

WORCESTER POLYTECHNIC INSTITUTE

# Effects of the Lower Colorado River Water Issues on Biota and the Future conditions of the Salton Sea

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By:

Jing Fu  
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## ABSTRACT

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This project investigated changing habitats of the lower Colorado River. By collecting and reviewing authoritative publications and examining information from various sources a comprehensive understanding of the issues was developed. A continuous increase in salinity and nutrient composition of the Colorado River and reduction in its water flow have created many issues for the local biota. This report presents future scenarios of the River and the Salton Sea and proposes possible solutions for rescuing this important environment.

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## INTRODUCTION

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With rapid increase in the human population, water has become more precious. Societies demand water for drinking, irrigating lands, generating electricity, and many more tasks that sustain our lifestyle. Countries break out wars to fight for water supplies. The reduction of water quantity in water bodies, the irreversible conversion of fresh water into salty water, and the dreadful chemical contamination of water resources have become a serious global issue. These issues are common to one of the most important rivers in America as well, the Colorado River.

History shows that the Colorado River has been very important to the American people. It provided (and still provides) significant amount of natural resources: water, and aquatic animals. In addition, it used to be a main mode of transport. However, with the passage of time, human activities started to harm the river. Establishment of dams, increased irrigation, and excessive utilization of river water in cities caused severe water shortages. The water shortage in turn caused an increase in water salinity. It is hypothesized that those alternations in the lower Colorado River will influence the ecosystem, destroy animal habitats and endanger the local fauna. It is predicted that those water issues will alter the chemical composition and nutrient distribution of the river. Lastly, it is also estimated that the salinity of the Salton Sea will increase and that the Sea will undergo drastic chemical and physical changes.

This project intensively reviewed many scientific publications related to the Colorado River. The most recent information on issues affecting the Colorado River was collected. Through in-depth investigations conclusions were drawn pertaining to current issues of

the river. The issues faced by the water of the lower Colorado River and the Salton Sea has negative impacts on different aspects of the local ecosystem, such as, water temperature, turbidity, water chemistry, and aquatic habitats. It also disrupts fish migration and spawn, increases competition and predation from non-native species, reduces productivity of other animals, decreases the population of marine life, and extirpates native species (Stanford & Ward, 1986). Some important endangered animals living in the lower Colorado Delta are the Yuma clapper rail, tilapia, catfish, carp, largemouth bass, desert pupfish, widgeons, cormorants, terns, pelicans, and herons (Cohn, 2004). Among these endangered animals, studies related to tilapia, pike minnow, hump back chub, jaguar, vaquita porpoises, and Yuma clapper Rail were reviewed in detail. The studies showed that the alternation of water quality of the lower Colorado River and the Colorado River Delta resulted in serious ecological consequences.

## BACKGROUND

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### BRIEF INTRODUCTION TO COLORADO RIVER

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The Colorado River is one of the most important rivers in North America. It is about 1,450 miles (2,333 kilometers) long and it passes through the southwestern United States and northwestern Mexico. The river originates in Rocky Mountain National Park in north-central Colorado, travels through Utah, Lake Powell, the Grand Canyon, Lake Mead, and finally ends at the western shore of the Gulf of California, Mexico. During its passage from its origin to the sea, the river drops more than 10,000 feet (3048 meters) in elevation generating dangerous whitewater rapids. The watershed of the river and its tributaries covers 242,000 square miles in seven US States (8.5 percent of the continental United States) and 2,000 square miles in Mexico (Cohn, 2004).

Three-fourths of the Colorado basin is federal land which comprises national forests, national parks, and Indian reservations. It also covers 17 miles (27 kilometers) at the international boundary between Arizona and Mexico. Two thirds of water from the Colorado River is used for irrigation while the rest is either used in urban areas, or it evaporates into the atmosphere, or supplies water to riparian vegetation. The river is also the main power resource for southern and western America. It supports industrial development, transportation, and utilities in urban communities (Atkins).

The Colorado River is one of the most controlled rivers in the world. Abundant dams and water management agencies have been established for the exploitation of this water resource. It is the main source of water for the states of Arizona, California, Colorado,

Nevada, New Mexico, and Utah. The river is also the main supplier of water for the Mexicali city in northern Mexico. States and nations have been competing for more than a hundred years in order to use water from this river. Although sophisticated divisions of the river lead to high efficiency in water usage, they also cause many environmental and ecological problems. The excessive establishment of dams and excessive river diversions cause water resource shortages in Mexico.

The reduction of water inflow also leads to an increase in river water salinity. Moreover, this has negative impacts on different aspects of the riparian ecosystem, such as, water temperature, turbidity, water chemistry, and aquatic habitat. It also disrupts fish migration and spawn, increases competition and predation from non-native species, reduces productivity of the estuary, decreases the population of marine life, and extirpates native species (Stanford & Ward, 1986). Some important animals living in the lower Colorado Delta are: clapper rail, tilapia, catfish, carp, largemouth bass, desert pupfish, widgeons, cormorants, terns, pelicans, and herons (Cohn, 2004). Scientists have been conducting plentiful studies on the otolith, catfish, clam, and *typha domingensis*. They use these animals as biomarkers to show that the alternation of water quality of the Colorado River Delta results in serious ecological consequences.

Another major contributor of increased salinity would be high evapotranspiration. High evapotranspiration causes the shrinkage of the Imperial Valley and Mexicali Valley wetland. This leads to increased numbers of endangered species and reduction of migratory bird habitats.



## MEXICALI VALLEY

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Mexicali is the capital of the Mexican state of Baja California. It is located at the border of Southern California and northern Mexico. About sixty years ago Mexicali Valley developed into a large producer of cotton. At present, it is still a productive region for cotton, vegetables, and wheat. The food produced in the valley is exported to the world. However, a court regulation from San Francisco could alter many Mexican farmers' lives. A policy intends to fix leaky canals in Southern California for the purpose of water conservation. However, the leaks have been the main ground water resource for farms in the Mexicali Valley. The reduction of the ground water resource will reduce their agricultural productivity, influence the income of the Mexican farmers, and decrease the export of food to other neighboring countries (BBC, 2007).

## THE GULF OF CALIFORNIA

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The Gulf of California is a water body in Mexico that separates the Baja California Peninsula from the Mexican mainland; it is to the south of the state of California. The Colorado River flows into the Gulf of California, and the estuary is well known as "The Colorado River Delta". This delta has the most distinctive marine ecosystem. People also call it "the Sea of Cortez". The beautiful coastlines, green cacti, smooth sandy beaches, pleasant lagoons, fancy reefs and lovely palm oases are the unique traits of this region. It is famous for its biodiversity and is the home for many seabirds and marine animals. However, over-pollution, unregulated tourism development, and reduction in freshwater all threaten the ecosystem (Nature Conservancy).

## THE SALTON SEA

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The Salton Sea is a saline lake and is situated in the south-eastern part of California, connected to the Imperial Valley. Its altitude is lower than sea level. California has lost more than ninety percent of its wetlands and the Salton Sea is crucial for supporting the remaining aquatic habitats. However, in the past few decades, due to selenium pollution, lack of water outflow, and other human interferences, the living conditions of animals and plants in the Salton Sea have been greatly damaged. The Salton Sea Authority has recognized these issues and is trying to encourage restoration of the environment there (Salton Sea Authority, 2000).

## WATER QUALITY STUDY

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Human activities often have a negative influence on water quality. The Colorado River basin has been one of the major crude oil extraction and mining resources. Therefore, a significant amount of salt, petroleum oil, and highly toxic elements such as arsenic (As), selenium (Se), and heavy metals disperse into the environment. A variety of chemicals including arsenic based defoliants, pesticides, metals, and salts are used in agricultural areas along the Gila River and in the Mexicali Valley of the Colorado River Delta. Increasing water usage and highly frequent drought have deteriorated water-quality in the Colorado River and its tributaries. Water that flows into the Gila River Basin is irrigation-return water, storm water, and effluent from wastewater treatment plants. As such, it has harmful effect on aquatic life.

The lower Colorado River watershed area is one of the most highly developed agricultural areas in the U.S. The sophisticated irrigation canals and extensively used pesticides enhance crop yield. Commercial profit and economic demands drive farmers and residents to take no notice of the chemical usage that have exceeded nature's tolerance limit. Many studies show that fishes have a high possibility of being exposed to those contaminants before spawning. The wildlife in the area of Gila River and Lower Colorado River Delta are at risk of poisoning from DDT and other pesticides (Baker, et al., 1992; King, et al., 1993, 1997; Schmitt, et al., 1999; Gebler, 2000; García-Hernández, et al., 2001).

Higher selenium concentrations in fishes of the lower Colorado River are a consequence of local agricultural activities. Mercury in the Colorado River Basin comes from gold amalgamation, mineralized soil, and atmospheric deposition. Fish and amphibians in those areas have had reproductive problems. The intersex bass of the Yampa River are a result of higher incidents in adult fishes exposed to estrogenic compounds in the river during early development (Hinck, 2007).

## THE COLORADO RIVER RESTORATION

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The U.S. has been taking numerous actions to restore the Colorado River. However, such is not the case in Mexico. Therefore, the Colorado River Delta of Mexico should be the priority for restoration. The reasons for restoring this delta are stated in the following passage.

Two-thirds of the species in the delta rely on the water resource and riparian ecosystem of the Colorado River (Luecke, 2000). In 1922 water landscapes covered 1,927,422 acres (780,000 hectares), which shrunk to one-tenth of its size by 1996. The Colorado River

supplies water for more than 3,700,000 acres (1,500,000 hectares) of irrigated land in the United States and Mexico. Dams along the river generate around 4425 megawatts of electricity. Water loss started from 1930 to 1980 because of constructing those dams (Hoover Dam and Glen Canyon Dam). The reduction in water changed vegetated areas. Nonnative species of animals replaced native species. Flooding of the Colorado River has many functions which can help restore the ecosystem. It can remove salts from the soil, spread seeds of plants, and re-establish native vegetation. As the environment deteriorated, many native animals became endangered. Thus, both the U.S. and Mexico's environment regulation committees have listed those native animals as endangered in order to protect them. Some example of these animals are the desert pupfish, the Yuma clapper rail, the bobcat, the vaquita porpoise, the totoaba, the yellow-footed gull, the peregrine falcon, the elegant tern, the reddish egret, the house finch, the great blue heron and the mockingbird (Garcia-Hernandez, 2001).

Rivers are important to migratory birds. In 1992, there were more than 160,000 documented birds in the delta. The delta provides nesting, breeding, and nursing sites. In the lower Colorado River, birds prefer forests to cottonwood (Alvarez-Borrego, in press, 1999). The abundant nutrition in the estuaries provides significant food sources for marine species. The reduced water flow decreases fish populations. Since the Colorado River Delta has such an important function, it is necessary to take actions and restore the delta (Pitt, 2001).

According to Pitt's studies, water used for maintaining the wetlands and riparian areas is only 1% of the original average annual river flow. The expense of restoration is predicted

to be around \$46 million to \$75 million for long-term water flow maintenance. In this way, the annual water flow reaches its minimum required amount of 40,000,0000 m<sup>3</sup> (Pitt, 2001).

Environmental agencies of the United States and Mexico have taken actions to help restore the delta. The United States and Mexico signed an agreement called “Minute Thirty-Six”, which is a supplemental document for 1944’s treaty between Mexico and the United States. Following is a list of chronologically ordered agreements between the governments of the United State and Mexico. “In 1936, the two nations reached an agreement on protecting migratory birds.”(Pitt, 2001) “In 1986, both nations agreed on implementing the North America Water Management Plan.” In this plan, the delta was entitled as one of the most important wetlands for Mexico (Pitt, 2001). “In 1992, both nations participated in the “Western Hemisphere Shorebird Reserve Network” policy.” (Pitt, 2001) This policy emphasized the importance of the delta to Mexico. “In 1993, Mexico executed the plan named “Biosphere Reserve of the Upper Gulf of California” and financially supported this program” (Pitt, 2001). “In 1996, the delta wetlands were added to the world protection list, called the Ramsar Convention. In 1997, secretaries from both nations officially consented on the “Delta Biosphere Reserve policy” (Babbitt & Carabias, 1997). In May 2000, the two nation once again signed a document, “Joint Declaration between the Department of the Interior(DOI) of the United States of America and the Secretariat of the Environment, Natural Resources, and Fisheries of the United Mexican States to enhance Cooperation in the Colorado River Delta”(Babbitt & Carabias, 2000). Both nations are aiming to establish an effective cooperation for reconstructing and reserving nature and they intend to implement effective regulations to develop and reserve all the resources of

the Colorado River Delta. Although in the past, governments did not provide enough financial support for the research on ecology in the Colorado River Delta, at present, Mexico's National Science Foundation funds more of the research to save the delta (Pitt, 2001).

The Colorado River tribes in Yuma have restored 250 acres (101 hectares) of riparian areas since 1996 (Cohn, 2004). The four national wildlife refuges that protect Lake Mead are the Havasu, the Bill William Rivers, the Cibola and the Imperial refuge. About 3.5 acres (1.4 hectares) of cottonwood and willow nursery had been planted in 1993. The Cibola National Wildlife Refuge preserved more than 17,000 acres (6880 hectares) of plants and riparian lands. Federal wildlife agencies, the power company in California, and other organizations contributed \$6,700,000 for establishing an animal conservation plan in Colorado in 1944. The plan would cover 57 mammals, birds, and fishes listed as endangered by the U.S. Fish and Wildlife Service. However, this plan did not include the part of Colorado Delta located in Mexico. The Center for Biological Diversity and several other US and Mexican environment groups sued the Bureau of Reclamation and the US fish and Wildlife Service under the endangered Species Act in 2000 for not considering the effects of US dams on fish and other US-listed endangered species in the Gulf of California and the Colorado River Delta in Mexico (Cohn J. P., 2001).

## EFFECTS OF THE DAMS

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Before the construction of the Hoover dam, riparian habitats covered around 400,000 acres (161,874 hectares) of land. About 90,000 acres (36,422 hectares) of the land was left after the dam was established. At present, there are only 6,000 acres (2,428 hectares) of the land left. Most of the riparian areas are dominated by salt cedar for managing soil erosion. The high-salt soil prevents cottonwoods and willows from germinating. As a result, the willow flycatchers, which were once common in southwestern US and northern Mexico, are now rarely seen. Bony tails, chubs and razorback suckers are no longer reproducing in the wild due to the change of the ecosystem (Cohn, 2001). Figure 1 shows the location of the dams.

Colorado Basin Map Image was removed due to the copyright.

FIGURE 1 : THE COLORADO RIVER BASIN AND ITS SURROUNDING MAJOR DAMS AND CITIES. (IMAGE IS RETRIEVED FROM [HTTP://WWA.COLORADO.EDU/TREEFLOW/LEES/IMAGES/CRB DAMS.JPG](http://wwa.colorado.edu/treeflow/lees/images/crb_dams.jpg))

## METHODOLOGY

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This project mainly revolved around perusing prior scientific studies related to the Colorado River. We especially focused on the effects of reduced water flow in the Colorado River and increased salt concentration of the river. These deleterious issues have many negative influences on the surrounding environment and local biota. We also conducted a systematic study to estimate the future environmental conditions of the Salton Sea. Most of our information was summarized from professional science articles and review papers. We started off by searching and gathering reliable resources, such as comprehensive articles and research papers from Science Direct, Bio-one and other systems that document original research. Then we compiled relevant knowledge and categorized them according to various themes. Finally, we organized all the materials in a logical order and compiled a report that tried to convey a complete picture of our understanding of these issues and their social impact.



## RESEARCH

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### EFFECTS ON THE LOCAL FLORA

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#### PLANTS *TYPHA DOMINGENSIS* PERS

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*Typha domingensis* Pers is a type of plant which grows in brackish water and marshes in the Colorado River Delta, Mexico. Although typha grows in saline water, the severe salinity of the delta water inhibits its growth. Scientists investigated the growth and distribution of *Typha domingensis* to determine the environmental conditions of wetlands around the Colorado River. Glenn concludes, in his article “Effects of salinity on growth and evapotranspiration”, that the Yuma desalting plants will decrease water flow into the Cienega de Santa in Mexico by sixty percent, resulting in harmful effects on the growth of *Typha domingensis*. The data from Glenn’s article indicates that 6 parts-per-trillion (ppt) is the upper limit for the Typha, therefore, it has been suggested that other high salt tolerant plants will substitute for *Typha domingensis* (Glenn, 1995).

Because of the increased salinity of the water, salt-tolerant plants, such as salt cedar and *Tamarix ramosissima*, have taken up the once native plants’ habitat, and changed the riparian system in the Colorado River Delta, Mexico. *Tamarix ramosissima* has the ability to extract water from earth faster, and so has a higher drought tolerance, and can endure the irregular flood periods. All these characteristics of *Tamarix ramosissima* make it the strongest among all other plants. This leads to a monoculture environment which reduces plant variation in the habitat. In order to enhance the plant diversity, it is suggested that a

periodic release of flood be required to rescue the living environment for native plants, and promote germination of native species (Vandersande, 2001).

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## EFFECTS ON THE LOCAL FAUNA

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### CLAMS

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The clam, *Mulinia coloradoensis*, is found in brackish water and in shallow burrows. There is a decline in clam population which is related to diminished flow of water into these rivers. The decline of the clam has also caused a decline in the abundance of its predators such as crabs and birds.

Scientists have identified the predators of clam based on their shell morphology. If there is a borehole on its shell, the clam was killed by predatory gastropods; if there is a marginal damage, it was killed by a predatory crab. The common phenomena, drilled holes, edge damage and shell repair all suggest that clams are important food resource for the gastropods and crabs in the pre-dam's areas. One research study took clam samples from different sites along the Colorado River Delta, and statistically showed that ninety percent of reduction in the clam population was caused by decreased flow of the river water. Moreover, the reduction indicated potential reduction of the gastropod and crab population (Cintra-Buenrostro, 2005).

*Chione Cortezi* is a type of clam, marine bivalve mollusk, which favors a saltwater environment. Its family name is Veneridae. This species has a cross size of about 13/4 inches (8 centimeters), and has a triangular shape with smooth outlines. Researchers have

performed studies related to clam growth rates in areas upstream and downstream of dams along the Colorado River. They applied oxygen isotope analysis to compare and contrast how salinity of the river water affects clam growth. They took samples from different sites around the lower Colorado River Delta and found that increased salinity accelerated clam growth in post-dam areas. However, the growth rate decelerated in pre-dam areas. Increased salinity has an adverse effect on animals which rely on fresh water, but can enhance the survival factors for other marine animals which prefer salty water (Schone, 2003).

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#### TILAPIA

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Tilapia is a type of freshwater fish which was introduced to the Salton Sea around 1964-65. Since it has a relatively high salt tolerance, it adapted to the living environment of the Salton Sea and became a dominant fish species of the water body during the 1960s (Cohen, 2006). However, it has been predicted that the tilapia will disappear from the Salton Sea within the next twelve years due to increasing salinity (Suresh and Lin, 1992; Riedel, 2002). Many environmental factors affect the viability of the tilapia, such as, low temperature, decreased dissolved oxygen (DO) concentrations, high parasite loads, and increased ammonia and hydrogen sulfide concentrations. These alterations have more influence on the survival rate of the tilapia than the raising salinity of the water body. The critical low temperature for tilapia mortality is 55°F (13°C). Based on abundant laboratory studies, it was found that the tilapia survive well in water that is a warm 77°F (25°C) and has a salt concentration of 95 grams per liter (g/L). However, the mortality rate of this fish

species jumped to 100% in 59°F (15°C) water with salinity of 60 g/L. In Sardella's experiment, the salinity of water decreased from 95 g/L to 60 g/L. It is supposedly favorable for the tilapia's viability; however the mortality rate of the fish increased significantly. This is due to the simultaneous drop in water temperature from 77°F to 59°F (25°C to 15 °C). This laboratory result demonstrated that water temperature is a more significant factor for the viability of the tilapia than water salinity (Sardella, et al., 2004). Tilapia has a strong ability to adapt to the environment of the Salton Sea. When dissolved oxygen diminishes in the middle of the Sea, tilapias congregate at areas which are close to the shore or to the estuary in order to find more dissolved oxygen. Moreover, tilapias in the Salton Sea have a higher reproduction rate than tilapias at other locations, which also explains why they exhibit high resilience in severe conditions (Sardella, et al., 2004). Riedel (2000) reported that tilapia populations grow normally at a salinity of 49 g/L. The highest salinity that they can tolerate is about 120 g/L. However, Brauner and Sardella (2005) noted that the tilapia survival rate is reduced at around 55-65 g/L salinity.

Although the salinity of the Salton Sea is not the only factor that determines mortality of the tilapia, rising salinity does greatly affect the tilapia's immune system, lowering their body's defense and increasing their susceptibility to disease and infection by parasites. The reason for this is that when water salinity increases, tilapias have to spend much more energy regulating their internal water and salt balance, and maintaining blood osmotic pressure by constant secretion of the salt through their skin and gills. As a result, a combination of all the stressors reduces their resistance. Besides rising salinity, low temperature and diminished oxygen levels in the sea force the tilapia to breed near

estuaries and shallow water areas; those areas might not be beneficial for the development of their progeny.

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### HISTORY OF TILAPIA INVASION AND CHANGE IN FISH POPULATION

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During the late 1950s and the 1960s, biodiversity boom reached its peak in the Salton Sea. Fisheries obtained tremendous amounts of sargo, corvine and bairdiella. Two tilapia species were introduced into the lake in the 1960s; those two new species were the *Tilapia zillii* and the hybrid *Oreochromis mossambicus* x *O. urolepis hornorum*. Soon the tilapias adapted to the new environment and reproduced, resulting in many offspring (Legner and Fisher, 1980). Since the early 1970s, tilapia population in the Salton Sea has grown exponentially because they can utilize multiple types of food, like, phytoplankton, zooplankton, benthos, detritus, periphyton, and algae. When scientists dissected tilapia specimens, and examined their stomach contents, they found out that tilapia was the only fish that feeds on phytoplankton and zooplankton in both juvenile and adult periods. Tilapias depend on a broader range of biomass for food; therefore, they dominated over the other fish species that only relied on, for example, worms for nutrition. In addition, during the 1970s, more frequent storms decreased sea water salinity, which helped fish reproduction (Matthews, 1982). However, flourishing of the tilapia started to change in the 1980s. The following reasons explain its decreasing population. The Salton Sea salinity increased from 40 g/L to 43 g/L between 1986 and 1991. The sea temperature decreased to 55°F (13°C). The increasing organic matter decomposition slowly created an anoxic environment in the deep regions of the Sea. Because of the lack of oxygen, sulfide levels were increasing and sulfate levels were decreasing. Furthermore, wind caused frequent

mixing of the water column, resulting in surface water changes to anoxic levels as well. The harmful sulfide toxin dissolved in the water, degraded the water quality and decreased the reproduction rate of the fish (Hurlbert, 2007). Decreased reproduction caused fish populations to decrease. The significant reduction in fish population caused some fish companies to withdraw from the fish market during the 1990s. In addition, fish-eating birds did not have sufficient food resources from the Salton Sea, therefore, they migrated away. Sometimes, the birds even fed on fish from nearby ponds owned by fish companies. Between 2001 and 2004, the “crash” happened, resulting in a huge drop in the overall fish population. The number of tilapia was reduced by 99.6% and the number of bairdiella by 96.3%. Figure 2 shows the different fish species distribution in the Salton Sea from 1900 to 2000. Panel-A shows the change in fish biomass from freshwater fish to marine fish due to increase of the salt concentration. Panel B shows the change in dominant fish species over time.

Image was removed due to copyright.

FIGURE 2 : FISH SPECIES DISTRIBUTION IN THE SALTON SEA IN 1900-2000(HURLBERT, 2007). (IMAGE TAKEN FROM HURBERT ARTICLE, 2007.)

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## THE NEW FISH SPECIES IN THE COLORADO RIVER- THE GIZZARD SHAD

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Gizzard shad is a relatively new fish species to the Colorado River. So how did this fish enter the Colorado River? In 1988, Gizzard shad were occasionally brought into the river along with shipments of bass. After a few years, the fish shipments terminated, but, this new fish species had already successfully established itself in the water system of the Colorado River. In 2001, people discovered gizzard shad in Lake Powell. ("New fish species," 2009) They predicted that the Shad swam from upstream Morgan Lake to downstream Lake Powell. Furthermore, people found that they even reached as far as the Grand Canyon in Arizona during early 2008s (Knowels, 2002). The gizzard shad is silver blue on the side, silver on the top, and white on the abdomen. Their average length is 52 cm. They prefer temperatures from 73°F to 75°F (22.8°C to 23.9°C). The lowest temperature that they can tolerate is 41°F (5°C). Gizzard shad usually congregate in large schools and swim in deep water with sunlight. Their life span is around two to three years. They are distributed in the St. Lawrence River, the Great Lakes system, the Mississippi River, the Atlantic Ocean, and the Gulf Slope drainages from Quebec to central North Dakota and New Mexico, and south to central Florida and Mexico (Fuller, 2008). The gizzard shad invasion will bring some changes in the biological system of the lake. They are the only Shad in Lake Powell. During their larvae stage, they usually compete with bass for plankton. But adult bass are dependent on many small fish for food, such as the threadfin and shad. Since they grow at a fast pace, and reproduce well, all the fish which depend on shad for food should realize a population increase. For example, bass will be larger because of the enriched food. Figure 3 shows the gizzard shad. (Fuller, 2008)

Image of gizzard shad was removed due to copyright.

FIGURE 3 : GIZZARD SHAD (IMAGE TAKEN FROM [HTTP://BAIT-FISHING.COM/BLOG/BAIT-FISH/](http://BAIT-FISHING.COM/BLOG/BAIT-FISH/) ON FEBRUARY 11, 2010)



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## PIKE MINNOW (SQUAWFISH)

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The pike minnow is one of the most well known fish in the Colorado River. They have a common name “squawfish”. In the past, they could grow up to six feet long and weigh about eighty pounds (Molholland, 2003). However, since their habitat has changed, now they only develop into two feet long specimens and weigh about five pounds. Usually it takes them five to seven years to grow into a mature fish. Since they can grow into a relatively large size, they are well known for their strong predatory ability. Pike minnows used to be abundant throughout the entire Colorado River system. However, at present the squawfish are found only in Lake Powell. The decreased number is attributed to the newly established dams that cause changes in river water and other fish habitat factors. Pike minnows are used to living in warm water, especially in water from 64°F to 68°F (18°C to 20 °C), the optimal temperature range for spawning. Sadly, the dams collect water from upstream and cause water in the downstream region, which lie below the dam, to become colder. The tall dams also prevent sunlight from penetrating deeper into the water. They also prevent the mixing of water columns at different depths, resulting in an uneven distribution of temperatures. According to one study, the temperature of the Colorado River in the summer is 75°F to 86°F (24°C to 30°C) and in the winter is 39°F (4°C). During spring and fall, water temperatures stay at around 64°F to 72°F (18°C to 22°C). But when the dam releases water with a constant temperature of 45°F (7°C), pike minnow have to stay upstream of the dam because water downstream of the dam is too cold to live in. The second factor that influences the pike minnow population is other invading fish species. The invading species threaten the pike minnow’s survival rate. Green sunfish, red shiner, northern pike and mosquito fish prey on the young squawfish. Since 1967, the squawfish

has been listed as an endangered species by the federal government. A recovery program has been established which is helping this species by supervising its population, recovering habitats, and expanding the number of healthy immature offspring. Figure 4 shows a pike minnow.

Image of pike minnow was removed due to copyright.

FIGURE 4 : PIKE MINNOW (SQUAWFISH) (IMAGE TAKEN FROM  
[HTTP://CALFISH.UCDAVIS.EDU/CALFISH/SACRAMENTO\\_PIKEMINNOW\\_1.JPG](http://CALFISH.UCDAVIS.EDU/CALFISH/SACRAMENTO_PIKEMINNOW_1.JPG) ON FEBRUARY 11, 2010)

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### HUMPBACK CHUB

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The humpback chub is another common fish species found in the Colorado River. Similar to squawfish, they stay in warm deep water. They have a dark blue back, a white belly, metallic sides, and are characterized by a hump on their back. Their life span can reach upto thirty years. The chubs spawn in the spring, and the optimal temperature for spawning is around 57°F to 75°F (14°C to 24°C). Usually eggs and juvenile chubs cannot tolerate water that is below 45°F (7°C), found downstream of the dams. However, adult humpback chub have developed a better ability to adapt to colder environments. According to a study, at present, the adult humpback chub population in the entire Colorado River system is decreasing significantly. Besides the colder water temperatures, there are other factors that contribute to the population decline of this fish species. Newly established dams cause many harmful ecological changes. In addition, exotic species prey on the humpback chub, and the chub's reproductive habitat is shrinking in size. In 1964, the

humpback chub was listed as an endangered fish by the federal government. Figure 5 shows a humpback chub.

Image of humpback chub was removed due to copyright.

FIGURE 5 : HUMPBACK CHUB (IMAGE WAS OBTAINED FROM:  
[HTTP://WWW.GCMRC.GOV/RESEARCH/HUMPBACK\\_CHUB/DSC\\_9039.JPG](http://www.gcmrc.gov/research/humpback_chub/dsc_9039.jpg) ON FEBRUARY 11, 2010)

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## YUMA CLAPPER RAIL

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The Yuma clapper rail is a chicken-like bird, which has a long and curved beak. Its habitat is in the marsh regions of California and Mexico. They prefer living in freshwater marshes as to living in brackish water marshes. They rely on open water for food resources, such as crayfish, beetles and isopods. Besides food, they also need the open-water habitat for establishing nests and raising their offspring. Recent researchers have found that the Yuma clapper tends to stay in the same area without migrating. However, many studies conducted during recent years, suggest that river diversion and dam construction near the Colorado River Delta caused reduction of marsh lands. Besides the dam construction, human interventions, such as execution of the mosquito abatement program and the erosion control program, and the releasing of selenium, have indirectly harmed the daily functions and reproduction of the Yuma clapper rails. ("California Department of Pesticide Regulation Endangered Species Project"

The Yuma clapper rail dwells and breeds in the Cienega de Santa Clara wetland and the wetlands near the Hardy River. The Yuma clapper rails are broadly distributed in the Colorado River Delta. Cienega de Santa Clara has the highest density of rails among the wetlands. Their abundance is difficult to measure. It is estimated that more than seventy percent of all the breeding Yuma clapper rails are living in Mexico and the U.S. Most of the birds are concentrated in the lower Colorado River.

The wetlands of the Colorado River Delta are very crucial for sustaining the Yuma clapper rail. Both Mexico and the U.S. will have to take responsibility for the restoration of the delta's ecosystem. The methods for conserving the rails are to expand their habitat, to

sustain the quality of vegetation, to enlarge the marsh area in the southern part of the delta, and to maintain optimal water quality (Hinojosa-Huerta, 2001).

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### SOUTHWESTERN WILLOW FLYCATCHER

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The southwestern willow flycatcher shown in Figure 6 is one of the smaller birds living near the Colorado River. They are usually 5.75 inches (15 centimeters) long and weigh about 12 grams (0.42 oz). They have grey feathers on their back and white feathers on their belly. These birds prefer to live in dense areas, wetlands, marshes, and regions along a river. Their main food source is insects, especially mosquitoes. They are considered to be important for farmers as they help to reduce insects harmful to their crops. In the spring, the flycatchers stay in the southwest to reproduce. A female southwestern willow flycatcher usually lays three to four eggs, which takes twelve days to hatch. In the winter, they fly south to Central America. In the past, they were considered as a type of common songbird; however, in recent years according to studies, their population has been declining. The following reasons could explain the decline of the bird population. First, the reduction in the number of willow cottonwoods significantly decreased their nesting opportunities. The willow flycatchers primarily nest on the Cottonwood willows. These birds are losing their favorite habitats because of human activities such as excessive land utilization for growing crops, and plants. Dams along the river cut down water flow which hinders cottonwood reproduction as they require periodical floods to spread their seed. Furthermore, dams alter the water flow rate, and keeps the water flowing at a constant rate without any substantial seasonal change. As a result, floods in the downstream areas have

disappeared. Since the willow trees fail to spread their seeds, they cannot grow in population. Moreover, the willow trees are also harmed by excessive cattle grazing. Excessive grazing results in the loss of grass, moss and liverworts as well. Due to this, trees are not able to grow as before and the biota starts to lose variety. Willow flycatchers prefer to mate in areas flourishing with plants rather than in barren fields. Therefore, the changes in plant diversity significantly affect the future of the willow flycatchers. Besides the reduction in native plants species, invading plants, such as tamarisks, contribute to decreasing flycatchers' population. Tamarisks compete for water and soil resources with native plants. They are a type of shrub which grows in the grass lands of Europe and Asia. They usually grow up to 15 feet. In the past, they barely grew along the river shores; however, in recent years, they have started to dominate the banks, replacing the willow cottonwoods. Since the tamarisks are relatively short and densely distributed, willow flycatchers do not like to nest on them. Even if they do build their nests on tamarisks, the immature birds will not grow as well as before. Therefore, the loss of native living and mating habitats is a very significant factor that influences the fate of the willow flycatchers. Secondly, interspecies competition reduces southwestern willow flycatcher's survival opportunities. There is another common bird in the Colorado River habitat called the cowbird shown in Figure 7. They are notorious for their parasitism. This brown headed cowbird lays eggs in the willow flycatcher's nests. The mother willow flycatchers cannot distinguish the eggs of the cowbird from its own eggs. When the chick cowbird hatches, it pushes away all the other eggs out of the nest. As such, none of the willow flycatchers' eggs survive. According to a recent study, willow flycatchers now only exist in a small area in the Colorado River basin, Arizona. In 1995, the federal government registered them as an

endangered animal. Soon after, the wildlife service reached a compromise with the southwest center for biological diversity and started to restore more habitats along the river for the willow flycatchers.

Image of southernwestern willow flycatchers was removed due to copyright.

FIGURE 6 : SOUTHWESTERN WILLOW FLYCATCHERS (IMAGE OBTAINED FROM:  
[HTTP://3.BP.BLOGSPOT.COM/\\_P3TAP38GUXI/SGXLXCFIL6I/AAAAAAAAACNC/FBQ8IXR0TMG/S400/BROWNHEADED COWBIRD.JPG](http://3.bp.blogspot.com/_P3TAP38GUXI/SGXLXCFIL6I/AAAAAAAAACNC/FBQ8IXR0TMG/S400/BROWNHEADED COWBIRD.JPG) ON FEBUARY 15TH 2010)

Image of cowbird was removed due to copyright.

FIGURE 7 : COWBIRD (IMAGE OBTAINED FROM:  
[HTTP://ANIMAL.DISCOVERY.COM/GUIDES/ENDANGERED/BIRDS/GALLERY/SOUTHWESTERN\\_WILLOW\\_FLYCATCHER.JPG](http://animal.discovery.com/guides/endangered/birds/gallery/southwestern_willow_flycatcher.jpg) ON FEBUARY 15TH, 2010)

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## JAGUAR

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The jaguar is the largest “cat” living on this land. They are a type of smart and furious feline. The majority of this genus has lived in Africa and in South America. However, they also inhabited the American southwest, and avoid human settlements. They have sharp teeth, and are orange-brown in color. They are known to prey on many different species of animals. Their strong body and large size allows them to defeat even a cougar. However, the population of the jaguar is decreasing very quickly. The major reason for this is illegal hunting. It has been reported that “between 1895 and 1960, of the 51 jaguars sighted in Arizona, 45 were killed” (Doddridge, 1997). The other reason for their population decline is the continuous decrease of their wetland habitats in Mexico and Central America. One of their habitats, the Colorado River Delta is undergoing changes that favor against the jaguar. In the past, the Colorado delta was rich in vegetation, with numerous wetlands, green lagoons and jungles. These types of ecological systems provide the jaguar more food sources and better living conditions. However, today, the lagoons have mostly disappeared due to the lack of water and resulted in a shortage of food sources. The federal government listed the jaguar as an endangered animal in the United States in 1997. Figure 8 shows a jaguar.

Image of Jaguar was removed due to copyright.

Figure 8 : Jaguar (Image obtained from <http://www.tropical-rainforest-animals.com/image-files/jaguar.jpg> on February 15th 2010)



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## VAQUITA PORPOISES

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Vaquita porpoise are found only in the Gulf of California. Adult porpoises are around 5 feet (1.5 meters) long, and weigh about 121 lbs (55 kg). Their morphologies are similar to that of a typical dolphin; however, porpoise is a different species from the dolphin. Compared to dolphins, they are usually shorter in length, but have a stronger body, and their fins are smaller. They are more quiet and shy, unlike the active dolphins, and scientists have found it very hard to study them, because they tend to shy away from human supervision. Their food source mostly consists of fish and squid. In 1997, scientists estimated the number of porpoises to be around 567; however, in 2009, the number was reduced to 150 or fewer in Mexico. They reproduce in a relatively slow manner. One female Vaquitas only produces one calf each year. In 1985, the Defenders of Wildlife categorized it as an endangered species. There are two reasons for the decline of the Vaquitas's population. Human overfishing activities significantly cut down their food sources. Moreover, they were also victims of fishing. The Mexican government has outlawed fishing of the Vaquita. In 1975, however, they were smuggled illegally to the west coast area of America. The second reason for their population decrease is the loss of their habitat. Most of the water flowing into the Gulf of California comes from the Colorado River. Water quality and quantity changes caused the decline of Vaquita Porpoise habitats. Figure 9 shows Vaquita Porpoises (Endangered vaquita porpoises, 2008).

Image of Vaqutia Porpoises was removed due to copy right.

FIGURE 9 : VAQUITA PORPOISES (IMAGE OBTAINED  
FROM [HTTP://WWW.BAJALIFE.COM/ECOWATCH/VAQUITA.HTML](http://WWW.BAJALIFE.COM/ECOWATCH/VAQUITA.HTML) ON FEBUARY 16TH, 2010)

## YUMA DESALTING PLANTS

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“The Yuma desalting plants, which utilize reverse osmosis, process 72 million gallons of water each day. They are located adjacent to the Colorado River in Yuma, Arizona.”

(Lohman, 2003) The desalting plants are designed to reduce river water salinity. The United States government has spent more than \$245,000,000 on this program. Figure 10 shows the location of the Yuma desalination plant which is highlighted by a red square. The Imperial Dam and the Laguna Dam are indicated by black squares. The Colorado River runs through the city of Yuma and the wetlands of Cienega de Santa Clara in Mexico and finally ends at the Gulf of California.

Yuma desalting plants map was removed due to copyright.

FIGURE 10 : YUMA DESALTING PLANTS (PICTURE WAS RETRIEVED FROM NEW YORK TIME SEPTEMBER 14, 2009, [HTTP://WWW.NYTIMES.COM/IMAGEPAGES/2009/09/14/US/14DROUGHT\\_MAP\\_READY.HTML](http://www.nytimes.com/imagepages/2009/09/14/US/14DROUGHT_MAP_READY.HTML) ON FEBRUARY 20TH 2010)

Around fifty years ago, the salt concentration of the Colorado River was 50 parts per million (ppm) near its origin in the Rocky Mountains and 400 ppm at the Mexican border. During the 1960s, salt concentrations of the river jumped to 1200 ppm. The high salt concentration disrupted irrigation systems of both the United States and Mexico. Therefore, the U.S. government started to take actions against this issue. In June of 1974, the Colorado River Basin Salinity Control Act was passed. Title I of the act enforced regulation of the Colorado River’s salt concentration in order to meet the standard recorded in a treaty signed in 1944. The regulation demanded construction of desalting

plants in Yuma, Arizona. Title II of the act enforced salinity management in Utah and Nevada. (Jonez)

The Yuma Desalting Program has been established to control and reduce the continuously increasing salinity of the Colorado River. The U.S. government hopes that the program can recover more than 73,000 acre-feet of water per year. The construction of the desalting plants was successfully completed in 1993. Since its completion, water quality of the river has improved to national standards. However, soon after the water quality improved, the desalting capacity of the plants decreased to 61 percent of its previous capacity (Lohman, 2003). Many government agencies have been involved in this plan. Table 1 shows the benefits of the Yuma Desalination program. Table 2 lists the reasons for which agencies participate in the Yuma Desalination Plan.

TABLE 1 BENEFITS OF THE YUMA DESALTING PROGRAM

Aspects	Benefits
<b>Economic</b>	Cut down the cost of desalting the water through chemical treatment and other costly methods
<b>Law</b>	Improve water quality to meet the treaty of 1944 between Mexico and the United States.
<b>Agricultural</b>	Increase water quality to enhance farming and crop yield.
<b>Water usage</b>	Wastewater can be used for other tasks.
<b>Materials</b>	Reduction in pipeline corrosion will prolong their usage.

TABLE 2 AGENCIES AND THEIR REASONS TO SUPPORT THE YUMA DESALTING PROGRAM

Agency	Supporting reasons
The U.S. federal government	Abide by the 1944 treaty with Mexico
Mexico government	Increase water inflow into its country and improve environmental conditions at the U.S.-Mexico border.
Southern California Cities	Need water supply from the Colorado River.
Arizona and surrounding cities	Need water supply for the Central Arizona Project.
Agriculture districts	Require water supply for irrigation.

Although the Yuma Desalting Program addresses the Colorado River's salinity problem, it also creates some issues. All the salt extracted from the river is deposited on the marshlands of the river delta, which are situated to the north of the Gulf of California. This has caused the salinity of the marshlands to increase up to 8200 ppm. Therefore, many environmentalists oppose this plan. They believe that the waste should have been transferred to abandoned and drying pools on the Yuma mesa. When the water evaporates, excessive salt precipitates and forms limestone (Lohman, 2003). In 2007, the desalting plants demonstrated their ability to desalt the river water. In the future, the desalting plants should be able to desalt eighty five percent of the Colorado River water (March 3, 2007--Desalting plant undergoing test run, 2007).

## FUTURE CONDITION OF THE SALTON SEA

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### THE DECREASED INFLOW

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William DeBuys' article (1999) notes that the volume of water flowing into the Salton Sea is less than the amount of water that is lost due to evaporation. It has been predicted that the volume of water entering the Salton Sea will significantly decrease by about forty percent by the year 2077. Moreover, climate changes can also have a negative effect on the water balance. It has been predicted that the temperature of the Salton Sea basin will increase by 36 to 43°F (2 to 6°C) during this century (Cavagnaro, et al, 2006). The increase in temperature will raise the evaporation rate by 4.5% to 6%. The article also indicates that the size of the lake will continue to decrease in the future.

There are few reasons which explain the decrease in the amount of water flowing into the Salton Sea. First, agricultural areas use water from the rivers that flow into the Salton Sea for irrigation. The policy, "California's Quantification Settlement Agreement of 2003", required to take water resources from the Imperial Valley to San Diego. The required amount of water will increase by 20 fold in the next decade, from 10 kilo acre feet (KAF) in 2003 to 200 KAF in 2020. Furthermore, the water from the Imperial Valley will be transported to the Coachella Valley as well. It is predicted that more water will be removed from the river in the future. The amount of water removed will increase from 4 KAF in 2008 to 103 KAF in 2026 (Cohen, 2006).

The continual decline of water inflow at the beginning is quite subtle; however, if the loss of water continues to occur, it will significantly reduce the water inflow. Table 3 shows Cohen’s estimation for the decline in water flowing into the Salton Sea by the year 2026. The action column represents the implementation of a proposed policy. The data in the middle column show the reduction amount and the column on the right shows water decrease percentage.

TABLE 3 THE PREDICTED DECLINE OF THE WATER FLOWING INTO THE SALTON SEA.  
(COHEN, 2006)

Action	Reductions in Inflow by Year	% of pre-QSA
	2026 (aflyr)	flows
<b>QSA/IID Transfer</b>	303,000	23.3
<b>Entitlement Enforcement</b>	59,120	4.5
<b>Mexicali Wastewater Treatment and Plant Operations</b>	22,500	1.7
<b>Mexicali Power Plant Operations</b>	10,700	0.8
<b>Reduced Colorado River flows to Mexico</b>	10,700	0.8
<b>Total</b>	<b>-406,000</b>	<b>31</b>



In addition, the Salton Sea Ecosystem Restoration Program, which was designed to last for about seventy five years, also contributes to the water flow reduction issue of the Salton Sea. The implementation of the regulatory storage policy on the lower Colorado River resulted in significant reduction of water inflow into Mexico. The factors that could affect the amount of water inflow of Salton Sea are listed in Table 4.

TABLE 4 HUMAN AND NATURE FACTORS THAT COULD INFLUENCE THE ECOLOGY OF SALTON SEA IN THE FUTURE. (COHEN, 2006)

Human activity influence	
Advanced water flow regulatory reservoir facilities in the U.S. are established.	Improved water efficiency in farming and community uses
U.S. supply delivery below what was requested in the 1944 Treaty with Mexico ( reference to other part)	Executive of the Total Maximum Daily Load (TMDL) programs.
The constant increase in population and utilization of river water for agriculture and urbanization in the Coachella, Imperial, and Mexicali Valleys	Implementation of the Colorado River basin states’ “Intentionally Created Surplus” program for the Colorado River.
Nature alteration influence	
Global warming leads to the high evaporation and evapotranspiration rate	Global warming cause salt precipitation

Cohen predicted that the Salton Sea will lose more than 45% of its current water volume within the period from 2003 to 2077. The TMDL project\* will guard against pollution level increase and also maintain the quality of water flowing into the Salton Sea. However, the phosphorus pollution of the water is predicted to be unavoidable. This is due to the increased population growth in the area of the Imperial and Mexicali valleys.

**\*TMDL:** “Under section 303 (d) of the clean Water Act, states, territories and tribes are commended to make a report of blemished waters. A Total Maximum Daily Load, or TMDL, is a quantification of the up- limit of a pollutant that a waterbed can tolerate and reach water quality standards safely.” (This information obtained from <http://www.epa.gov/OWOW/tmdl/>)

The Salton Sea is a closed lake, which means that evaporation is the only method for the water to leave. As a result, the salt concentration will only continue to increase as evaporation takes place. Also, salt precipitation in the lake will also increase. The Salton Sea Science Subcommittee predicted that the salt precipitation from the Sea’s water column will increase from 0.33 to 1.5 million metric tons by 2077. Salt precipitations are mostly in the form of calcium carbonate ( $\text{CaCO}_3$ ) and calcium sulfate bihydrates ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ). In addition, silicate and phosphate minerals have been detected in the precipitates as well (Amrhein, 2001).

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## WATER QUALITY

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The changes in the water quality of the Salton Sea have a great effect on the utility of the Salton Sea and the biota living there. The following aspects of the water will be discussed to determine their effects on the Salton Sea: temperature, dissolved oxygen content, pH value, turbidity, nutrients concentration, and trace element quantity. (Cohen, 2006)

The accumulated salts in the water have increased the thermal capacity of the water. In other words, water warms up and cools down at a much slower rate during different seasons. The decreased water depth will result in the water temperature becoming much higher in the summer and much lower in the winter. The water temperature changes could affect many living organisms in the river. Some fish species might not be able to tolerate the broad temperature fluctuation (Cohen, 2006). At the same time, the rising salinity in the water will also cause the concentration of the dissolved oxygen to decrease. As a result, the survival rate of the aerobic species, such as fish and clams, will decrease. As a consequence, birds which depend on fish and clams will confront a food shortage issue. Besides, the number of the sulfate-reducing bacteria will increase (Cohen, 2006).

Furthermore, calcium carbonate will precipitate at the bottom of the sea which will cause the pH value of the water to increase. The more basic environment might be harmful to certain species. The high salinity and increased hydrodynamics together cause an increased suspension of the micro-particles that block sunlight from photosynthetic plants (Cohen, 2006). Meanwhile, the sediments from the bottom of the lake will mix with water in the upper water column of the sea. Nitrogen and phosphorus nutrients will be more

abundant in the future which will likely cause algae to grow in population. The extraordinary amount of algae that grows will block most sunlight and compete with other species for the sunlight. The insufficient oxygen will be wastefully used for decomposing the excessive algae. As a result, fish will become reduced in number and the brine shrimp might become the major species (Cohen, 2006). Some other elements also affect the water quality. Selenium is the main trace element found in the Salton Sea. As the toxicity of the water increases, fish populations will be reduced affecting fish farms and marketing of the local business people. (Cohen, 2006)

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#### HYDROLOGY

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Cohen predicted that the size of the Salton Sea will shrink in the next few years. By the end of 2017, more than ten thousand acres of the lakebed will dry up. In the future, water will cease to flow into the Salton Sea. The Salton Sea drought issue will become worse. In the next ten to twelve years, its surface elevation will decrease by eighteen to twenty feet. Eventually, the sea will reach a new dynamic equilibrium. Table 5 shows the new elevation, area, volume and depth changes that will take place from 2003 to 2078. From the data given in Cohen's study, it is noticed that water volume will decrease significantly from year 2018 to 2029, which is almost a 60% decline.

TABLE 5 SALTON SEA HYDROLOGY (COHEN, 2006)

Date	Elevation (feet)	Extent (acres)	Vs 2003 extent	Max. depth (feet)	Avg. Depth (feet)	Volume (KAF)	Vs2003 Volume
<b>Jan.31, 2003</b>	-228.4	237,956	--	49.6	30.6	7,319	--
<b>Jan.31, 2006</b>	-228.8	236,786	99.5%	49.2	30.4	7,224	98.7%
<b>c. 2018</b>	-233.6	220,960	93%	44	28	6,124	84%
<b>c.2029</b>	-254	154,600	65%	24	14	2,287	31%
<b>c. 2044</b>	-256	148,000	62%	22	14	1,984	27%
<b>2078</b>	-253	156,000	66%	25	15	2,364	32%

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### HYDRODYNAMICS

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Wind is the primary energy to drive water currents and mix water columns in the Salton Sea. Currents with either long or short period waves can compel physical and biological interactions in the sea. In some occasions, the current forms a gigantic counterclockwise swirl in its southern region. (Cook, et al., 2002)

Thermal differences between different depths of the sea water strongly affect oxygen concentration in the water. Holdren and Montano (2002) reported that the temperature at the bottom of the sea is 48°F (9°C) lower than that of the surface during the summer. Due to this terminal stratification, oxygen is unsuccessful in migrating from the top to the bottom. As a result, an anaerobic environment forms at the deeper parts of the sea. Anaerobic bacteria, which absorb nutrition from hydrosulfide and ammonia, live in the deep sea. If

the wind does not stir up the sea, hydrosulfide and ammonia will not move upwards to the surface.

It has been predicted that the Salton Sea will shrink in area and reduce in depth in the coming years. The smaller the sea becomes, the more frequent the water currents move. It has been predicted that the sea will stabilize in thirty five years. At that point its volume will have been reduced by 70%, its water level will have been lowered by 50% and its length will have been decreased by 20%. As the sea shrinks, the lakebeds will have a better chance of being exposed to air. Oxygen will have a better chance to dissolve into the deep waters.

At present, the Salton Sea has a relatively moderate rate of transporting sediments and other organic particles. However, in the future, frequent blending of the sea will potentially cause sediment suspension and increase the amount of particles and the element selenium in the water.

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## TEMPERATURE

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Brauner and Sardella's study in 2005 showed that the temperature of the Salton Sea ranges from 9°C to 37°C, that is, 48°F to 99°F (Brauner and Sardella, 2005). Based on the increasing salinity and the decreasing depth of the Salton Sea, scientists, Michael J. Cohen and Karen H. Hyun, predicted that the fluctuation range of the Salton Sea's temperature will be smaller (Cohen, 2006).

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## PH

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The pH value range of the Salton Sea is 7.2 to 8.2, which means that the lake water is slightly basic. Therefore, calcium will be depleted from the lake because of its precipitation under alkaline conditions. If more calcium carbonates deposit at the bottom of the lake, its pH value will increase. Meanwhile, calcium and magnesium continue to flow into the lake from agricultural areas. Therefore, the overall prediction is that the pH range of the Salton Sea will remain the same in the future (Schroeder, et al., 2002).

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## SALINITY OF THE SALTON SEA

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At present, salt concentration of the Salton Sea is 46.5 g/L, which is thirty-three percent more than that of the Pacific Ocean. It is estimated that the Sea's salinity will rise to 60 g/L by the year 2018 and will become more than 180 g/L by the year 2030. Furthermore, 70 years from now, the Salton Sea's salinity will be higher than 390 g/L, which is above the saturation limit of sodium chloride. Change in salinity of the Sea will cause changes in local biodiversity, local environment, animal distribution patterns, and geological interactions. Moreover, the change will also alter food chain relationships and harm marine animals (Williams, 1998). In 2003, scientists quantified the salt composition of the Salton Sea and generated a table that compared the salt composition of the Sea with that of the Pacific Ocean.

TABLE 6 THE COMPARISON OF THE RELATIVE CONCENTRATION OF THE SALT ION IN THE SALTON SEA WATER AND THE OCEAN WATER (AGRARIAN, 2003)

Location		Salt (percent)						
		g/L	Cl	SO4	Ca	Mg	Na	K
<b>Salton</b>	Sea near Test	44	1.78	1.06	0.10	0.15	1.36	0.02
<b>Sea</b>	Base							
<b>Water</b>	Sea near	44	1.79	1.03	0.09	0.14	1.24	0.06
	Niland							
<b>Ocean water</b>		35	1.9	0.27	0.04	0.14	1.05	0.04

Upon reviewing the data in Table 6, we can conclude that the salt composition of the Salton Sea is different from that of the ocean. Moreover, the salt concentration of the Salton Sea is higher than that of the ocean by 11 g/L. Also, the sulfate concentration of the Salton Sea is four folds higher than that of the ocean. The high sulfate concentration implies presence of abundant sulfate utilizing bacteria. These bacteria can influence the population growth of other protistans and planktons (Agrarian. 2003).

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**SALT PRECIPITATION:**

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According to the report prepared by Agrarian (2003) and Oren (2001), calcium will disappear from the Salton Sea within the next sixty to seventy years. Through numerous experiments, scientists have found that the majority of the precipitate on the Salton Sea



bed comprises of calcium carbonate and gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ). The reason for the excessive precipitation of these compounds is their relatively low solubility. As the amount of sulfate and carbonate anion increases, more salt precipitates. Thus, Calcium ion will finally be depleted and cause an imbalance in the ion equilibrium (Cohen, 2006).

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### HYDROGEN SULFIDE

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It is predicted that the hydrogen sulfide content of the Salton Sea will decrease significantly in the future. Hydrogen sulfide is a highly toxic gas to most organisms. It is the byproduct of sulfate reducing anaerobic bacteria. In the future, there will be more mixing of water columns; as such, dissolved oxygen will mix well in water columns and hydrogen sulfide will undergo biological oxidation forming oxidized sulfates. Also, the study by Brandt notes that when the salinity of the Sea reaches 250 g/L, the water environment will not be favorable for those sulfate reducing bacteria, and their number will decrease (Brandt, et al., 1999).

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### SELENIUM

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Selenium is a trace element in the Colorado River. Ohlendorf reports that in 1989, selenium concentration of the river was about 2 mg/L. It is predicted that the amount of selenium in the river will keep increasing as each year, water with higher selenium concentration flows into the river. Selenium is a toxic element that is easily absorbed by animals. Selenium in birds and fishes has reached a dangerous level. For example, the fish tilapia contains up to 9  $\mu\text{g/g}$  of dehydrated selenium (Moreau, et al, 2006). Consumption of the selenium contaminated fish will lead to numerous health problems. Anaerobic bacteria can help with

selenium removal. Natural sedimentation also assists with removing selenium from the lake. Selenium mostly stays on the top layer of the lakebed, with its concentration ranging from 0.086 mg/kg to 8.5 mg/kg (Vogal and Henry, 2002). In the future, sediments of the lakebed will diffuse into the lake due to higher hydrodynamics and the concentration of selenium will continue to increase.

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### NUTRIENTS AND THEIR CHEMISTRY INTERACTION

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The major nutrients of the Salton Sea are phosphate and nitrogen. This is because chemical fertilizers from ranches and farms leak into the Sea. According to Cagle's publication, each year more than 13,750 tons of nitrogen is released into the Sea. In the future, the extravagant nourishing materials will promote the red tide issue, which will cause unlimited expansion of seaweed, and extreme use of dissolved oxygen (Holdren and Montano, 2002). On one hand, the areas of farms and plantation fields continue to grow; therefore, nitrogenous compounds will continue to increase in the Salton Sea. However, on the other hand, Amrhein's study in 2005 mentions that the phosphorus loaded into the sea will be reduced by 13% to 20% of the current amount after the execution of the Best Management Practices (BMPs) program. This program promotes better wastewater treatment in the Mexicali area. As the Sea decreases in size, interaction between water and other ion molecules will increase. Based on Schroeder, Holdren and Montano's studies, the highly insoluble hydro-oxyapatite and fluorapatite will be generated at a faster rate until they finally reach a point where salts start to precipitate. Overall, in the future, water from the Salton Sea will become more hypereutrophic (Setmire, et al., 2000). In addition, it will maintain the same amount of nutrients as it has at present (Cohen, 2006).

## CONCLUSION

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The Colorado River is one of the most important rivers in America. It has been one of the primary suppliers of water, especially for irrigation and electricity generation. The Colorado River also sustains numerous species of fishes, birds, and plants. Its flow greatly affects the biological and the ecological conditions of its surroundings. Since the river passes through the border between America and Mexico, it also plays a crucial role in building the relationship between the two nations.

Since the 1980s, divergence of the river, excessive water usage, and overwhelming construction of dams has significantly deteriorated the river's conditions, its surrounding environment, and the local biodiversity. From our study we learned that local animal distribution has been out of balance in areas upstream and downstream of the dams. The salt concentration of the water is increasing because of reduction in water flow and deposition of chemical salts coming from fertilizers used in local farms. We learned that this will impact the survival rate of fresh water fishes like the tilapia, and that the increased salt will precipitate on riverbeds. Furthermore, the changes of the river also affect the survival of many endangered birds, such as the southwestern willow flycatcher, and even bigger animals, such as the Jaguar and the Vaquita porpoises.

The consequences of the deteriorating conditions of the lower Colorado River, especially the Salton Sea, have been predicted by many researchers. We have learned that, in the future, the salinity of the Salton Sea will continue to increase, salt precipitates will mostly consist of calcium carbonate and gypsum, the temperature range of the water body will shrink, and hydrogen sulfide will increase. In addition, local fresh water fishes will be

replaced by brackishwater fishes. If the river's condition continues to worsen, the Salton Sea will eventually lose all its biota except for some brackish shrimps and insects.

Although the Colorado River and its delta are deteriorating, their environmental issues can be alleviated by taking amendatory actions. For example, the government could provide sufficient financial support to improve the situation; the U.S. government can collaborate with the Mexican government to effectively rescue the river and its native biota. Also other social organizations can help to improve conditions at the lower Colorado River Delta.

Complete implementation of the Yuma desalting plant program can also help to control the increasing salinity problem. Also, the U.S. government can expand its recovery programs to help maintain native animal populations and restore more habitats.

Environmental issues of the Colorado River, especially the Salton Sea, are very critical. As such, besides organizations, efforts of individuals in the matter are also crucial. If the local populace advocates for improvement of the Colorado River, it would stimulate authorized organizations and the government to devote sufficient efforts to prevent the issue from further depreciating. Environmental researchers can further investigate a better recovery plan and supplement the recovery of the Colorado River and the Salton Sea. This in turn can serve as a role model for other nations facing similar issues.

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