

# Assessment

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**Table 10** Scoring table for the Colorado River Basin region.

Assessment of GIWA concerns and issues according to scoring criteria (see Methodology chapter)		The arrow indicates the likely direction of future changes.					
<b>IMPACT</b> 0	No known impacts	<b>IMPACT</b> 2	Moderate impacts	↗	Increased impact	→	No changes
<b>IMPACT</b> 1	Slight impacts	<b>IMPACT</b> 3	Severe impacts	↘	Decreased impact		
Colorado River Basin		Environmental impacts	Economic impacts	Health impacts	Other community impacts	Overall Score**	Priority***
<b>Freshwater shortage</b>		2.6* ↘	1.8 ↗	1.0 →	2.3 ↗	<b>2.0</b>	<b>1</b>
Modification of stream flow		3					
Pollution of existing supplies		1					
Changes in the water table		2					
<b>Pollution</b>		1.1* ↘	2.3 →	2.2 →	2.4 →	<b>2.0</b>	<b>2</b>
Microbiological pollution		1					
Eutrophication		1					
Chemical		2					
Suspended solids		1					
Solid waste		1					
Thermal		0					
Radionucleid		1					
Spills		1					
<b>Habitat and community modification</b>		3.0* ↘	1.8 →	0 →	1.6 →	<b>1.5</b>	<b>3</b>
Loss of ecosystems		3					
Modification of ecosystems		3					
<b>Unsustainable exploitation of fish</b>		2.9* ↘	1.4 →	0 →	1.6 →	<b>1.3</b>	<b>4</b>
Overexploitation		3					
Excessive by-catch and discards		3					
Destructive fishing practices		3					
Decreased viability of stock		2					
Impact on biological and genetic diversity		3					
<b>Global change</b>		0* →	0 →	0 →	0 →	<b>0</b>	<b>5</b>
Changes in hydrological cycle		0					
Sea level change		0					
Increased UV-B radiation		0					
Changes in ocean CO <sub>2</sub> 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.

## IMPACT 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 16<sup>th</sup> 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<sup>2</sup>, including 5 200 km<sup>2</sup> 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<sup>3</sup>/year (USBR 2000b). The average flows between 1906 and 1930 were almost 22.1 km<sup>3</sup>/year, but this average reduced to only 17.5 km<sup>3</sup>/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).

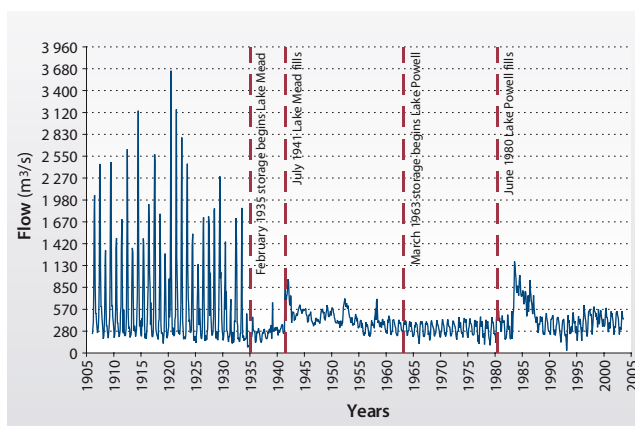
Before the filling of Hoover Dam in the 1930s (creating Lake Mead), the delta experienced a perennial discharge from the Colorado River (USGS 2002a). By the time Glen Canyon Dam was completed in 1962, regular input of Colorado River water to the delta and Upper Gulf of California had completely ceased 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).

**Table 11** Estimated Colorado River budget.

Water demand	Quantity (km <sup>3</sup> /year)
Upper Basin (9.25 km <sup>3</sup> ) Lower Basin (9.25 km <sup>3</sup> ) – 1922 Colorado River Compact	18.5
Central Arizona Project (rising to 3.48 km <sup>3</sup> ) – 1922 Colorado 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)

### 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<sup>3</sup> 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 <sup>a</sup>	723	-
Colorado River at Parker Dam <sup>a</sup>	747	-
Colorado River at Imperial Dam <sup>b</sup>	784	713
Colorado River at Northerly International Boundary <sup>b</sup>	906	760
Other deliveries near Southerly International Boundary <sup>b</sup>	1 274	1 222
Main Outlet Drain Extension canal (MODE) <sup>b</sup>	2 838	2 045
New River at border <sup>c</sup>	2 836	2 583
Hardy River <sup>c</sup>	1 810	560
Ciénega de Santa Clara <sup>c</sup>	3 000	5 000
Salton Sea <sup>b</sup>	42 271	43 304

(Source: <sup>a</sup> MWD/USBR 1998, <sup>b</sup> IBWC 1991-1998, <sup>c</sup> 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

**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 <sup>3</sup> )	Average postlarvae relative abundance (larvae/m <sup>3</sup> )	Standard error
1993	312.01	43.6 <sup>a</sup>	13.6
1994	67.28	11.63 <sup>b</sup>	1.35
1995	76.25	11.20 <sup>b</sup>	2.25
1996	71.42	16.01 <sup>b</sup>	3.37
1997	115.65	33.32 <sup>c</sup>	8.06

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

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.

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).

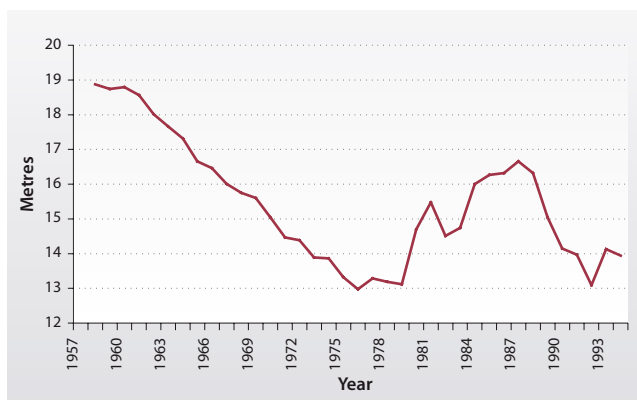
### Changes in water table

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.

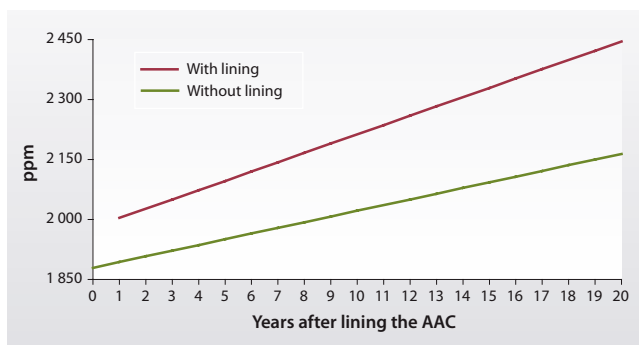
		Without lining AAC (million m <sup>3</sup> /year)	With lining AAC (million m <sup>3</sup> /year)
<b>Inflow (Recharge)</b>			
Sub-terranean	All American Canal (AAC)	100	20
	Arizona	70	70
	San Luis R.C.	50	50
Artificial	Drains	442	442
	Return flow	457	457
Superficial	Colorado River	7.8	7.8
Inflow total		1 127	1 047
<b>Outflow (Discharge)</b>			
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 ( $\Delta S_a$ )		-13	-92.8

Note: To calculate the change in aquifer storage  $\Delta S_a = [\text{Inflow}] - [\text{Outflow}]$ .  
(Source: Díaz-Cabrera 2001)

mounts 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<sup>3</sup> of groundwater is used annually in the San Luis region (23 million m<sup>3</sup>) and for urban areas like San Luis Rio Colorado, Mexicali (82 million m<sup>3</sup>), Tecate (0.33 million m<sup>3</sup>), Ensenada (9 million m<sup>3</sup>) and Tijuana (80 million m<sup>3</sup>). 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<sup>3</sup> 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<sup>3</sup> of groundwater annually at San Luis-Mesa Yuma (IBWC 1973).

Approximately 8 600 m<sup>3</sup> 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							
TDS	Softeners			Dispensed and filtered			
	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 (m <sup>3</sup> /year) <sup>1</sup>	Economic impact (%)		Equivalent crop salinity yield relationship	
		Crop value <sup>2</sup>		Crop value <sup>2</sup>	
		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: <sup>1</sup>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 m<sup>3</sup>/year. <sup>2</sup>Two values were assumed for ornamentals; 8 100 USD/ha and 20 200 USD/ha, respectively. (Source: MWD/USBR 1998)

123 million m<sup>3</sup> for 34.5 USD per m<sup>3</sup> 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 m<sup>3</sup> of conserved water from agricultural users to the authority.

If the work is to be completed, the Mexicali Aquifer would lose 80 million m<sup>3</sup> 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 m<sup>3</sup> 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/m <sup>3</sup> )	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	18 250 000	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/m <sup>3</sup> )	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/m <sup>3</sup> )	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 (*Distichlis 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-assignment, 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<sup>3</sup> water annually into the Rio Grande. The United States, in turn, releases 1.85 km<sup>3</sup> of Colorado River water to Mexico. Since 1992, Mexico has fallen more than 1.8 million m<sup>3</sup> 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 runoff (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 desalination 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<sup>3</sup>/s nor more than 113.3 m<sup>3</sup>/s.
- During the remaining months of the year the prescribed rate of delivery shall be not less than 31.9 m<sup>3</sup>/s nor more than 113.3 m<sup>3</sup>/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<sup>3</sup> 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,

**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 ( <i>Phalacrocorax auritus</i> )	16.7
Cattle egret ( <i>Bubulcus ibis</i> )	4.6
Red Winged blackbird ( <i>Agelaius phoeniceus</i> )	5.1
Great-tailed grackle ( <i>Quiscalus mexicanus</i> )	5.3
Mourning dove ( <i>Zenaida macroura</i> )	2.3
Tilapia ( <i>Tilapia zillii</i> )	6.8
Largemouth bass* ( <i>Micropterus salmoides</i> )	5.1

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

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).

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 ( $\text{ClO}_4^-$ ) - 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  $\mu\text{g/l}$ . 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 <sup>1</sup> (%)									
	Strawberry	Misc. vegetables	Nursery <sup>2</sup>	Cut flowers <sup>2</sup>	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: <sup>1</sup>Prepared for use in Salinity Impact Model in Metropolitan's service area. Crops are grouped into the main categories in Metropolitan's service area. <sup>2</sup>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<sup>3</sup> to 810 USD/million m<sup>3</sup> 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<sup>3</sup>, 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<sup>3</sup> (retail cost) and the disposal cost is about 490 USD/million m<sup>3</sup> resulting in a net cost increase of 31 USD/million m<sup>3</sup> of product water. Thus, the total unit cost of changing salinity from

**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 <sup>3</sup> )
Demineralisation	12	1.14
Softening	12	0.47
No treatment	21	--
Total	45	0.44

(Source: MWD/USBR 1998)

700 mg/l to 600 mg/l is about 114 USD/million m<sup>3</sup> or 1.14 USD/million m<sup>3</sup> per mg/l increase in salinity (Table 22) (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<sup>3</sup> to 122 USD/million m<sup>3</sup>, 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<sup>3</sup> 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<sup>3</sup> 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<sup>3</sup> 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 <sup>3</sup> )	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<sub>4</sub><sup>-</sup>) 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<sup>3</sup> 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<sup>3</sup> 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.

## 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 20<sup>th</sup> 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 threat 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 phreatophytes. 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 (*Ralusa 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. *Eleoterpis 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

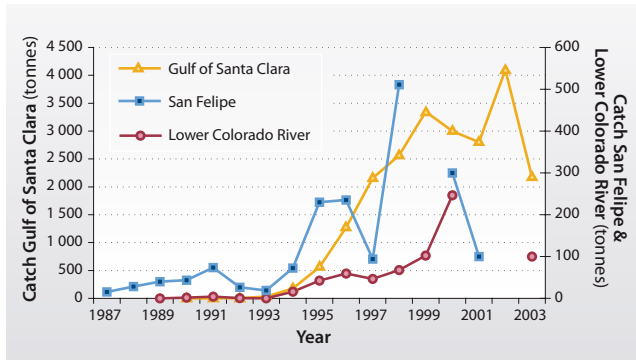
**Table 24** Fishes of the Colorado River in the Grand Canyon, and their status.

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

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

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.

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. Cucupá) 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<sup>3</sup> of water spilled from



**Figure 10** Totoaba fishery in the late 1940s.

upstream reservoirs and revitalised wetlands such as the Ciénega de Santa Clara. The Gila River floods in 1993 produced similar results.

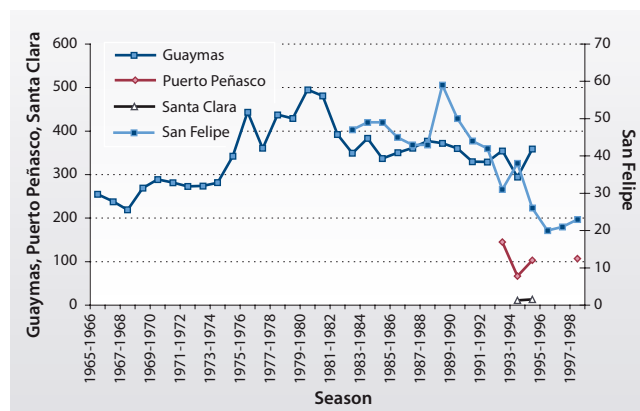
The Totoaba fishery declined dramatically since 1970 due to declining populations and to restrictions imposed (in 1975) when catch levels threatened the population. Despite closures, Totoaba gill net fisheries continue on a small-scale and they remain a threat to the Marine vaquita populations. Juvenile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

## Environmental impacts

### Overexploitation

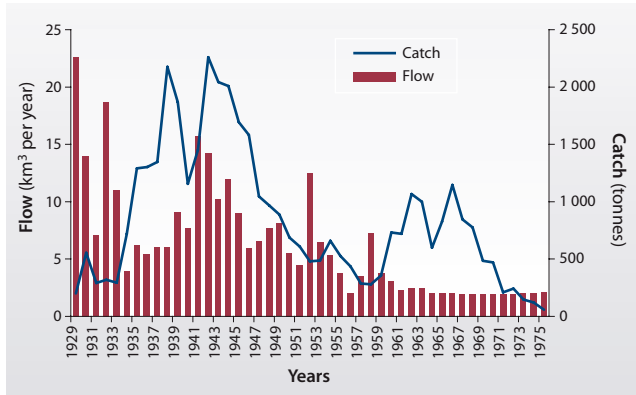
The overexploitation of fish resources is a considerable problem in the Colorado River Delta and the Upper Gulf of California. A large number of invertebrates (e.g. *Penaeus stylirostris* and *Penaeus californiensis*), mammals (e.g. *Tursiops truncatus*) and commercial species of fishes such as Totoaba (*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)



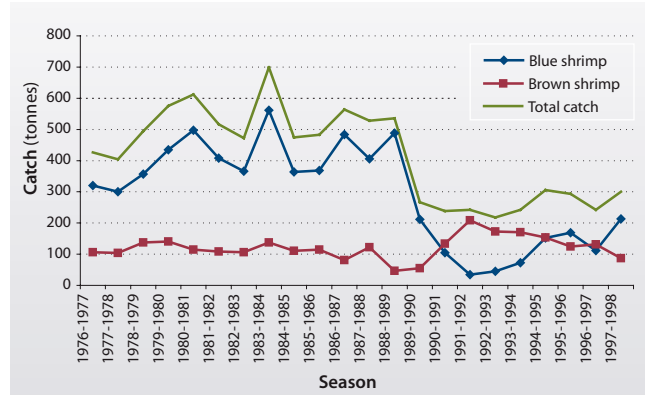
**Figure 12** Totoaba fishery annual yield and Colorado River flows to Mexico 1930-1975.  
(Source: Flanagan & Hendrickson 1976 with data obtained from Arvizu & Chavez 1974)

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



**Figure 13** Pangas fishing in the Upper Gulf of California.  
(Photo: G. Ybarra)



**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)

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).

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

(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<sup>2</sup> 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<sup>2</sup> 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 Zanjón 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

**Table 27** Average annual catches by fishery 1994-2000.

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

(Source: Secretaría de Desarrollo Económico 2000)

fish, although there also exists minor tonnage fisheries with important economic revenue, such as the shrimp fishery (Table 27).

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

**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 ( <i>Katsuwonus</i> spp.)	9 669	4 665	4 225 000	ND	ND	91 000
Curvina ( <i>Gynoscion</i> spp.)	124	422	441 000	195	2 496	2 386 000
Smoothhound ( <i>Mustelus</i> 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)

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 Sicklefins smoothhound (*Mustelus lunulatus*) are being overexploited (Table 28).

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 ( <i>Litopenaeus</i> 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 ( <i>Diplodus</i> spp.)	3 816 000	5 101	ND	Sinaloa (Topolobampo and El Castillo) and Sonora (Puerto Peñasco and Guaymas).
Corvina ( <i>Gynoscion</i> spp.)	3 638 000	3 947	Fished by fin fishers and shrimpers.	Upper Gulf of California.
Sierra ( <i>Scomberomorus</i> spp.)	2 632 000	3 275	15 vessels of 3 fishermen.	Upper Gulf of California and east to Huatabampo.
Berrugata ( <i>Menticirrhus</i> spp.)	2 519 000	4 860	Fished by fin fishers and shrimpers.	South of the Upper Gulf and southeast and east of Topolobampo.
Baqueta ( <i>Epinephelus</i> spp.)	2 505 000	1 201	Minor vessels of 3 fishermen.	Upper Gulf of California, between Guaymas and Huatabampo.
Bagre ( <i>Ictalurus</i> 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<sup>2</sup>. Today, the species typically occurs within 30 km of the River's mouth and at densities of only 0.15 individuals per m<sup>2</sup> (Rodríguez 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 (Rodríguez 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 (Rodríguez et al. 2001). Restoration of shrimp habitat would require a vastly larger volume (308 million m<sup>3</sup>/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<sup>3</sup> over four years, or an average of 130 million m<sup>3</sup>/year, which is much less than 1% of the annual base flow of the River (20 km<sup>3</sup>/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).

## 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<sup>3</sup> 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<sup>3</sup> per year – an amount exceeding the average annual surface flow of the state (2.8 km<sup>3</sup>/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.

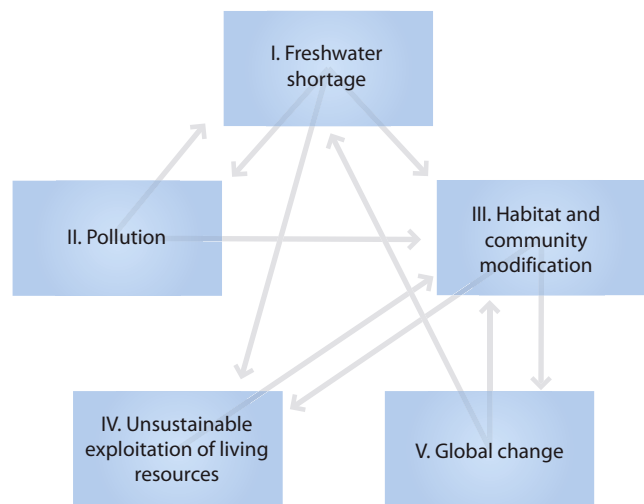


Figure 16 Linkages between the GIWA concerns.