Water Conflict in the Colorado River Basin:

A study of policy and its reflection on the land

Wellton-Mohawk Canal

"In the East, to 'waste' water is to consume it needlessly or excessively. In the West, to waste water is *not* to consume it – to let it flow unimpeded and undiverted downwards."

- Reisner, Cadillac Desert

By Noah Brautigam and Colin Struthers

Introduction

The Colorado River has been a centerpiece of western development in the United States since the first American settlers began carving out habitations in the American West in the late 19^{th} century (Figure 1). Today the river is the most regulated and developed river in the world, serving the citizenry of Wyoming, Colorado, Utah, New Mexico, Arizona, California, and Nevada (Christensen et. al. 2004). During the 19^{th} century, ready access to freshwater was necessary for expansion within the US. This was not a problem in the Eastern states, where heavy precipitation provided the necessary freshwater for agriculture, city growth, and the accompanying population boom (Figure 2).

The American West, however, was a different place. John Wesley Powell was the first man to travel the length of the Colorado River, a feat he undertook with his brother, a handful of faithfuls, and four wooden dories in 1869 (Reisner, 1993). Powell aptly noted that the region surrounding the river was largely a desert, and irrigation would be necessary to create any sort of sustainable society in such an arid climate (Powell, 1890). Powell's observations bore fruit for those who wished to population the West, and today the Colorado River is the most completely allocated river in the world. Its flow is the most important source of water for large agricultural economies in the US and Mexico, as well as urban growth in both countries.

With its headwaters in Rocky Mountain National Park of Colorado and fed by the Green River of Wyoming, the Colorado River snakes through the arid western desert of North America. It historically reaches its delta at the tip of the Gulf of California after crossing into Mexico along the border of California and Arizona (Figure 3). Today, the river is so heavily regulated that often very little or no water reaches the delta region (Carriquiry & Sanchez, 1999).

Spring melt from the snow pack of the Rocky Mountains contributes about 70% of annual runoff, and on average 90% of average streamflow is attributed to the Upper Basin (Christensen et. al., 2004). The Upper Basin is defined as the part of the river basin that is fed by waters from above Lee Ferry, Arizona (Colorado River Compact 1922). The fact that almost all of the streamflow is generated in the Upper Basin is indicative of the extremely low precipitation values of the Lower Basin (Figure 4), which conversely is where the most development and consumption of the river occurs (US Census Bureau).

While large-scale development of the Colorado River began in the late 1800s, the first legislation passed in the US that allocated water rights was the Colorado River Compact of 1922. The problems that have historically plagued the Colorado River Basin stem from the over-allocation of the river in this piece of legislation. Also, the precedent and lack of foresight set by the Compact underlie a variety of issues that have arisen between Mexico and the US (Hyun, 2005).

First-come first-serve politics are the foundation for all of the policy that has been enacted concerning water rights in the West. While certain treaties and laws have separately defined what constitutes water 'rights' on the river, they are all worded as exceptions to the underlying principle that it is the right of the first user, or of the upstream entity in some cases, to use streamflow as they see fit. When the first treaties were being drawn up between the western states of the US in the 1920s, Mexico was not invited to the table for discussion because of a ruling by the then Attorney General

Judson Harmon that "…the country of origin, in cases of international rivers, retained the right to use as much water as it desired from the stream in question" (Ward, 2003). While policies have since promised Mexico a certain amount of water from the river, they are all conceived as exceptions to this precept.

This report will use GIS and remote sensing technologies to attempt to correlate changes in water use, allocation, laws, and infrastructure development to changes on the ground, mainly in terms of agricultural scale and health of crops. The report will also follow legislation on water use between the US and Mexico, and how the large agricultural complexes in both countries that rely on streamflow and irrigation from the Colorado River have been effected.

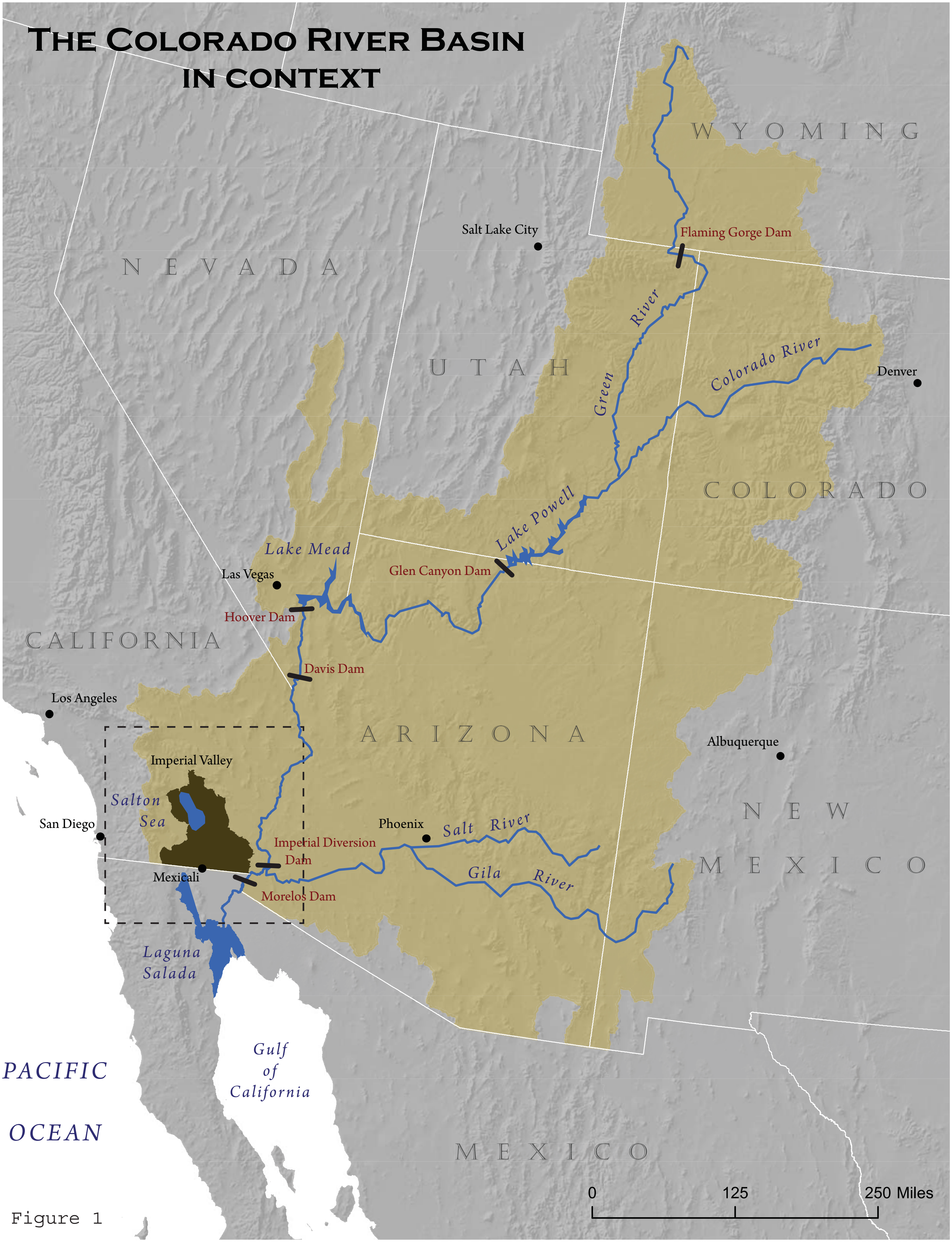

The Colorado River Basin in context
WYOMING
Salt Lake City
Flaming Gorge Dam
NEVADA
Green River
UTAH
Colorado River
Denver
COLORADO
Lake Powell
Lake Mead
Las Vegas
Glen Canyon Dam
Hoover Dam
CALIFORNIA
Davis Dam
Los Angeles
ARIZONA
Albuquerque
Imperial Valley
Salton Sea
San Diego
Phoenix
Salt River
NEW MEXICO
Imperial Diversion Dam
Mexicali
Gila River
Morelos Dam
Laguna Salada
Gulf of California
PACIFIC OCEAN
MEXICO
0
125
250 Miles
Figure 1

Figure 2

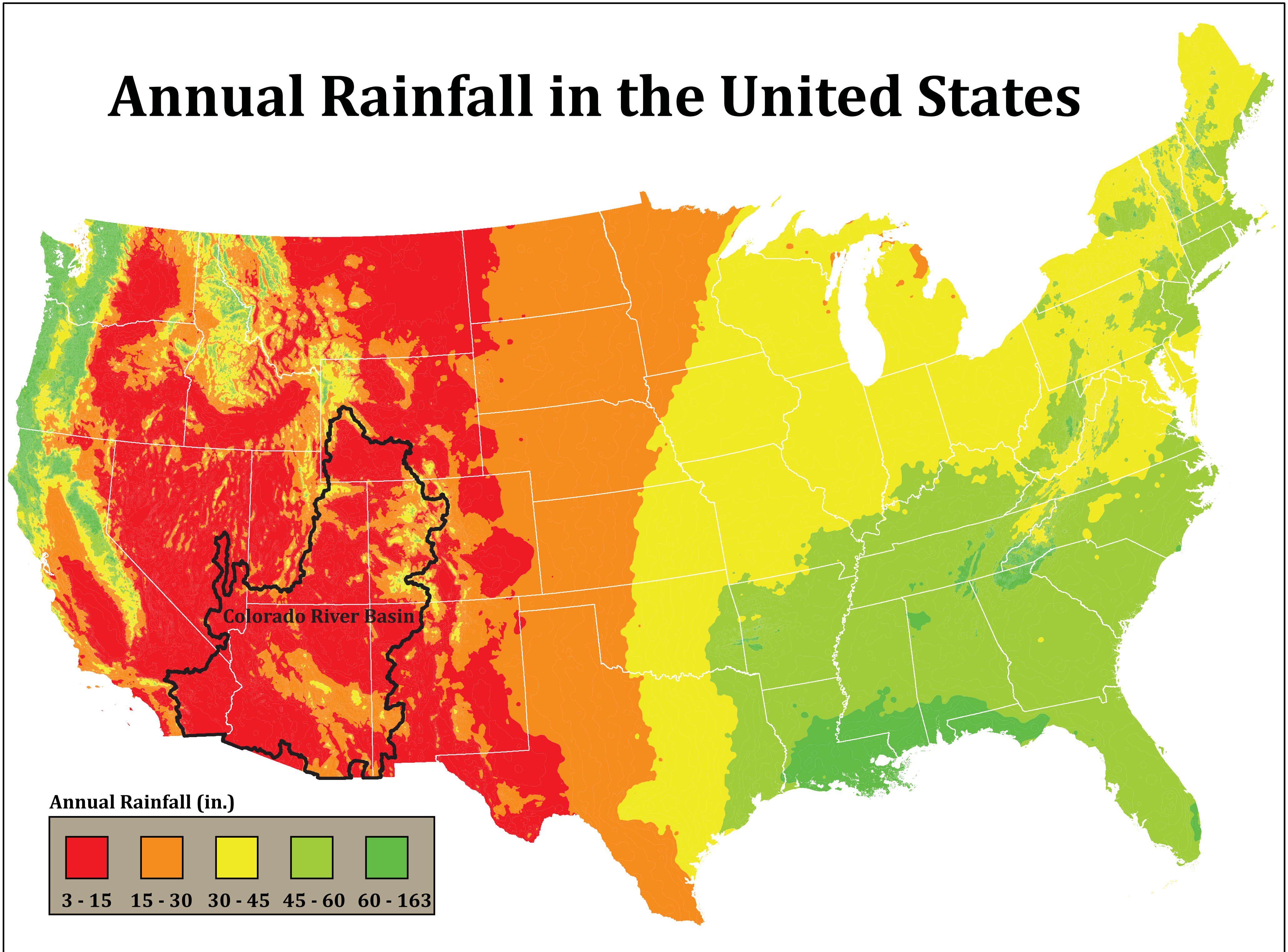
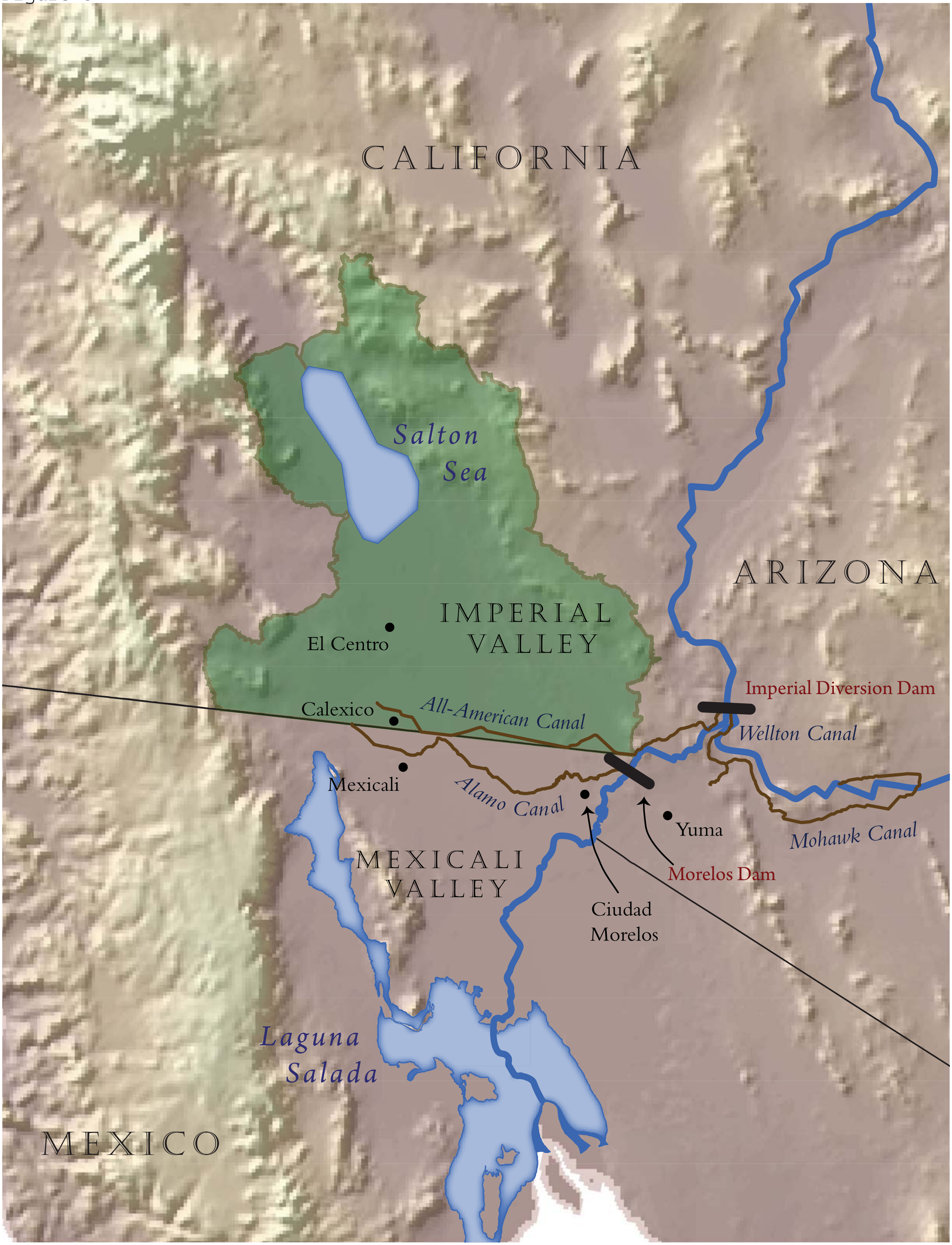
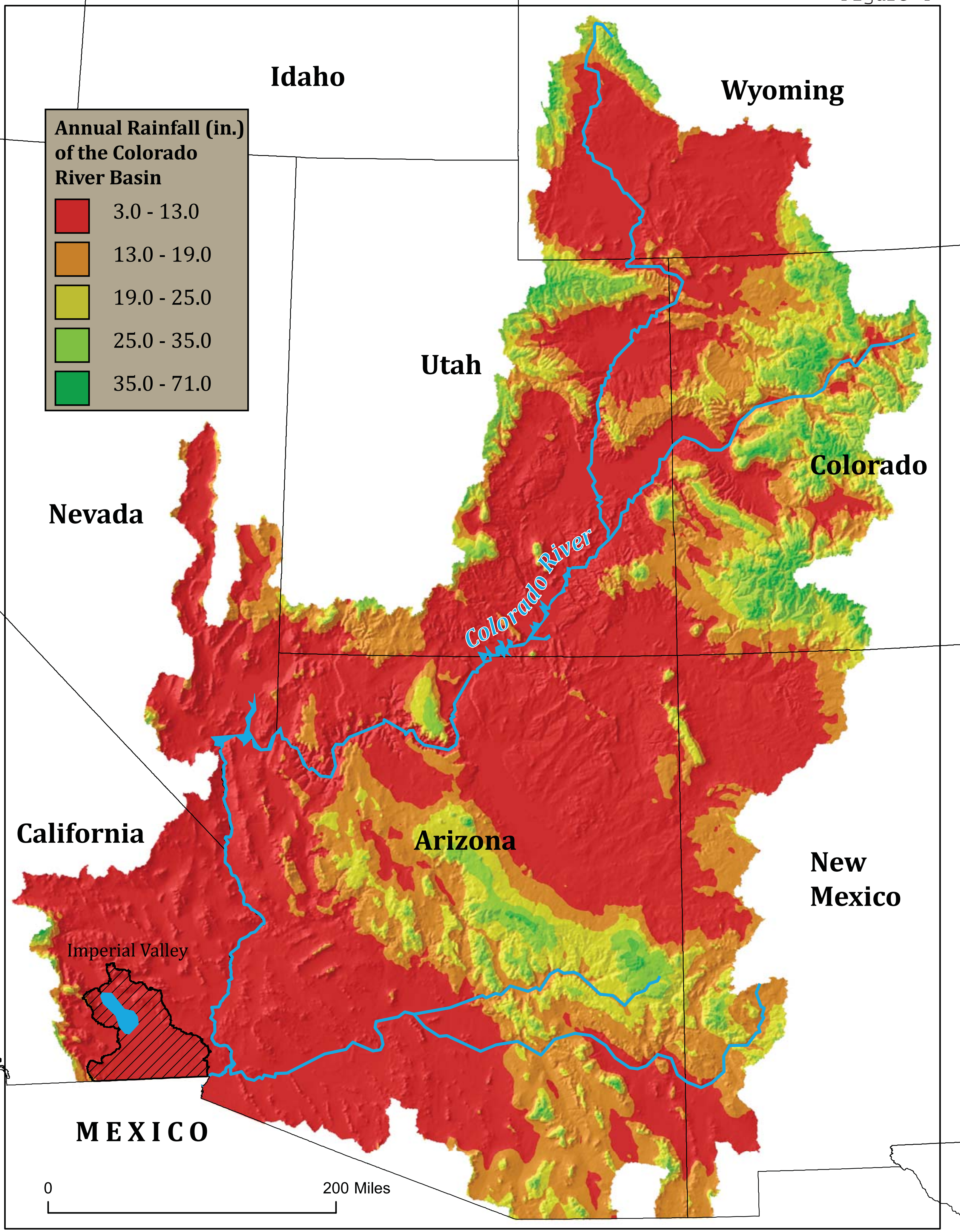

Annual Rainfall in the United States
Colorado River Basin
Annual Rainfall (in.)
3 - 15
15 - 30
30 - 45
45 - 60
60 - 163

Figure 3


CALIFORNIA
Salton Sea
ARIZONA
IMPERIAL VALLEY
El Centro
Imperial Diversion Dam
Calexico
All-American Canal
Wellton Canal
Mexicali
Alamo Canal
Yuma
Mohawk Canal
MEXICALI VALLEY
Morelos Dam
Ciudad Morelos
Laguna Salada
MEXICO


Annual Rainfall (in.) of the Colorado River Basin
3.0 - 13.0
13.0 - 19.0
19.0 - 25.0
25.0 - 35.0
35.0 - 71.0
Idaho
Wyoming
Utah
Colorado
Nevada
Colorado River
California
Arizona
New Mexico
Imperial Valley
MEXICO
0
200 Miles

Remote Sensing Methodology

In our study, we used remote sensing technology to correlate our research on historical development and policy changes and implementations to real data. Many of the major development projects on the Colorado River were undertaken in the early 20th century, and the Landsat imagery which we use in our study only goes back to 1982. Therefore, we are unable to document the large-scale changes in agricultural and urban development that accompanied projects such as the Hoover Dam, the Imperial Diversion Dam, and the All-American Canal. We were able, however, to use the remote sensing images to observe changes on the land that have occurred since that time. With the data we have gathered, we have been able to witness the product of the development of the Colorado River Basin, as well as changes that have occurred as the result of environmental change, hydrological variability, and new policy implementation.

We primarily used the Landsat images that we have gathered to pull out healthy vegetation across state and international lines. For this we experimented with a number of band combinations in an attempt to pull out differences in vegetation crop health. The band combinations we used primarily are 4, 5, 1, and 7, 4, 2. Band 4, the Near Infrared, is the best band for vegetation health, and band 7 has been shown to work well in differentiating between vegetation health in irrigated cropland (band combinations handout). Examples of these images will be shown.

We also used Landsat images to illustrate evidence of environment issues associated with the heavy regulation of the river through damming. Mostly, we use these images to pull out siltation of the river and the reservoirs behind the major dams on the river. The damming of the Colorado River has heavily influenced the silt content of different parts of the river, and there are many environmental issues that go along with these changes which will be further discussed.

In collaboration with the historical research that we have done on the Colorado River Basin, the Landsat imagery that we have collected and analyzed has allowed us to anticipate coming issues that will stress the entire infrastructure that depends on freshwater and/or electricity generated by the Colorado River.

Dams and Engineering

John Wesley Powell led the first full-scale exploration of the lower Colorado River in 1869. His observations of the surrounding desert climate were the first intimation that the waters of the Colorado were going to be necessary as the life-blood of any agricultural or urban expansion in the region. Unfortunately, for the first people to move westward across America's frontier this was not a matter of simply using the water, it required a harnessing of the entire river. Small-scale attempts by settlers to divert and dam the Colorado began in the late 19th century, but these attempts were inconsistent and unstable. The lack of success in controlling the Colorado River during these early years was due to the river's heavy silt content and its sudden and drastic floods (Nadeau, 1997). The river is one of the siltiest in the world and the silt can clog irrigation canals, raise the salinity of agricultural soil, and build up in different parts of the river periodically changing the course of the river. Prior to its development the flow of Colorado River "varied psychotically between a few thousand cubic feet per second and a couple of hundred thousand, sometimes within a few days" (Reisner, 1993). This was due to a variety of reasons. The headwaters of the Colorado River and the Green River start high in the Rocky Mountains where snowmelt rates and storms on the steep slopes can quickly swell the river.

Also, as the river moves down into the broad arid desert landscape of the Lower Basin rains come abruptly and the low absorption capacity of the soil make all precipitation funnel directly into the Colorado River, causing almost instantaneous flash floods (Reisner, 1993). Early operations to dam and divert the Colorado contended with intense forces of nature.

Industrial-scale engineering was required to provide the kind of consistent freshwater availability that is necessary for agriculture and urban growth. The story of the first attempts to do this on the Colorado River show just how far the United States has been willing to go to fully utilize this river. The first developers in the region recognized the promise that the low lying Imperial Valley had for agriculture. Although the region had desert-like climate when the first American settlers arrived there, they quickly realized that the soil was very rich. The Colorado River had at one time run through the Imperial Valley, and as it deposited year after year of siltation its course eventually changed to its current course (Reisner, 1993). The result of this geological process was rich soil in an arid landscape – prime for irrigation. With so little rainfall – averaging less than 3 inches annually – the water for agricultural growth would need to come from the river (Kahrl, 1979).

Following completion of the first diversion channel constructed in 1901 by the California Development Company, development of the valley exploded. However, problems began only three years after the canals became operational: the main cut from the river and all the subsequent cuts quickly silted up, cutting off all flow to the crops in the valley. The next four years were some of the wettest on record in the basin and the problems faced by developers changed drastically (Reisner, 1993). The subsequent floods, instead of following the course of the main river crashed through the irrigation cuts and sent almost the entire flow of the Colorado River into the Imperial Valley. Instead of having too little water, the valley was inundated, and there was the additional threat of the Salton depression filling entirely. The threat brought investment from the Southern Pacific Railroad which operated tracks into the Imperial Valley and around the boarder area. After another year of unsuccessful attempts at controlling the river the chief of the Southern Pacific went to Washington to ask for additional financial aid to continue battling the river (Ward, 2003).

Finally, in early 1907, after countless attempts to redirect the Colorado River back into the main channel had failed, enough boulders were dumped to close the breech. While these earthen barriers were sufficient for directing and channeling the river for the short term, the long-term security of water supply for a growing urban population and agricultural lands was absent. Battles to maintain the direction of channel flow continued between developers and natural processes, with the river winning its fair share. Another problem with the canal system was that the main channel, the Alamo Canal (Figure 3), crossed the Mexican border for a significant section before returning to the U.S in the Imperial Valley. A water concession to Mexico guaranteed farmers south of the boarder 50% of the water carried by the canal. Local interests found this agreement unsustainable and the infrastructure unreliable. After intense political jockeying between the states, which will be discussed later, the Hoover Dam and All-American Canal (Figure 3) were built, revolutionizing the entire water system. Construction on these projects began in the early 1930's, kicking off a long tradition of industrial-scale engineering of the Colorado River.

The 20th century in the southwestern U.S saw continued urban and agricultural growth which further augmented the need for efficient, effective and full use of the Colorado River water supply. Figure 5 shows the biggest and most important dams built in the Colorado River Basin, and gives a general outline of each. The logic for building all of these dams was to make the river more controllable while making the water supply more accessible. Unfortunately these benefits come with consequences.

The damming of the river changes the entire river system's ecology. The environmental problems referenced in Figure 5 primarily stem from the river's heavy silt content settling out in the standing water of the reservoirs. The water that is then released is clear and cold; a very different environment than what the river's native species adapted to long before human intervention. Additionally, the silt was a building block for creating the sandbars and habitats of many creatures. Figure 6 is a Landsat of Lake Powell; the inset shows the lake's inflow. The lighter blue/white water is slit laden, and the darker the water is the less suspended it has. These images clearly show the settling out at the inflow of the lake, and a clear gradient of silty to clear water as the distance to the inflow increases. Figure 7 and its inset show the same phenomena occurring at the inflow of Lake Mead.

The environmental impact of building these earlier dams was not even considered. The nationalist ideas of 'reclaiming' the frontier and economic drive for large projects during and after the Great Depression created an environment the offered little opposition to these projects. The word 'conservation' back then meant the efficient use of natural resources, not the preservation of natural environment, and the Sierra Club was still extremely small with negligible power over these issues. All they could do was watch "the most magnificent river canyons in the West filled by giant draw-down reservoirs" (Reisner, 1993).

Early Policy

The extensive reclamation of the arid western desert was a large-scale and long battle against the forces of nature. Unfortunately for all those involved in this development, the battle against nature was not the only battle taking place. Political battles were afoot at every step of development and on all scales, with different interests hoping to secure the most water possible for their country, state, region, or individual farm. These were not unforeseen problems. Powell, after extensive travel in the region, wrote a document called *A Report on the Lands of the Arid Region of the United States* published in 1876, predicting future problems given how the U.S Government was encouraging western expansion. He recognize that The Homestead Act, The Desert Lands Act, The Timber and Stone Act were ripe for exploitation and in most cases failed to address the issues involved with settling and developing the west (Powell, 1876). Powell presented two important realities to an "unbelieving Congress. First, even with all the water in the west being used only a small portion of the desert would have enough water to successfully grow crops. Second, Powell concluded that state boundaries were "non-sensical," and that "in the west, where the one thing that mattered was water, states should logically be formed around watershed…To divide the west any other way was to sow the future with rivalries jealousies, and bitter squabbles whose fruits would contribute solely to the nourishment of lawyers" (Reisner, 1993). Today the Colorado River is one of the most regulated and the most litigated river in the world (Kahrl, 1979).

This title has been a long time in the making. As the story of the early development of the Imperial Valley diversions and canals shows, the Federal government's involvement was needed for a number of reasons. It was needed to provide the funding and human power necessary for large scale projects, to settle water rights disputes between the basin states, and to settle water rights with Mexico. As soon as the development of water infrastructure began in the Colorado

River Basin in the early 1900's, the scramble was on to utilize as much water as possible. The prior use doctrine used by most states caused endless conflict and settled nothing definitively. California pushed for federal involvement in irrigation and water projects, a decision stemming from early issue with irrigating the Imperial Valley, and also because it had the most urban and agricultural growth of the river basin. The other states consistently fought and attempted to block these projects – specifically the Hoover Dam and All-American Canal – from making any headway until they could be guaranteed a portion of the all important resource (Nadeau, 1997).

From this the Colorado River Compact of 1922 was born. The Upper Basin states include Colorado, Utah, Wyoming. The Lower Basin States, where most of the water was needed, include Arizona, California, Nevada, and New Mexico (Kahrl, 1979). Each basin was allotted 7.5 MAF with an additional 1 MAF allowed for the use in Lower Basin development. Gridlock ensued in trying to subdivide the basins' allotment amongst the states. For six years no progress was made. In 1928 Congress was fed up and set forth limitations that asked for at least six of the seven basin states ratify a new agreement called the Boulder Canyon Project Act in order that work could move forward on the Hoover Dam and All-American Canal. The agreement annually allotted California 4.4 MAF, Arizona 2.8 MAF, and Nevada .3 MAF (Boulder Canyon Project Act). California was in desperate need of the benefits of the dam and canal and threw all its political weight behind getting the other states to ratify the agreement. In the end, Arizona was the only state not to ratify the agreement, largely because they wanted a greater allotment of the water – a desire that was in many ways justified considering that California did not contribute any water to the Colorado River, but was allotted 25% of its flow (Reisner, 1993). The California Seven Party Agreement of 1931 then "helped settle the long-standing conflict between California agricultural and municipal interests over Colorado River water priorities. The seven principal claimants - Palo Verde Irrigation District, Yuma Project, Imperial Irrigation District, Coachella Valley Irrigation District, Metropolitan Water District, and the City and County of San Diego - reached consensus in the amounts of water to be allocated on an annual basis to each entity" (US Bureau of Reclamation).

The only important party completely ignored in this debate was Mexico. During most of the debate in the United States over Colorado River projects in the early 20th century Mexico was embroiled in a bitter revolution and civil war. By the time that the internal situation in Mexico stabilized and Lázaro Cárdenas assumed the presidency, America's development and its use of Colorado River water was in full swing. The prospect of Mexico securing enough water to adequately supply the Mexicali Valley (Figure 1) was bleak. As the Hoover dam was being built the Mexican government was furiously encouraging agricultural land and water infrastructure growth in an attempt to augment its 'prior-use' water claims before the completion of the dam (Ward, 2003).

In 1941 a committee from the western states recommended that Mexico receive the rights to no more than .75 MAF, the amount they used prior to completion of the Hoover Dams. Fortunately, Mexico had the Rio Grande water rights to bargain with. Most of the Rio Grande's flow comes from Mexico but was used in Texas agriculture. In 1944, despite protest from the basin states, the government proposed a treaty guaranteeing Mexico 1.5 MAF, twice what they had been using prior to the Hoover Dam construction (Nadeau, 1997). Because California had the most to lose due to its large portion of allocated water, they fought the treaty until the moment the Senate ratified it. This was despite the agreement receiving support from the other six states. The Mexico Water Treaty of 1944 finally secured Mexicali farmers a small level of security in their water supply.

Salinity Debate

The next major political battle grew out of an issue not addressed by the 1944 Treaty. Despite its obvious importance, no promises of quality of the water being delivered to Mexico were included. This issue lay dormant for 16 years, as the natural flow was still enough to dilute the “mineral-charged” runoff (Ward, 2003). The land of the Colorado River Basin contains a high level of salt and other minerals that the river suspends as it runs down to the Gulf of California. When these waters are used for irrigation, the water deposits these minerals near the water table below the crops. If the water is not cleared from below the crops the water table will rise and poison the plants with its excess salt content (Ward, 2003). In 1961 the Bureau of Reclamation built a canal to drain this water from the Wellton-Mohawk Valley and deposit the unusable water back into the Colorado River. The water being delivered to Mexico quickly jumped to 3.5 times normal salinity levels. Unable to use the water the Mexican farmers let it flow by starving their crops and losing around 100,000 acres of crops. Mexico vigorously protested but the U.S denied any responsibility. Instead of coming to a long-term solution, the U.S decided to simply fund a canal through Mexico to deposit this waste water directly into the Gulf (Nadeau, 1997).

The United States finally agreed to a conclusive settlement regarding water quality delivered to Mexico in 1973. Technology for a desalting plant had recently been discovered and plans were set in motion for its construction. Minute 242 of the U.S. - Mexico International Boundary and Water Commission of 1973 agreed to deliver water that, “have an annual average salinity of no more than 115 p.p.m. ± 30 p.p.m. U.S. count (121 p.p.m. ± 30 p.p.m. Mexican count) over the annual average salinity of Colorado River waters which arrive at Imperial Dam” (Minute 242). When possible the U.S planned to meet this requirement by simply diluting the waste water with river water. If necessary, the Yuma Desalting Plant, completed in 1992, would clean up the necessary water. The plant cost $250 million to build, $39 -50 million to prepare to operate prior to running, and $322-556 dollars per acre-foot to run. The plant has since run twice (Yuma Desalting Plant, Demonstration Run Report).

Each one of these political agreements continues to define water operations in the Colorado River Basin. The following section will look at how the western water politics and hydrological processes over the last century directly impact the landscape. We will use Landsat images, available from 1982 to present, to view the affects on the ground in the Imperial Valley/Mexicali Valley region.

Figure 5

Important Dams of the Colorado River Basin

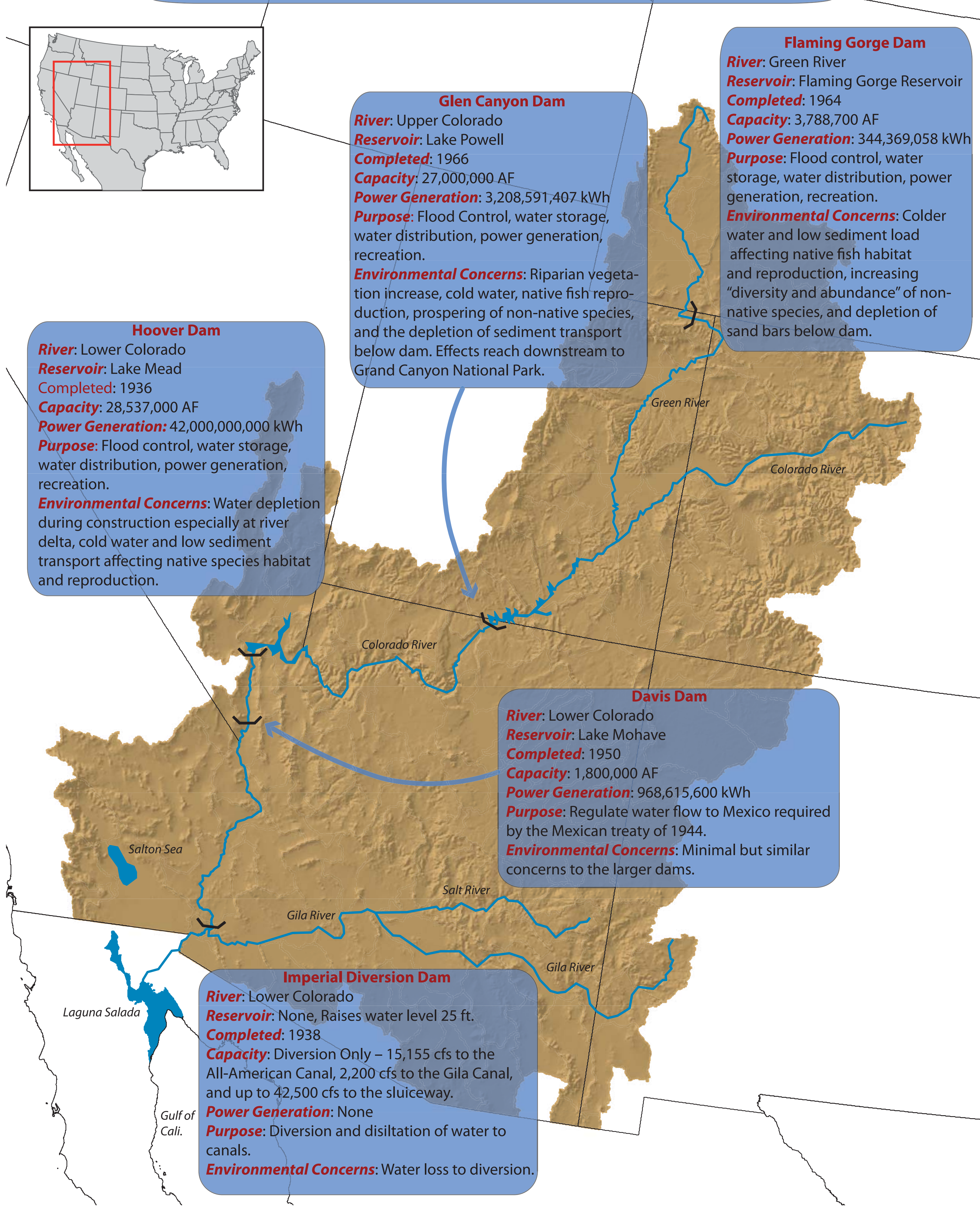
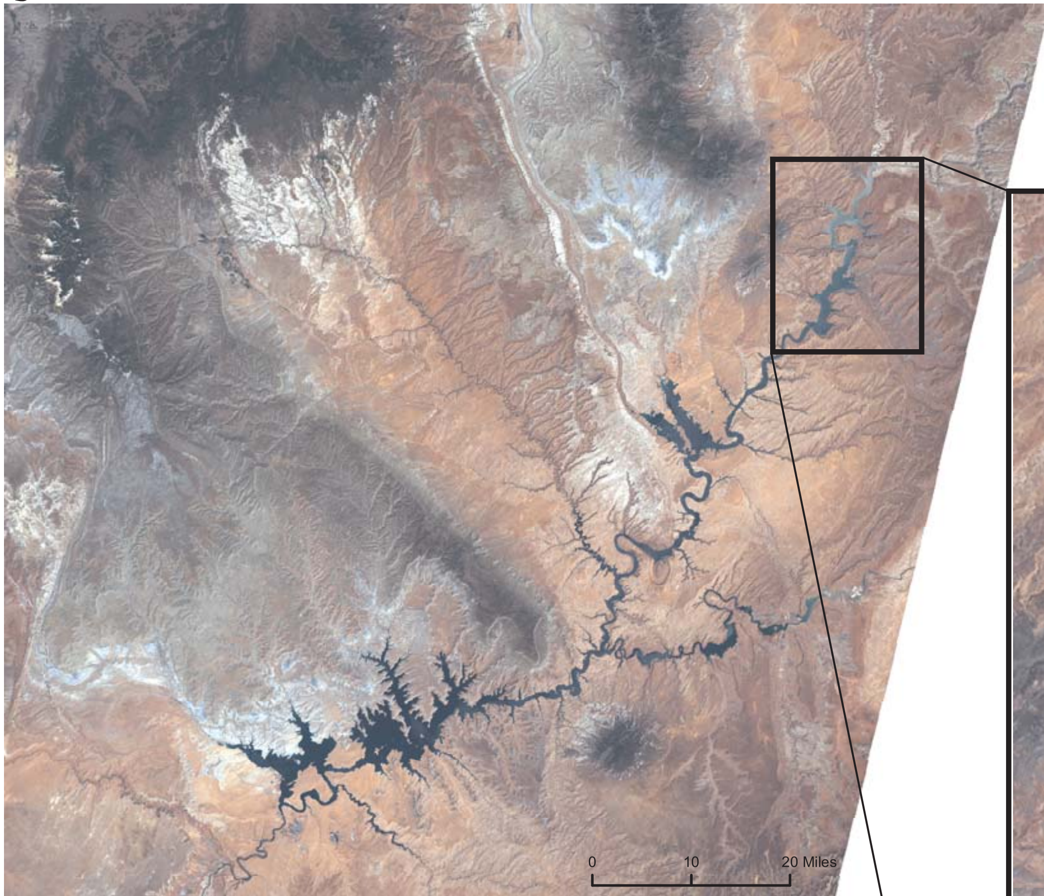
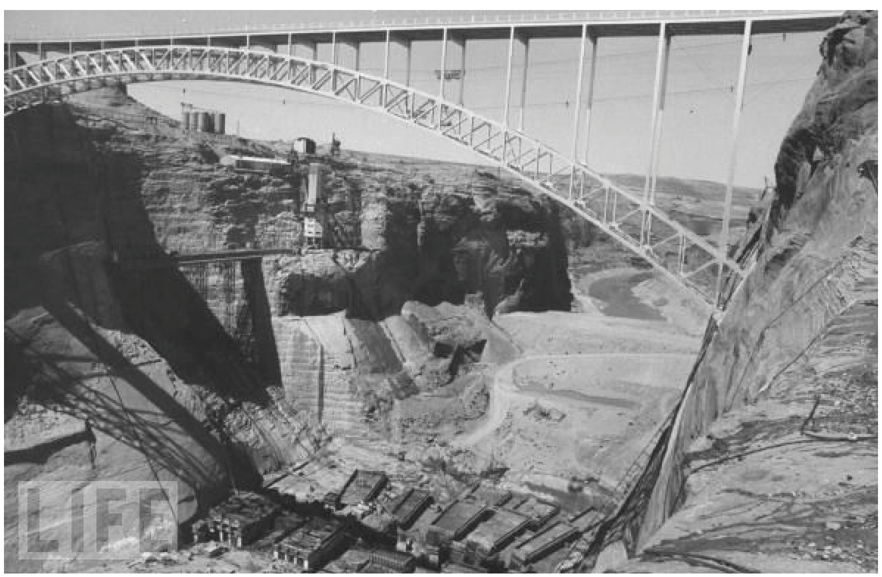


Figure 6

Lake Powell Landsat



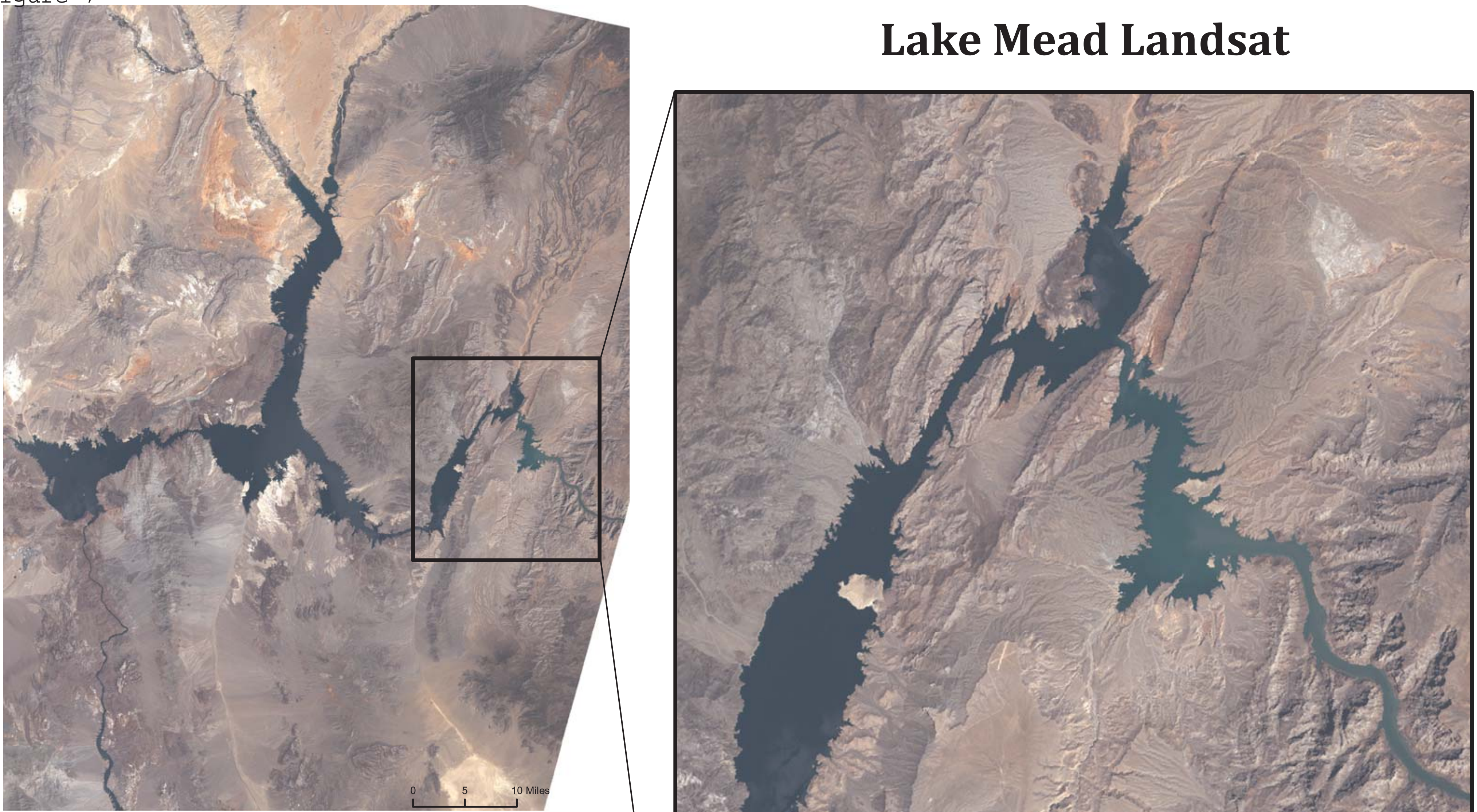


Glen Canyon Dam Construction

(Life.com)

Figure 7

Lake Mead Landsat



Hoover Dam Construction

(Auburn.edu)

Imperial Valley

The Imperial Valley, located in southern California, was at one point in geologic history an arm of the Gulf of California, and lay at the mouth of the Colorado River. As the streambed flowed through the region it flattened nearing its delta, and as its flow slowed suspended silt settled out and began to build up. This geological process had three results that are relevant to the modern-day agricultural giant that is the Imperial Valley. First, the deposited silt eventually accumulated enough to separate the region from what is now the Gulf of California, and the Colorado River migrated eastward to lower ground and its current channel. Secondly, the silt left in the old riverbed was rich in nutrients that were carried downstream by the river. The healthy soil made for guaranteed agricultural success – if only freshwater could be brought somehow to hydrate cropland. The third effect of the depositional environment of the region was that much of the Imperial Valley now lies below sea level, allowing for gravity fed irrigation by way of the Colorado River main stream to the east (Billington and Jackson, 2006).

The potential of the Imperial Valley did not go unnoticed as the development of the American West began in earnest in the late 1800's. The powerful and heavily funded California Development Company (CDC) took advantage of the initially proposed irrigation project using the dry channel of the Alamo River (Figure 3), and agriculture in the region was in full swing by the turn of the century (Billington and Jackson, 2006). The Alamo Canal had its own problems, as discussed previously, leading to the construction of the All-American Canal in the 1930's (Ward, 2004).

By 1910, the population of the Imperial Valley was 13,591, and the County of Imperial claimed to have 223,662 acres of farmland in 1,322 farms, 176,069 of those acres being "improved" (Imperial County Crop and Livestock Report, 1907-1910). The costs listed for development construction show that the County of Imperial was focused on building up an agricultural powerhouse as quickly as possible. These numbers have skyrocketed since then, and the All-American Canal now carries approximately 3.0 MAF of freshwater annually to irrigate more than 450,000 acres of cropland in the Imperial Valley (Nasa, Earth Observatory 2009, and UC Davis Irrigation Management 2010). This is in comparison to the 1.5 MAF that is allotted to all of Mexico. This disparity in policy, water allotment, and water use can be seen clearly in the crop health images we have gathered in this study.

Today, the Imperial Valley is a huge exporter of agricultural commodities, with an estimated value of close to $1.5 billion in 2009 (IC Crop and Livestock Report, 2009). It ranks consistently in the top ten counties in California for gross value of agricultural production. The region specializes in cattle, lettuce, and wheat (USDA NASS California Agricultural Commissioners Reports, 2008-2009). Through unrelenting development and a push to utilize resources to and past their availability, the farming interests in the Imperial Valley have made themselves an integral part of the American agricultural supply structure. People living in the Northeast are now used to eating salad and fresh fruit even through the long and barren winter months, and the Imperial Valley is a large part of what makes that possible. In 2007, the County of Imperial provided 9% of national exports of iceberg lettuce, and 15% of the nation's cantaloupe (Leopold Center for Sustainable Agriculture). The Imperial County Farm Bureau estimates that two-thirds of the vegetables consumed in the US during the winter are grown in the Imperial Valley (2008 statistic). While this is a point of pride for the Farm Bureau, it is a stark reminder that the majority of Americans rely on food produced at least half a continent away, in a region that by definition is a desert, and by farm workers who are largely illegal Mexican immigrants (Ward, 2004).

The Landsat images that we have gathered help to show the agricultural giant that the region has become. They illustrate disparities in crop health between the different regions in California, Arizona, and Mexico that rely on Colorado River water for irrigation.

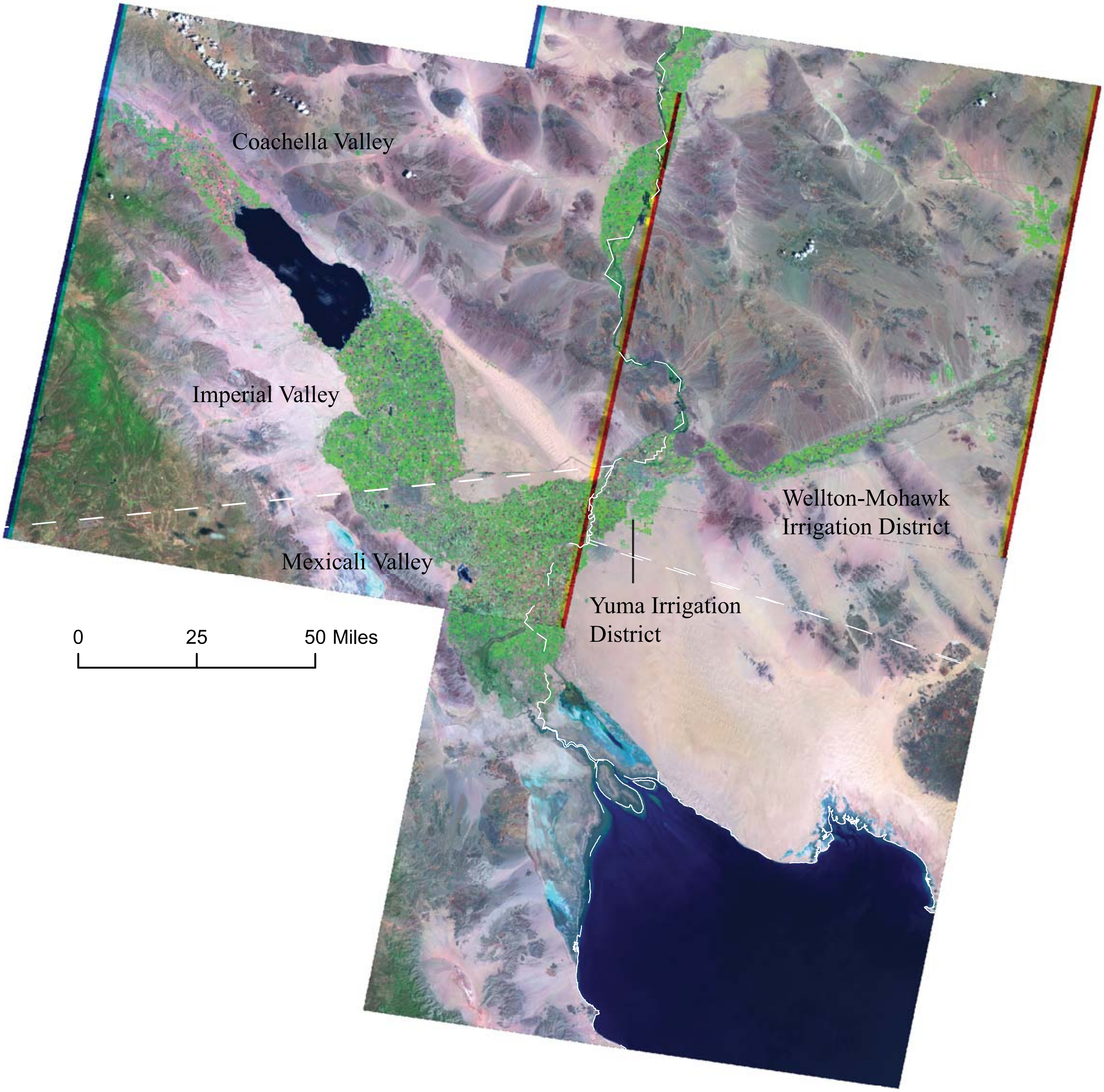


Figure 8.
The delta region of the Colorado River. The two northern images were taken in August, 2001, and the lower image was taken in March, 2000. No clear image of the quadrant including the Gulf of California could be found from August 2001. The band combination used is 7, 4, 2, and all healthy vegetation is green. Because of the arid climate, the only healthy vegetation is irrigated cropland. The brighter green shows healthier vegetation.
The main agricultural areas shown here are the Imperial Valley, the Coachella Valley, the Mexicali Valley, the Yuma Irrigation District, and the Wellton-Mohawk Irrigation District.

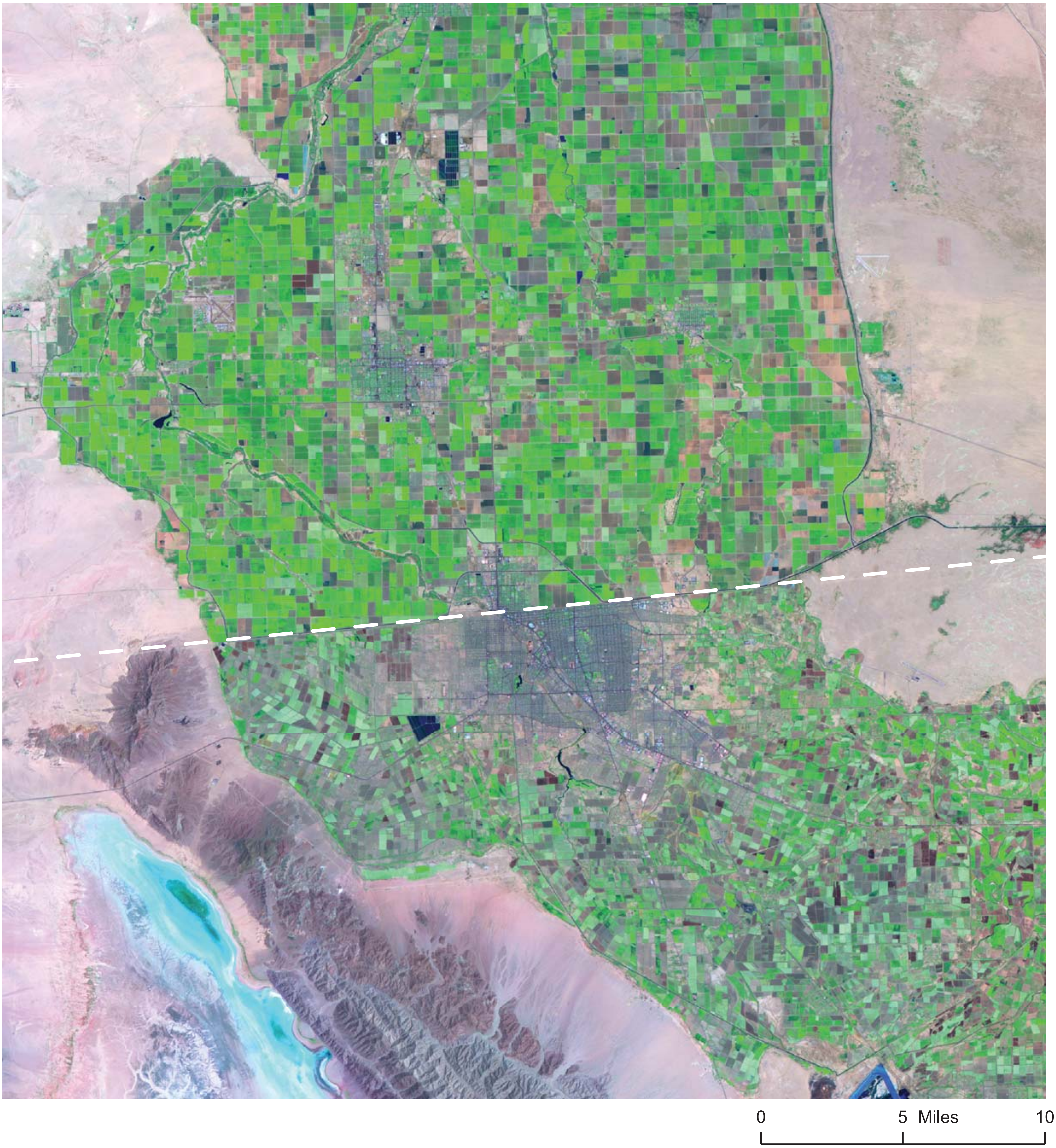
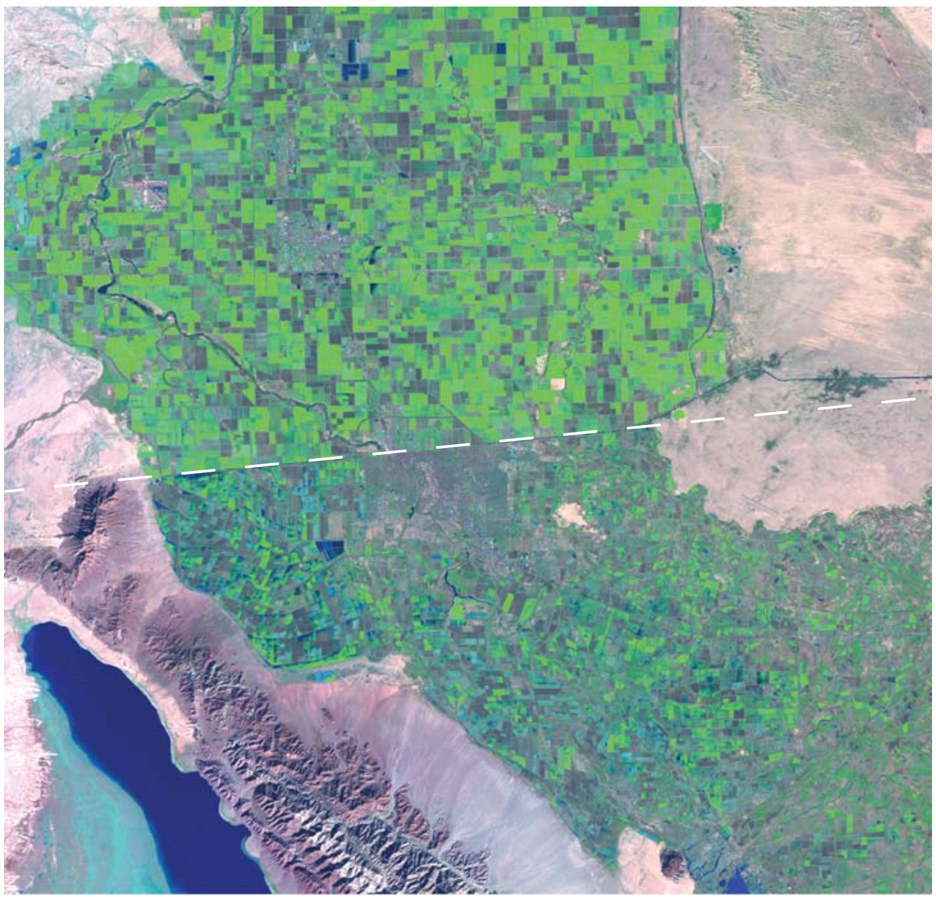


Figure 9.
The border between the Imperial Valley and the Mexicali Valley in the US and Mexico respectively. The crop formations of both regions are clear, as is the difference in crop health. The All-American Canal can be seen coming into the Imperial Valley from the east, just north of the US-Mexico border. The stark difference in crop health between the two countries is evidence of how the political power relationship plays out on the landscape. This image was taken in August of 2001.

Figure 10.
The US-Mexico border again. Both images were taken in August of their respective years. We believe that the improved crop health in Mexico that can be seen over this nineteen year period is evidence of at least a measure of success in the negotiations and legal battles between the US and Mexico concerning the salinity of the water the US delivers over the border.

1982



2001

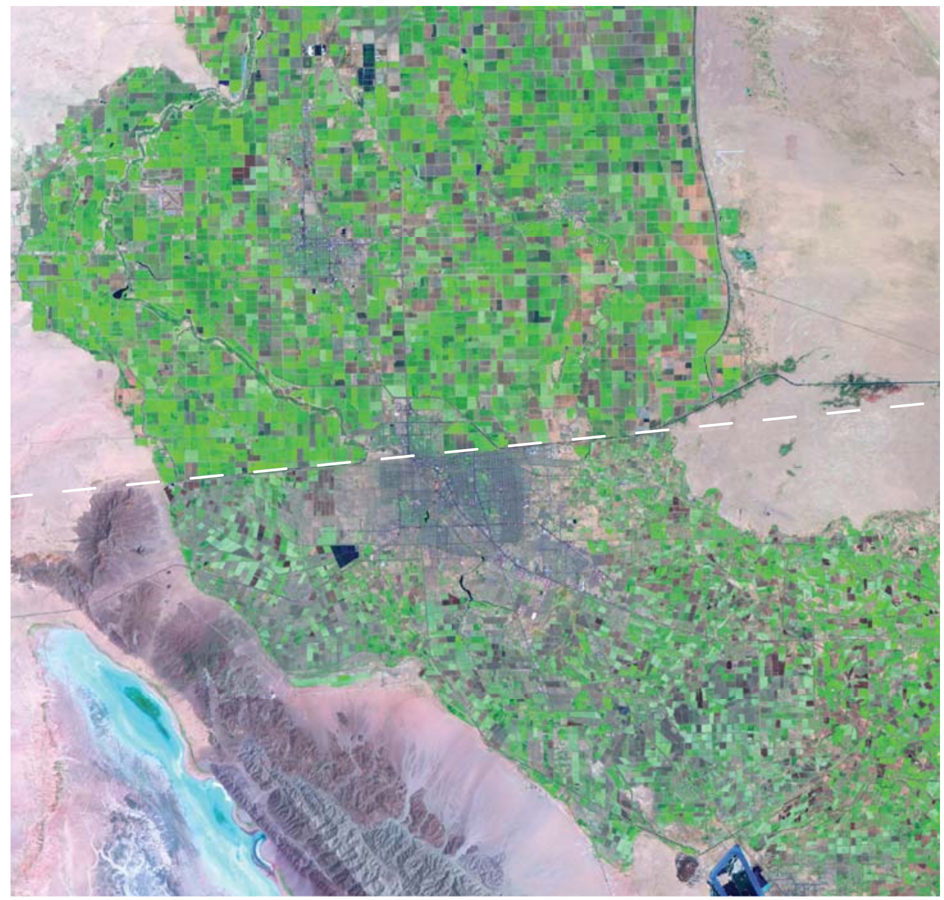
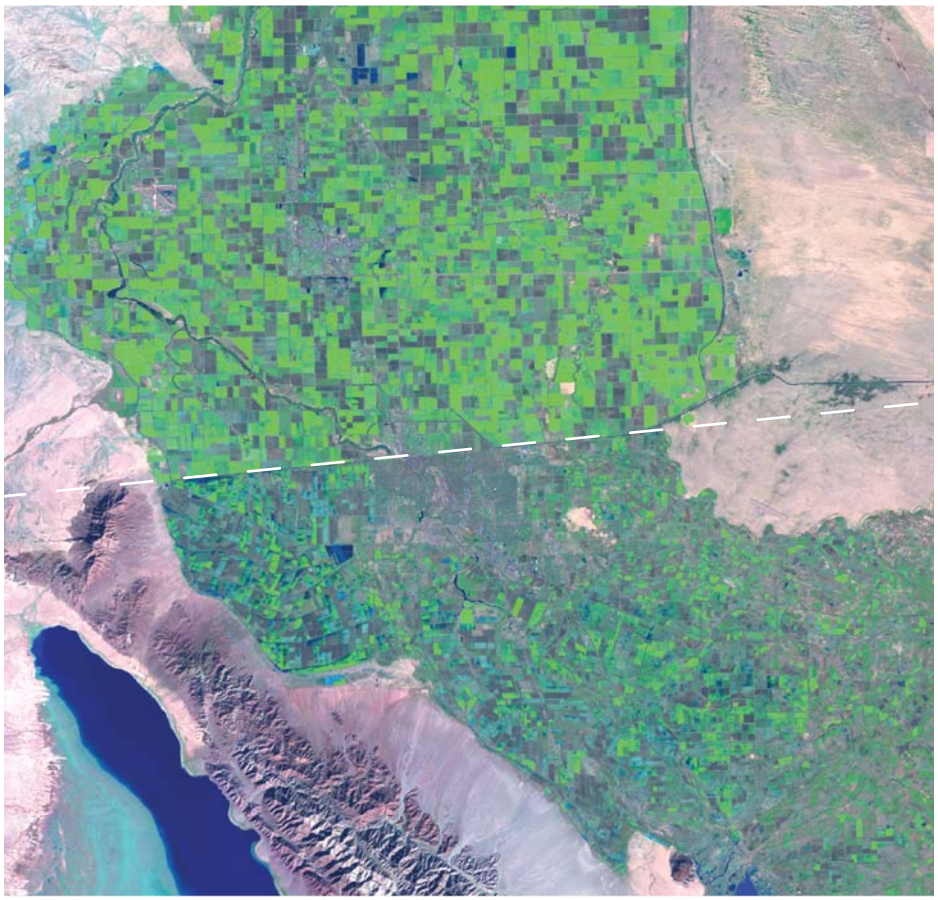


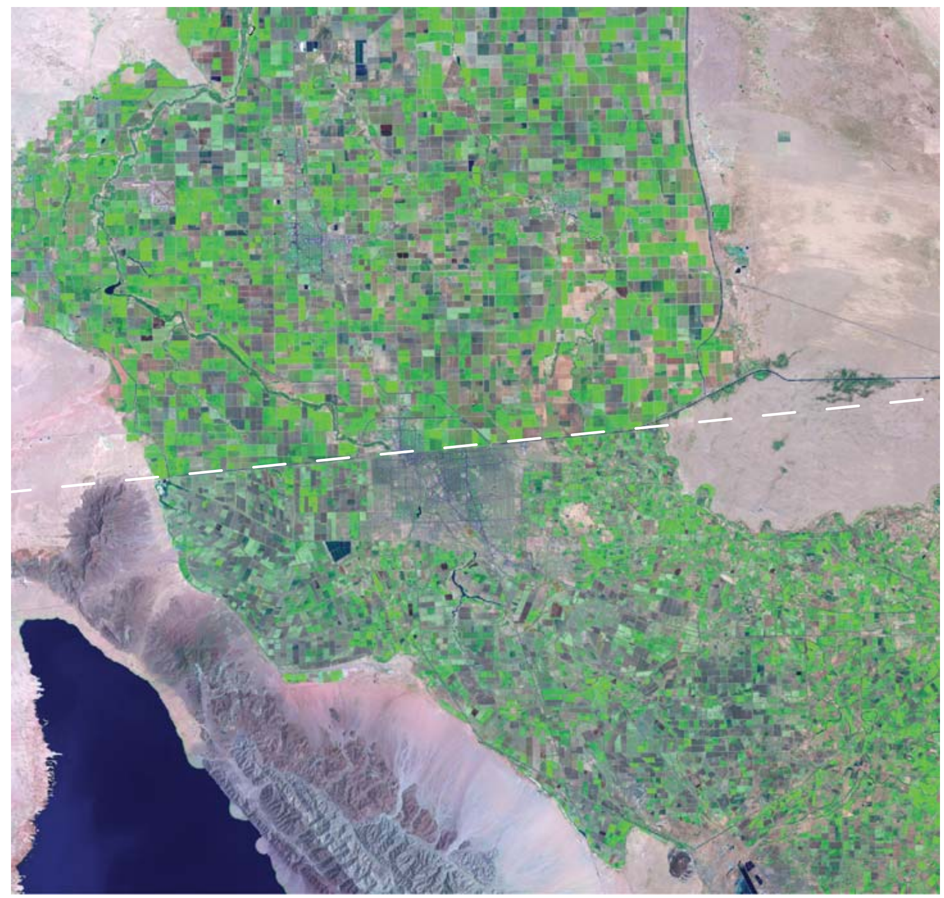
Figure 11.
This set of images (Both from August) of the same region as the previous figure offers an alternate explanation to better crop health in Mexico. The image to the right is from 1984, but the improved Mexican crop health looks similar to that observed in the 2001 image. 1984 witnessed an unusually high water year in the Colorado River Basin, but more importantly the Bureau of Reclamation forecasted that the flow of the river would be 174% of normal, and thus released more water from the Hoover and Glen Canyon Dams, allowing much more water to reach Mexico than normal. 1982 saw 1.8 MAF passed over the border, while 1984 saw 17 MAF (Bureau of Reclamation, 1984) . This illustrates the fact that Mexico is highly dependant on US water use, and also that anything above the 1.5 MAF promised in the Treaty of 1944 is very helpful to Mexican Agriculture.

1982



1.8 MAF passed to Mexico

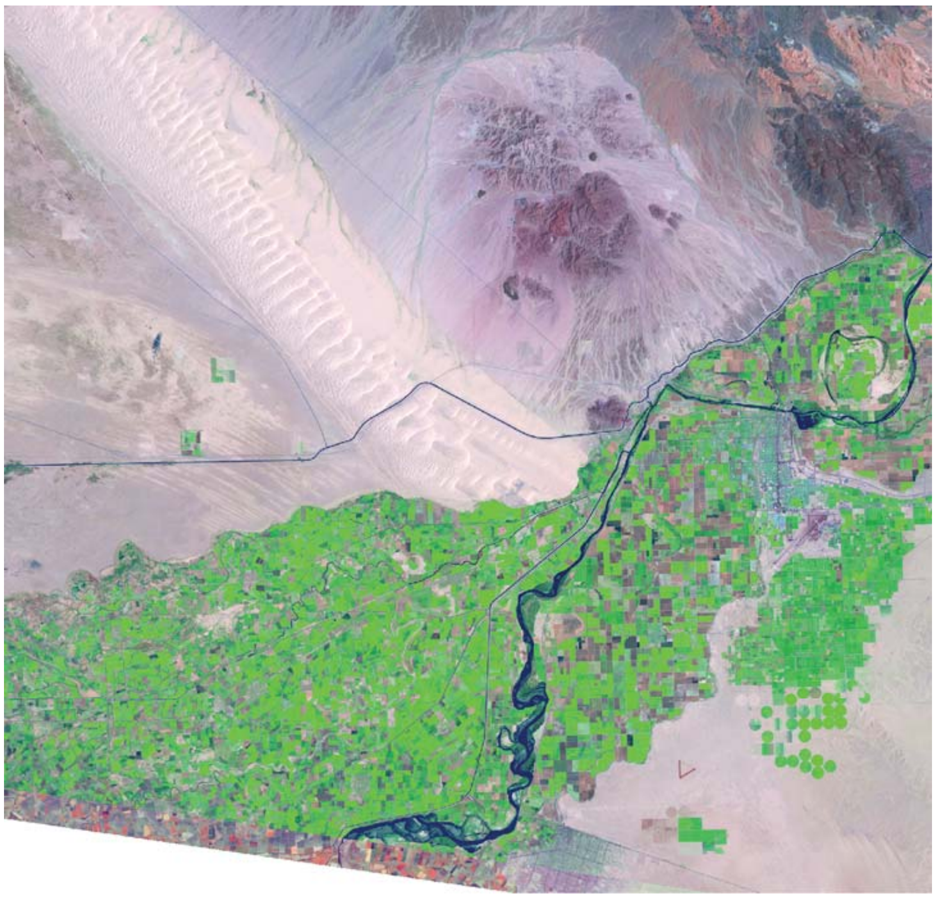
1984



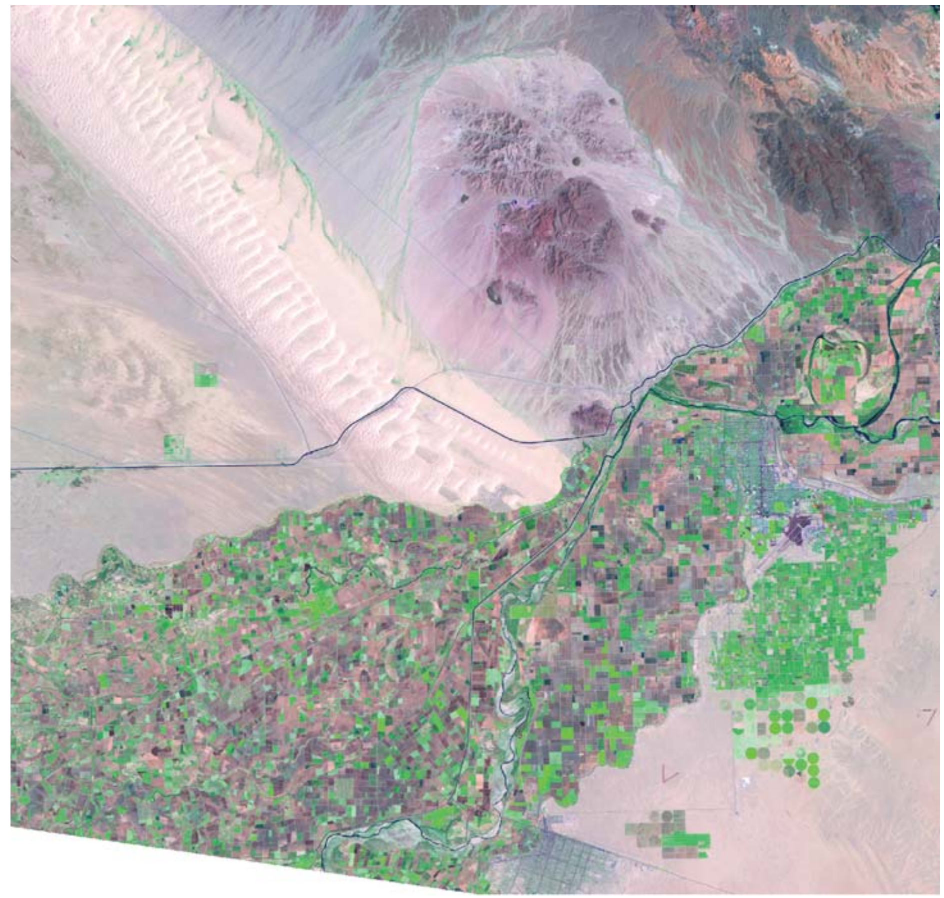
17 MAF passed to Mexico

Figure 12.
This set of Images from August of 1984 and 1993 is of the Yuma Irrigation District to the east of the Colorado River, and a continuation of the Mexicali Valley to the West of the river. The 1984 image clearly shows the large amount of water released to Mexico by the visible flow in the river, the release in 1984 was close to 16.5 MAF over the amount required by the treaty of 1944. Compare this to the 1993 image, where it is difficult to see the river basin because there is no water in it. The US still delivered at least the required 1.5 MAF in 1993, but these images show that crop health is highly dependant on more than the treaty approved amount.The Yuma irrigation district is also suffering from the reduced flow.

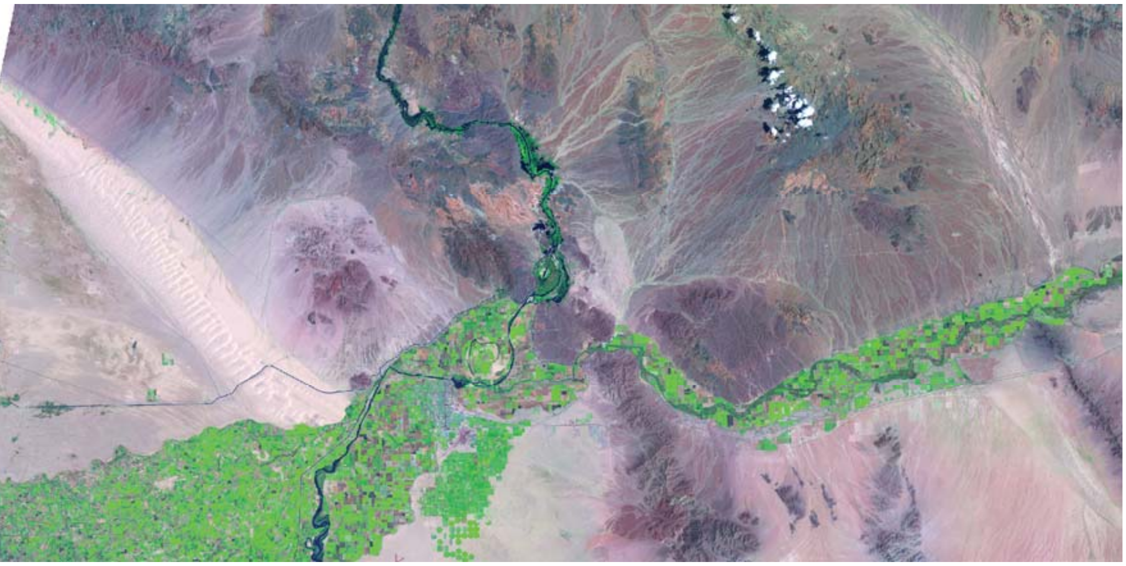
1984



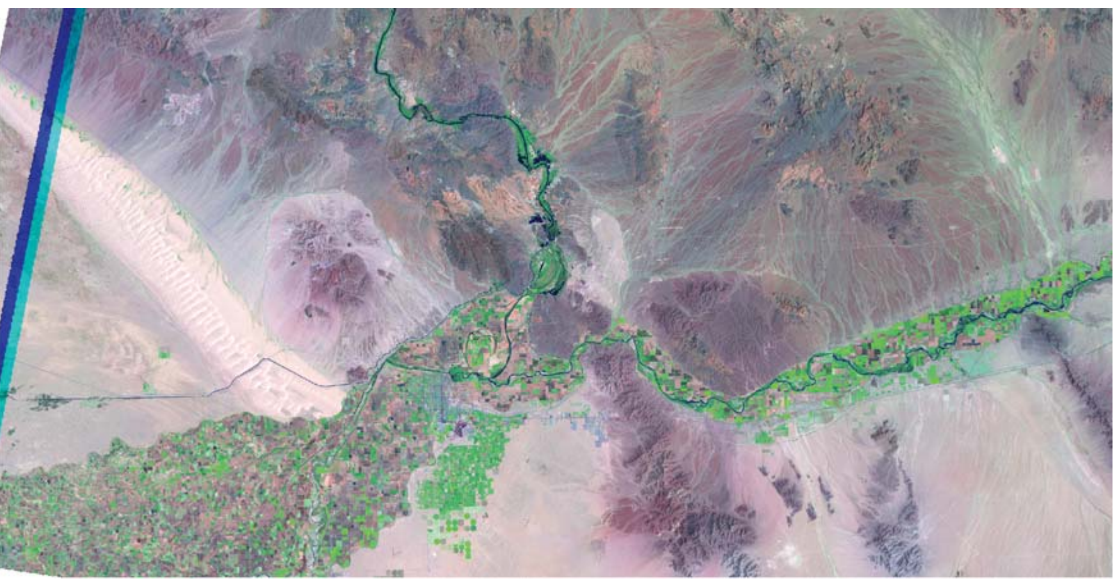
1993



August 1984



August 1993



August 2010

Figure 13.

This time series of the Yuma Irrigation District, the Wellton-Mohawk Irrigation District, and the eastern edge of the Mexicali Valley illustrates a few points.

First, the fact that cropland was much more healthy in 1984 compared to 2010 illustrates the fact that while the Bureau of Reclamation can control the water in the Colorado River Basin once it is there, they cannot control how much water flows into the river in the first place. Agriculture in the US is dependent on the highly variable hydrological cycles and erratic processes of the Colorado River Basin, and Mexico is dependant both on those processes and on the US for delivery of enough water.

Second, heavy streamflow years such as 1984 are not happening as often, as demonstrated by the current drought that has been persistent since 2000 (Bureau of Rec). This is happening at the same time as increasing agricultural and rural development.

As global climate change continues to effect weather in the Rocky Mountains in ways that we cannot yet predict, the flow of the Colorado River will likely fluctuate even more radically. Currently, heavy snowfall in the Rockies is melted more quickly than normal as Spring temperatures rise, causing heavy streamflow in the Spring, and dry conditions later in the Summer. At some point, the snowpack of the Rockies will become depleted by global warming, and the entire infrastructure that relies on the river will be put in jeopardy.

Conclusion

The remote sensing images that we have collected paint an ominous picture of the future of the Colorado River Basin. Development of the region, especially in the area surrounding the delta of the river, is continuing, and the river is being put under increasing stress. Adding to this is the problem of climate change, and the increase in variability and unknowns in the future flow of the Colorado as the snowpack of the Rocky Mountains becomes more unpredictable. Associated with this is continuing urban and agricultural growth in the Imperial Valley in California, the Mexicali Valley in Mexico, and the Wellton-Mohawk Irrigation District and Yuma Irrigation District of Arizona.

The Colorado River is over-allocated. When drawn up, the Colorado River Compact assumed a naturalized flow of 17 MAF, an estimate that turned out to be based on the two wettest decades of the last 500 years. Actual naturalized flow has recently been estimated at about 13 MAF, a figure based on tree ring studies (Hyun, 2005). Currently, The Upper Basin does not use its full allocation, which foreshadows greater problems as the region continues to develop. As of 2004, Upper Basin consumptive use was about 4.2 MAF, but is projected to rise to 5.4 MAF by 2060 (Christensen et al. 2004). While this is still more than 2 MAF less than the amount allocated to the Upper Basin states, that additional water is already in use by the Lower Basin and Mexico.

In this study, we have been able to put the modern issues of the Colorado River Basin in the historical context of growth, politics, and environmental problems that began with westward expansion in the late 19th century. The Landsat images that we have collected show the product of a century and a half of attempts to control the waters of the Colorado River both physically and legally. Water is the lifeblood of the American West, and in the true spirit of the fast-paced American growth model, development of the basin has been focused on each political entity involved grabbing as much water for themselves as possible. Little thought has been put into creating a sustainable system of water use, especially when considering the US-Mexico border region.

This has proven to be an interesting study in both environmental justice and water rights, with Mexico clearly coming out on the losing end. The images that we have collected show that the 1.5 MAF of water that Mexico is promised in the Treaty of 1944 is not enough for the farmers of the Mexicali Valley to maintain crop health at the same level of American farmers immediately to the north. This raises the question, how much *is* enough water? Based on our research and the Landsat images we have collected, we have concluded that it is less a matter of *enough*, and more a matter of *how much.* The more water that is passed on to Mexico, the healthier their crops will be. This shows that farmers in the Mexicali Valley are much more dependant on natural stream flow, while farmers in the US are able to maintain crop health even in low water years through control of reservoir releases.

Much more research is necessary to create a comprehensive study of water issues in the Colorado River Basin. We only used satellite imagery that dated back to 1982, and it would be very interesting to mine into state archives to find aerial photography of the river basin, especially of the US-Mexico border along California and Arizona, from the early 1900's. This would allow a researcher to follow trends of water and human development alongside of large physical changes such as the building of the great dams. Additionally, with more time we would have studied demographic changes in the region, and observed how population, wealth, and employment changed with water usage and policy development. While we could anticipate the results that we would have found, a more in-depth study of demographic fluctuation could provide material for a discussion of the effectiveness of certain policies. Good data on Mexican demographics in the region would also be necessary for this.

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