over the entire region using the best available information from a wide range of sources and the knowledge and experience of the each of the experts comprising the regional team. In order to enhance the comparability of the assessment between different regions and remove biases in the assessment caused by different perceptions of and ways to communicate the severity of impacts caused by particular issues, the results were distilled and reported as standardised scores according to the following four point scale:

- 0 = no known impact
- 1 = slight impact
- 2 = moderate impact
- 3 = severe impact

The attributes of each score for each issue were described by a detailed set of pre-defined criteria that were used to guide experts in reporting the results of the assessment. For example, the criterion for assigning a score of 3 to the issue Loss of ecosystems or ecotones is: "*Permanent destruction of at least one habitat is occurring such as to have reduced their surface area by >30% during the last 2-3 decades*." The full list of criteria is presented at the end of the chapter, Table 5a-e. Although the scoring inevitably includes an arbitrary component, the use of predefined criteria facilitates comparison of impacts on a global scale and also encouraged consensus of opinion among experts.

The trade-off associated with assessing the impacts of each concern and their constituent issues at the scale of the entire region is that spatial resolution was sometimes low. Although the assessment provides a score indicating the severity of impacts of a particular issue or concern on the entire region, it does not mean that the entire region suffers the impacts of that problem. For example, eutrophication could be identified as a severe problem in a region, but this does not imply that all waters in the region suffer from severe eutrophication. It simply means that when the degree of eutrophication, the size of the area affected, the socio-economic impacts and the number of people affected is considered, the magnitude of the overall impacts meets the criteria defining a severe problem and that a regional action should be initiated in order to mitigate the impacts of the problem.

When each issue has been scored, it was weighted according to the relative contribution it made to the overall environmental impacts of the concern and a weighted average score for each of the five concerns was calculated (Table 2). Of course, if each issue was deemed to make equal contributions, then the score describing the overall impacts of the concern was simply the arithmetic mean of the scores allocated to each issue within the concern. In addition, the socio-economic impacts of each of the five major concerns were assessed for the entire region. The socio-economic impacts were grouped into three categories; Economic impacts, Health impacts and Other social and community impacts (Table 3). For each category, an evaluation of the size, degree and frequency of the impact was performed and, once completed, a weighted average score describing the overall socio-economic impacts of each concern was calculated in the same manner as the overall environmental score.

Table 2 Example of environmental impact assessment of Freshwater shortage.

Environmental issues	Score	Weight %	Environmental concerns	Weight averaged score
1. Modification of stream flow	1	20	Freshwater shortage	1.50
2. Pollution of existing supplies	2	50		
3. Changes in the water table	1	30		

Table 3 Example of Health impacts assessment linked to one of the GIWA concerns.

Criteria for Health impacts	Raw score	Score	Weight %
Number of people affected	Very small – Very large (0 1 2 3)	2	50
Degree of severity	Minimum – Severe (0 1 2 3)	2	30
Frequency/Duration	Occasion/Short – Continuous (0 1 2 3)	2	20
Weight average score for Health impacts		**2**	

After all 22 issues and associated socio-economic impacts have been scored, weighted and averaged, the magnitude of likely future changes in the environmental and socio-economic impacts of each of the five concerns on the entire region is assessed according to the most likely scenario which describes the demographic, economic, technological and other relevant changes that might influence the aquatic environment within the region by 2020.

In order to prioritise among GIWA concerns within the region and identify those that will be subjected to causal chain and policy options analysis in the subsequent stages of the GIWA, the present and future scores of the environmental and socio-economic impacts of each concern are tabulated and an overall score calculated. In the example presented in Table 4, the scoping assessment indicated that concern III, Habitat and community modification, was the priority concern in this region. The outcome of this mathematic process was reconciled against the knowledge of experts and the best available information in order to ensure the validity of the conclusion.

In some cases however, this process and the subsequent participatory discussion did not yield consensus among the regional experts regarding the ranking of priorities. As a consequence, further analysis was required. In such cases, expert teams continued by assessing the relative importance of present and potential future impacts and assign weights to each. Afterwards, the teams assign weights indicating the relative contribution made by environmental and socio-economic factors to the overall impacts of the concern. The weighted average score for each concern is then recalculated taking into account

Table 4 Example of comparative environmental and socio-economic impacts of each major concern, presently and likely in year 2020.

Concern	Types of impacts								Overall score
	Environmental score		Economic score		Human health score		Social and community score		
	Present (a)	Future (b)	Present (c)	Future (d)	Present (e)	Future (f)	Present (g)	Future (h)	
Freshwater shortage	1.3	2.3	2.7	2.8	2.6	3.0	1.8	2.2	**2.3**
Pollution	1.5	2.0	2.0	2.3	1.8	2.3	2.0	2.3	**2.0**
Habitat and community modification	2.0	3.0	2.4	3.0	2.4	2.8	2.3	2.7	**2.6**
Unsustainable exploitation of fish and other living resources	1.8	2.2	2.0	2.1	2.0	2.1	2.4	2.5	**2.1**
Global change	0.8	1.0	1.5	1.7	1.5	1.5	1.0	1.0	**1.2**

the relative contributions of both present and future impacts and environmental and socio-economic factors. The outcome of these additional analyses was subjected to further discussion to identify overall priorities for the region.

Finally, the assessment recognises that each of the five GIWA concerns are not discrete but often interact. For example, pollution can destroy aquatic habitats that are essential for fish reproduction which, in turn, can cause declines in fish stocks and subsequent overexploitation. Once teams have ranked each of the concerns and determined the priorities for the region, the links between the concerns are highlighted in order to identify places where strategic interventions could be applied to yield the greatest benefits for the environment and human societies in the region.

Causal chain analysis

Causal Chain Analysis (CCA) traces the cause-effect pathways from the socio-economic and environmental impacts back to their root causes. The GIWA CCA aims to identify the most important causes of each concern prioritised during the scoping assessment in order to direct policy measures at the most appropriate target in order to prevent further degradation of the regional aquatic environment.

Root causes are not always easy to identify because they are often spatially or temporally separated from the actual problems they cause. The GIWA CCA was developed to help identify and understand the root causes of environmental and socio-economic problems in international waters and is conducted by identifying the human activities that cause the problem and then the factors that determine the ways in which these activities are undertaken. However, because there is no universal theory describing how root causes interact to create natural resource management problems and due to the great variation of local circumstances under which the methodology will be applied, the GIWA CCA is not a rigidly structured assessment but should be regarded as a framework to guide the analysis, rather than as a set of detailed instructions. Secondly, in an ideal setting, a causal chain would be produced by a multidisciplinary group of specialists that would statistically examine each successive cause and study its links to the problem and to other causes. However, this approach (even if feasible) would use far more resources and time than those available to GIWA[1]. For this reason, it has been necessary to develop a relatively simple and practical analytical model for gathering information to assemble meaningful causal chains.

Conceptual model

A causal chain is a series of statements that link the causes of a problem with its effects. Recognising the great diversity of local settings and the resulting difficulty in developing broadly applicable policy strategies, the GIWA CCA focuses on a particular system and then only on those issues that were prioritised during the scoping assessment. The starting point of a particular causal chain is one of the issues selected during the Scaling and Scoping stages and its related environmental and socio-economic impacts. The next element in the GIWA chain is the immediate cause; defined as the physical, biological or chemical variable that produces the GIWA issue. For example, for the issue of eutrophication the immediate causes may be, inter alia:

- Enhanced nutrient inputs;
- Increased recycling/mobilisation;
- Trapping of nutrients (e.g. in river impoundments);
- Run-off and stormwaters

Once the relevant immediate cause(s) for the particular system has (have) been identified, the sectors of human activity that contribute most significantly to the immediate cause have to be determined. Assuming that the most important immediate cause in our example had been increased nutrient concentrations, then it is logical that the most likely sources of those nutrients would be the agricultural, urban or industrial sectors. After identifying the sectors that are primarily

[1] This does not mean that the methodology ignores statistical or quantitative studies; as has already been pointed out, the available evidence that justifies the assumption of causal links should be provided in the assessment.

responsible for the immediate causes, the root causes acting on those sectors must be determined. For example, if agriculture was found to be primarily responsible for the increased nutrient concentrations, the root causes could potentially be:

- Economic (e.g. subsidies to fertilisers and agricultural products);
- Legal (e.g. inadequate regulation);
- Failures in governance (e.g. poor enforcement); or
- Technology or knowledge related (e.g. lack of affordable substitutes for fertilisers or lack of knowledge as to their application).

Once the most relevant root causes have been identified, an explanation, which includes available data and information, of how they are responsible for the primary environmental and socio-economic problems in the region should be provided.

Policy option analysis

Despite considerable effort of many Governments and other organisations to address transboundary water problems, the evidence indicates that there is still much to be done in this endeavour. An important characteristic of GIWA's Policy Option Analysis (POA) is that its recommendations are firmly based on a better understanding of the root causes of the problems. Freshwater scarcity, water pollution, overexploitation of living resources and habitat destruction are very complex phenomena. Policy options that are grounded on a better understanding of these phenomena will contribute to create more effective societal responses to the extremely complex water related transboundary problems. The core of POA in the assessment consists of two tasks:

Construct policy options

Policy options are simply different courses of action, which are not always mutually exclusive, to solve or mitigate environmental and socio-economic problems in the region. Although a multitude of different policy options could be constructed to address each root cause identified in the CCA, only those few policy options that have the greatest likelihood of success were analysed in the GIWA.

Select and apply the criteria on which the policy options will be evaluated

Although there are many criteria that could be used to evaluate any policy option, GIWA focuses on:

- Effectiveness (certainty of result)
- Efficiency (maximisation of net benefits)
- Equity (fairness of distributional impacts)
- Practical criteria (political acceptability, implementation feasibility).

The policy options recommended by the GIWA are only contributions to the larger policy process and, as such, the GIWA methodology developed to test the performance of various options under the different circumstances has been kept simple and broadly applicable.

Global International Waters Assessment

Table 5a: Scoring criteria for environmental impacts of Freshwater shortage

Issue	Score 0 = no known impact	Score 1 = slight impact	Score 2 = moderate impact	Score 3 = severe impact
Issue 1: Modification of stream flow "An increase or decrease in the discharge of streams and rivers as a result of human interventions on a local/ regional scale (see Issue 19 for flow alterations resulting from global change) over the last 3-4 decades."	■ No evidence of modification of stream flow.	■ There is a measurably changing trend in annual river discharge at gauging stations in a major river or tributary (basin > 40 000 km^2); or ■ There is a measurable decrease in the area of wetlands (other than as a consequence of conversion or embankment construction); or ■ There is a measurable change in the interannual mean salinity of estuaries or coastal lagoons and/or change in the mean position of estuarine salt wedge or mixing zone; or ■ Change in the occurrence of exceptional discharges (e.g. due to upstream damming.	■ Significant downward or upward trend (more than 20% of the long term mean) in annual discharges in a major river or tributary draining a basin of >250 000 km^2; or ■ Loss of >20% of flood plain or deltaic wetlands through causes other than conversion or artificial embankments; or ■ Significant loss of riparian vegetation (e.g. trees, flood plain vegetation); or ■ Significant saline intrusion into previously freshwater rivers or lagoons.	■ Annual discharge of a river altered by more than 50% of long term mean; or ■ Loss of >50% of riparian or deltaic wetlands over a period of not less than 40 years (through causes other than conversion or artificial embankment); or ■ Significant increased siltation or erosion due to changing in flow regime (other than normal fluctuations in flood plain rivers); or ■ Loss of one or more anadromous or catadromous fish species for reasons other than physical barriers to migration, pollution or overfishing.
Issue 2: Pollution of existing supplies "Pollution of surface and ground fresh waters supplies as a result of point or diffuse sources"	■ No evidence of pollution of surface and ground waters.	■ Any monitored water in the region does not meet WHO or national drinking water criteria, other than for natural reasons; or ■ There have been reports of one or more fish kills in the system due to pollution within the past five years.	■ Water supplies does not meet WHO or national drinking water standards in more than 30% of the region; or ■ There are one or more reports of fish kills due to pollution in any river draining a basin of >250 000 km^2 .	■ River draining more than 10% of the basin have suffered polysaprobic conditions, no longer support fish, or have suffered severe oxygen depletion ■ Severe pollution of other sources of freshwater (e.g. groundwater)
Issue 3: Changes in the water table "Changes in aquifers as a direct or indirect consequence of human activity"	■ No evidence that abstraction of water from aquifers exceeds natural replenishment.	■ Several wells have been deepened because of excessive aquifer draw-down; or ■ Several springs have dried up; or ■ Several wells show some salinisation.	■ Clear evidence of declining base flow in rivers in semi-arid areas; or ■ Loss of plant species in the past decade, that depend on the presence of ground water; or ■ Wells have been deepened over areas of hundreds of km^2;or ■ Salinisation over significant areas of the region.	■ Aquifers are suffering salinisation over regional scale; or ■ Perennial springs have dried up over regionally significant areas; or ■ Some aquifers have become exhausted

Table 5b: Scoring criteria for environmental impacts of Pollution

Issue	Score 0 = no known impact	Score 1 = slight impact	Score 2 = moderate impact	Score 3 = severe impact
Issue 4: Microbiological pollution "The adverse effects of microbial constituents of human sewage released to water bodies."	■ Normal incidence of bacterial related gastroenteric disorders in fisheries product consumers and no fisheries closures or advisories.	■ There is minor increase in incidence of bacterial related gastroenteric disorders in fisheries product consumers but no fisheries closures or advisories.	■ Public health authorities aware of marked increase in the incidence of bacterial related gastroenteric disorders in fisheries product consumers; or ■ There are limited area closures or advisories reducing the exploitation or marketability of fisheries products.	■ There are large closure areas or very restrictive advisories affecting the marketability of fisheries products; or ■ There exists widespread public or tourist awareness of hazards resulting in major reductions in the exploitation or marketability of fisheries products.
Issue 5: Eutrophication "Artificially enhanced primary productivity in receiving water basins related to the increased availability or supply of nutrients, including cultural eutrophication in lakes."	■ No visible effects on the abundance and distributions of natural living resource distributions in the area; and ■ No increased frequency of hypoxia[1] or fish mortality events or harmful algal blooms associated with enhanced primary production; and ■ No evidence of periodically reduced dissolved oxygen or fish and zoobenthos mortality; and ■ No evident abnormality in the frequency of algal blooms.	■ Increased abundance of epiphytic algae; or ■ A statistically significant trend in decreased water transparency associated with algal production as compared with long-term (>20 year) data sets; or ■ Measurable shallowing of the depth range of macrophytes.	■ Increased filamentous algal production resulting in algal mats; or ■ Medium frequency (up to once per year) of large-scale hypoxia and/or fish and zoobenthos mortality events and/or harmful algal blooms.	■ High frequency (>1 event per year), or intensity, or large areas of periodic hypoxic conditions, or high frequencies of fish and zoobenthos mortality events or harmful algal blooms; or ■ Significant changes in the littoral community; or ■ Presence of hydrogen sulphide in historically well oxygenated areas.

Issue 6: Chemical pollution "The adverse effects of chemical contaminants released to standing or marine water bodies as a result of human activities. Chemical contaminants are here defined as compounds that are toxic or persistent or bioaccumulating."	■ No known or historical levels of chemical contaminants except background levels of naturally occurring substances; and ■ No fisheries closures or advisories due to chemical pollution; and ■ No incidence of fisheries product tainting; and ■ No unusual fish mortality events. If there is no available data use the following criteria: ■ No use of pesticides; and ■ No sources of dioxins and furans; and ■ No regional use of PCBs; and ■ No bleached kraft pulp mills using chlorine bleaching; and ■ No use or sources of other contaminants.	■ Some chemical contaminants are detectable but below threshold limits defined for the country or region; or ■ Restricted area advisories regarding chemical contamination of fisheries products. If there is no available data use the following criteria: ■ Some use of pesticides in small areas; or ■ Presence of small sources of dioxins or furans (e.g., small incineration plants or bleached kraft/pulp mills using chlorine); or ■ Some previous and existing use of PCBs and limited amounts of PCB-containing wastes but not in amounts invoking local concerns; or ■ Presence of other contaminants.	■ Some chemical contaminants are above threshold limits defined for the country or region; or ■ Large area advisories by public health authorities concerning fisheries product contamination but without associated catch restrictions or closures; or ■ High mortalities of aquatic species near outfalls. If there is no available data use the following criteria: ■ Large-scale use of pesticides in agriculture and forestry; or ■ Presence of major sources of dioxins or furans such as large municipal or industrial incinerators or large bleached kraft pulp mills; or ■ Considerable quantities of waste PCBs in the area with inadequate regulation or has invoked some public concerns; or ■ Presence of considerable quantities of other contaminants.	■ Chemical contaminants are above threshold limits defined for the country or region; and ■ Public health and public awareness of fisheries contamination problems with associated reductions in the marketability of such products either through the imposition of limited advisories or by area closures of fisheries; or ■ Large-scale mortalities of aquatic species. If there is no available data use the following criteria: ■ Indications of health effects resulting from use of pesticides; or ■ Known emissions of dioxins or furans from incinerators or chlorine bleaching of pulp; or ■ Known contamination of the environment or foodstuffs by PCBs; or ■ Known contamination of the environment or foodstuffs by other contaminants.
Issue 7: Suspended solids "The adverse effects of modified rates of release of suspended particulate matter to water bodies resulting from human activities"	■ No visible reduction in water transparency; and ■ No evidence of turbidity plumes or increased siltation; and ■ No evidence of progressive riverbank, beach, other coastal or deltaic erosion.	■ Evidently increased or reduced turbidity in streams and/or receiving riverine and marine environments but without major changes in associated sedimentation or erosion rates, mortality or diversity of flora and fauna; or ■ Some evidence of changes in benthic or pelagic biodiversity in some areas due to sediment blanketing or increased turbidity.	■ Markedly increased or reduced turbidity in small areas of streams and/or receiving riverine and marine environments; or ■ Extensive evidence of changes in sedimentation or erosion rates; or ■ Changes in benthic or pelagic biodiversity in areas due to sediment blanketing or increased turbidity.	■ Major changes in turbidity over wide or ecologically significant areas resulting in markedly changed biodiversity or mortality in benthic species due to excessive sedimentation with or without concomitant changes in the nature of deposited sediments (i.e., grain-size composition/redox); or ■ Major change in pelagic biodiversity or mortality due to excessive turbidity.
Issue 8: Solid wastes "Adverse effects associated with the introduction of solid waste materials into water bodies or their environs."	■ No noticeable interference with trawling activities; and ■ No noticeable interference with the recreational use of beaches due to litter; and ■ No reported entanglement of aquatic organisms with debris.	■ Some evidence of marine-derived litter on beaches; or ■ Occasional recovery of solid wastes through trawling activities; but ■ Without noticeable interference with trawling and recreational activities in coastal areas.	■ Widespread litter on beaches giving rise to public concerns regarding the recreational use of beaches; or ■ High frequencies of benthic litter recovery and interference with trawling activities; or ■ Frequent reports of entanglement/ suffocation of species by litter.	■ Incidence of litter on beaches sufficient to deter the public from recreational activities; or ■ Trawling activities untenable because of benthic litter and gear entanglement; or ■ Widespread entanglement and/or suffocation of aquatic species by litter.
Issue 9: Thermal "The adverse effects of the release of aqueous effluents at temperatures exceeding ambient temperature in the receiving water body."	■ No thermal discharges or evidence of thermal effluent effects.	■ Presence of thermal discharges but without noticeable effects beyond the mixing zone and no significant interference with migration of species.	■ Presence of thermal discharges with large mixing zones having reduced productivity or altered biodiversity; or ■ Evidence of reduced migration of species due to thermal plume.	■ Presence of thermal discharges with large mixing zones with associated mortalities, substantially reduced productivity or noticeable changes in biodiversity; or ■ Marked reduction in the migration of species due to thermal plumes.
Issue 10: Radionuclide "The adverse effects of the release of radioactive contaminants and wastes into the aquatic environment from human activities."	■ No radionuclide discharges or nuclear activities in the region.	■ Minor releases or fallout of radionuclides but with well regulated or well-managed conditions complying with the Basic Safety Standards.	■ Minor releases or fallout of radionuclides under poorly regulated conditions that do not provide an adequate basis for public health assurance or the protection of aquatic organisms but without situations or levels likely to warrant large scale intervention by a national or international authority.	■ Substantial releases or fallout of radionuclides resulting in excessive exposures to humans or animals in relation to those recommended under the Basic Safety Standards; or ■ Some indication of situations or exposures warranting intervention by a national or international authority.
Issue 11: Spills "The adverse effects of accidental episodic releases of contaminants and materials to the aquatic environment as a result of human activities."	■ No evidence of present or previous spills of hazardous material; or ■ No evidence of increased aquatic or avian species mortality due to spills.	■ Some evidence of minor spills of hazardous materials in small areas with insignificant small-scale adverse effects one aquatic or avian species.	■ Evidence of widespread contamination by hazardous or aesthetically displeasing materials assumed to be from spillage (e.g. oil slicks) but with limited evidence of widespread adverse effects on resources or amenities; or ■ Some evidence of aquatic or avian species mortality through increased presence of contaminated or poisoned carcasses on beaches.	■ Widespread contamination by hazardous or aesthetically displeasing materials from frequent spills resulting in major interference with aquatic resource exploitation or coastal recreational amenities; or ■ Significant mortality of aquatic or avian species as evidenced by large numbers of contaminated carcasses on beaches.

Table 5c: Scoring criteria for environmental impacts of Habitat and community modification

Issue	Score 0 = no known impact	Score 1 = slight impact	Score 2 = moderate impact	Score 3 = severe impact
Issue 12: Loss of ecosystems or ecotones "The complete destruction of aquatic habitats. For the purpose of GIWA methodology, recent loss will be measured as a loss of pre-defined habitats over the last 2-3 decades."	■ There is no evidence of loss of ecosystems or habitats.	■ There are indications of fragmentation of at least one of the habitats.	■ Permanent destruction of at least one habitat is occurring such as to have reduced their surface area by up to 30 % during the last 2-3 decades.	■ Permanent destruction of at least one habitat is occurring such as to have reduced their surface area by >30% during the last 2-3 decades.
Issue 13: Modification of ecosystems or ecotones, including community structure and/or species composition "Modification of pre-defined habitats in terms of extinction of native species, occurrence of introduced species and changing in ecosystem function and services over the last 2-3 decades."	■ No evidence of change in species complement due to species extinction or introduction; and ■ No changing in ecosystem function and services.	■ Evidence of change in species complement due to species extinction or introduction	■ Evidence of change in species complement due to species extinction or introduction; and ■ Evidence of change in population structure or change in functional group composition or structure	■ Evidence of change in species complement due to species extinction or introduction; and ■ Evidence of change in population structure or change in functional group composition or structure; and ■ Evidence of change in ecosystem services[2].

[2] Constanza, R. et al. (1997). The value of the world ecosystem services and natural capital, Nature 387:253-260.

Table 5d: Scoring criteria for environmental impacts of Unsustainable exploitation of fish and other living resources

Issue	Score 0 = no known impact	Score 1 = slight impact	Score 2 = moderate impact	Score 3 = severe impact
Issue 14: Overexploitation "The capture of fish, shellfish or marine invertebrates at a level that exceeds the maximum sustainable yield of the stock."	■ No harvesting exists catching fish (with commercial gear for sale or subsistence).	■ Commercial harvesting exists but there is no evidence of over-exploitation.	■ One stock is exploited beyond MSY (maximum sustainable yield) or is outside safe biological limits.	■ More than one stock is exploited beyond MSY or is outside safe biological limits.
Issue 15: Excessive by-catch and discards "By-catch refers to the incidental capture of fish or other animals that are not the target of the fisheries. Discards refers to dead fish or other animals that are returned to the sea."	■ Current harvesting practices show no evidence of excessive by-catch and/or discards.	■ Up to 30% of the fisheries yield (by weight) consists of by-catch and/or discards.	■ 30-60% of the fisheries yield consists of by-catch and/or discards.	■ Over 60% of the fisheries yield is by-catch and/or discards; or ■ Noticeable incidence of capture of endangered species.
Issue 16: Destructive fishing practices "Fishing practices that are deemed to produce significant harm to marine, lacustrine or coastal habitats and communities."	■ No evidence of habitat destruction due to fisheries practices.	■ Habitat destruction resulting in changes in distribution of fish or shellfish stocks; or ■ Trawling of any one area of the seabed is occurring less than once per year.	■ Habitat destruction resulting in moderate reduction of stocks or moderate changes of the environment; or ■ Trawling of any one area of the seabed is occurring 1-10 times per year; or ■ Incidental use of explosives or poisons for fishing.	■ Habitat destruction resulting in complete collapse of a stock or far reaching changes in the environment; or ■ Trawling of any one area of the seabed is occurring more than 10 times per year; or ■ Widespread use of explosives or poisons for fishing.
Issue 17: Decreased viability of stocks through contamination and disease "Contamination or diseases of feral (wild) stocks of fish or invertebrates that are a direct or indirect consequence of human action."	■ No evidence of increased incidence of fish or shellfish diseases.	■ Increased reports of diseases without major impacts on the stock.	■ Declining populations of one or more species as a result of diseases or contamination.	■ Collapse of stocks as a result of diseases or contamination.
Issue 18: Impact on biological and genetic diversity "Changes in genetic and species diversity of aquatic environments resulting from the introduction of alien or genetically modified species as an intentional or unintentional result of human activities including aquaculture and restocking."	■ No evidence of deliberate or accidental introductions of alien species; and ■ No evidence of deliberate or accidental introductions of alien stocks; and ■ No evidence of deliberate or accidental introductions of genetically modified species.	■ Alien species introduced intentionally or accidentally without major changes in the community structure; or ■ Alien stocks introduced intentionally or accidentally without major changes in the community structure; or ■ Genetically modified species introduced intentionally or accidentally without major changes in the community structure.	■ Measurable decline in the population of native species or local stocks as a result of introductions (intentional or accidental); or ■ Some changes in the genetic composition of stocks (e.g. as a result of escapes from aquaculture replacing the wild stock).	■ Extinction of native species or local stocks as a result of introductions (intentional or accidental); or ■ Major changes (>20%) in the genetic composition of stocks (e.g. as a result of escapes from aquaculture replacing the wild stock).

Table 5e: Scoring criteria for environmental impacts of Global change

Issue	Score 0 = no known impact	Score 1 = slight impact	Score 2 = moderate impact	Score 3 = severe impact
Issue 19: Changes in hydrological cycle and ocean circulation "Changes in the local/regional water balance and changes in ocean and coastal circulation or current regime over the last 2-3 decades arising from the wider problem of global change including ENSO."	■ No evidence of changes in hydrological cycle and ocean/coastal current due to global change.	■ Change in hydrological cycles due to global change causing changes in the distribution and density of riparian terrestrial or aquatic plants without influencing overall levels of productivity; or ■ Some evidence of changes in ocean or coastal currents due to global change but without a strong effect on ecosystem diversity or productivity.	■ Significant trend in changing terrestrial or sea ice cover (by comparison with a long-term time series) without major downstream effects on river/ocean circulation or biological diversity; or ■ Extreme events such as flood and drought are increasing; or ■ Aquatic productivity has been altered as a result of global phenomena such as ENSO events.	■ Loss of an entire habitat through desiccation or submergence as a result of global change; or ■ Change in the tree or lichen lines; or ■ Major impacts on habitats or biodiversity as the result of increasing frequency of extreme events; or ■ Changing in ocean or coastal currents or upwelling regimes such that plant or animal populations are unable to recover to their historical or stable levels; or ■ Significant changes in thermohaline circulation.
Issue 20: Sea level change "Changes in the last 2-3 decades in the annual/seasonal mean sea level as a result of global change."	■ No evidence of sea level change.	■ Some evidences of sea level change without major loss of populations of organisms.	■ Changed pattern of coastal erosion due to sea level rise has became evident; or ■ Increase in coastal flooding events partly attributed to sea-level rise or changing prevailing atmospheric forcing such as atmospheric pressure or wind field (other than storm surges).	■ Major loss of coastal land areas due to sea-level change or sea-level induced erosion; or ■ Major loss of coastal or intertidal populations due to sea-level change or sea level induced erosion.
Issue 21: Increased UV-B radiation as a result of ozone depletion "Increased UV-B flux as a result polar ozone depletion over the last 2-3 decades."	■ No evidence of increasing effects of UV/B radiation on marine or freshwater organisms.	■ Some measurable effects of UV/B radiation on behavior or appearance of some aquatic species without affecting the viability of the population.	■ Aquatic community structure is measurably altered as a consequence of UV/B radiation; or ■ One or more aquatic populations are declining.	■ Measured/assessed effects of UV/B irradiation are leading to massive loss of aquatic communities or a significant change in biological diversity.
Issue 22: Changes in ocean CO_2 source/sink function "Changes in the capacity of aquatic systems, ocean as well as freshwater, to generate or absorb atmospheric CO_2 as a direct or indirect consequence of global change over the last 2-3 decades."	■ No measurable or assessed changes in CO_2 source/sink function of aquatic system.	■ Some reasonable suspicions that current global change is impacting the aquatic system sufficiently to alter its source/sink function for CO_2.	■ Some evidences that the impacts of global change have altered the source/sink function for CO_2 of aquatic systems in the region by at least 10%.	■ Evidences that the changes in source/sink function of the aquatic systems in the region are sufficient to cause measurable change in global CO_2 balance.

The Global International Waters Assessment (GIWA) is a holistic, globally comparable assessment of all the world's transboundary waters that recognises the inextricable links between freshwater and coastal marine environment and integrates environmental and socio-economic information to determine the impacts of a broad suite of influences on the world's aquatic environment.

Broad Transboundary Approach

The GIWA not only assesses the problems caused by human activities manifested by the physical movement of transboundary waters, but also the impacts of other non-hydrological influences that determine how humans use transboundary waters.

Regional Assessment - Global Perspective

The GIWA provides a global perspective of the world's transboundary waters by assessing 66 regions that encompass all major drainage basins and adjacent large marine ecosystems. The GIWA Assessment of each region incorporates information and expertise from all countries sharing the transboundary water resources.

Global Comparability

In each region, the assessment focuses on 5 broad concerns that are comprised of 22 specific water related issues.

Integration of Information and Ecosystems

The GIWA recognises the inextricable links between freshwater and coastal marine environment and assesses them together as one integrated unit.

The GIWA recognises that the integration of socio-economic and environmental information and expertise is essential to obtain a holistic picture of the interactions between the environmental and societal aspects of transboundary waters.

Priorities, Root Causes and Options for the Future

The GIWA indicates priority concerns in each region, determines their societal root causes and develops options to mitigate the impacts of those concerns in the future.

This Report

This assessment presents the assessment of the GIWA region 27, which comprises the economically and environmentally important Colorado River Basin. Insufficient water is being allocated for ecosystem maintenance and restoration of the Colorado River Delta, as a result of upstream diversion for intensive use by human activities, particularly irrigated agriculture. The past and present status and future prospects of the region are discussed, and the transboundary issues of freshwater shortage are traced back to their root causes. Policy options have been recommended to address these driving issues and secure water resources for the rehabilitation of the Delta's ecology and future prosperity of its inhabitants.

UNEP

GEF

HÖGSKOLAN KALMAR UNIVERSITY