

# **Closing the Tap on the American Southwest**

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**IQP Project**

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Introduction.....	4
History.....	12
Ancient Rome .....	13
American Southwest .....	14
The Move Westward.....	15
The Dustbowl.....	18
Los Angeles and Owens Valley.....	22
The Colorado River.....	26
The Boulder Canyon Project.....	30
The Federal Agencies .....	32
Current Situation.....	36
Positive Developments across the States .....	37
State Programs .....	38
Solutions .....	44
Individual Efforts .....	45
Technology .....	55
Desalination .....	55
Aquifer storage and recovery (ASR) .....	56
Water recycling and reuse.....	58
Improved irrigation practices and methods.....	59
Policies.....	64
Population growth control.....	64

Reduce the use of beef as a source of food.....	65
Limit development and land use to available water resources .....	68
Water rate structure.....	70
Education on water conservation .....	72
Regional cooperation on water management.....	73
Conclusion .....	75
List of Figures .....	80
Bibliography .....	81

## INTRODUCTION

Throughout its life, this planet has gone through numerous cycles of heating up and cooling down. Recently, in the past 100 years, Earth has begun once again to heat up but this time, at a much quicker rate than previously. This phenomenon has been dubbed, “Global Warming”. There are a number of arguments stating that human activity is largely responsible for this climate change which has led to a rapid increase in global temperature. This is ascribed to an increased output of “Greenhouse” gases, such as carbon dioxide and methane due to production and use of fossil fuels. In 2004, there was a 1.7% increase in greenhouse gas emissions by the US<sup>1</sup>, a record for the time. In 2005, about 7,000 million tons of CO<sub>2</sub> was released into the atmosphere<sup>2</sup>. These are incredible numbers to consider. Of course, there are counterarguments as well, that claim this cycle of global warming is a natural occurrence and human contribution is negligible.

Regardless of what the cause is, it is clear that climate change is occurring and that the temperature of our world is warming at a more rapid rate than usual. The average global surface temperature has increased by 1.1 degrees Fahrenheit since the 19th century. The 10 warmest years of the last century all occurred within the last 15 years - 1998 was the warmest year on record<sup>3</sup>. As little as a one degree change in temperature, heating up or cooling down, has an

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<sup>1</sup> <http://www.ens-newswire.com/ens/apr2006/2006-04-18-02.asp>

<sup>2</sup> <http://www.eia.doe.gov/oiaf/1605/ggcebro/chapter1.html>

<sup>3</sup> <http://www.climatechange.ca.gov/background/faqs.html>

effect of far greater magnitude than one might think. For example, during the last ice age, global temperatures were between 5 to 9 degrees C cooler than they are now. During that time, Canada, New York and New England were covered by three kilometers of ice<sup>4</sup>.

As atmospheric concentrations of greenhouse gases rise, so do temperatures because less heat is able to escape the atmosphere. This temperature increase will, and already has in many cases, have a number of major effects on the planet, which in turn affects how organisms live, adapt and survive. This increase in temperature is responsible for rising sea levels, melting the Greenland ice sheet alone would increase the sea level by 6.5 meters<sup>5</sup>, and increased release of carbon dioxide from melting icebergs, an increase in the magnitude of storms, between 1970 and 2004 the number of Category 4 and 5 hurricanes nearly doubled<sup>6</sup>, drought and increased need for crop irrigation, increased pollution, redistribution of disease patterns and perhaps most critical of all, a decrease in freshwater resources.

Historically, water has always been our most important resource, something to be treasured and protected. Everything living needs water to survive. Approximately 71% of the Earth is covered by water. Though water is a renewable resource, it is also a finite one.

As the population and temperature increase, so does the demand for water for human use, industrial use and for food crops which results in an associated increase in irrigation and

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<sup>4</sup> <http://www.stimson.org/southeastasia/?SN=SE200707231356>

<sup>5</sup> <http://pubs.usgs.gov/fs/fs2-00/>

<sup>6</sup> [http://www.livescience.com/environment/050915\\_more\\_hurricanes.html](http://www.livescience.com/environment/050915_more_hurricanes.html)

sanitation needs. At the same time as usage is increased, freshwater resources are being further reduced due to the effects of the temperature increase from global warming and to pollution from industrial waste, chemicals, human waste, and fertilizers and pesticides from crops.

Global warming decreases fresh water resources in multiple ways. One of the major ways is the increasingly rapid melting of the icebergs due to higher temperatures. The charts below illustrate the increasing melt period. This increase leads to more open water on the ice caps. Open water absorbs solar energy at a higher rate than ice does. This increased absorption leads to increases in water temperature which will speed up the ice melt, thus continuing this dangerous feedback cycle.

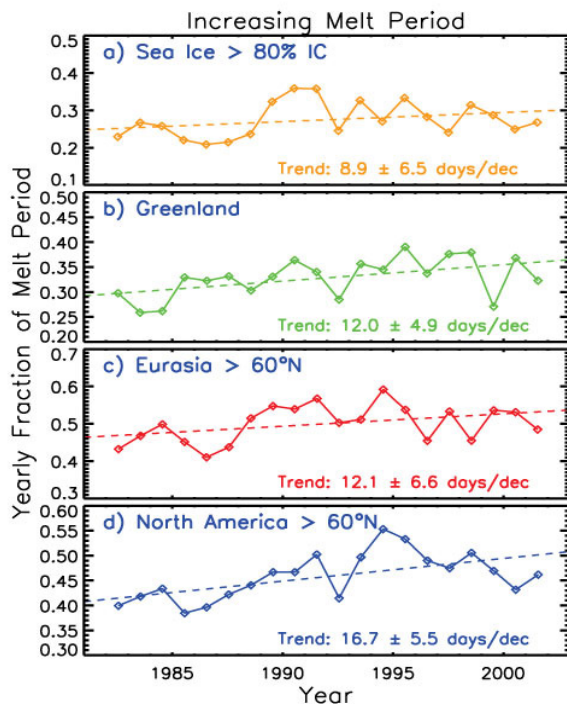


Figure 1 - Increasing Melt Period<sup>7</sup>

<sup>7</sup> <http://www.nasa.gov/centers/goddard/news/topstory/2003/1023esuice.html>

The water released from this melt results in a rising sea level which will eventually cause drastic change to the U.S. coastal communities where substantial areas of land mass such as in Florida, is either at sea level or below it. As the icebergs continue to melt, the sea level will continue to rise and low-lying coastal areas will be underwater unless heroic efforts are made to dam the sea back, as in the Netherlands. This rise in sea levels will also encroach upon the availability of fresh water resources by damaging the fresh-water ecosystems.

Melting icebergs not only increase the sea levels, but also increase carbon dioxide and methane levels being released. The ice at the Arctic Circle has a massive amount of carbon dioxide stored up. As this ice melts the carbon dioxide is released into the atmosphere where it will contribute to even more global warming. There is very little doubt that the amount of carbon dioxide stored in this ice is enough to cause an exponential increase in global temperature<sup>8</sup>. This is arguably the start of a vicious circle as if current trends continue, we will hit a point at which, even if we stop producing greenhouse gases, the planet will continue to heat up as more and more carbon dioxide is released by the melting ice and the sea levels will continue to rise.

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<sup>8</sup> <http://www.terracycles.com/elinolanina.htm>

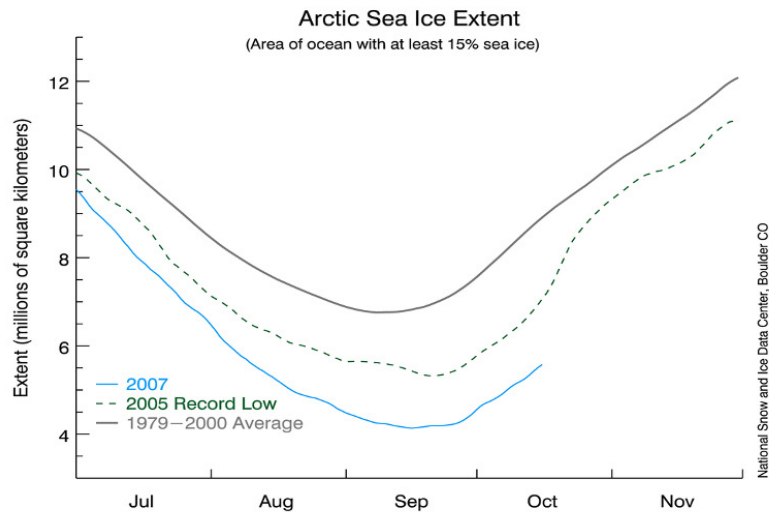


Figure 2 - Arctic Sea Ice Extent<sup>9</sup>

In the past number of years there has been an increase in the number and magnitude of storms, particularly on the southeast coast, in line with the global temperature increase. This means that we can expect this trend to continue as long as our global temperature increases. These storms have caused extensive damage, killed and displaced a large number of people, affected the water supplies and resulted in the spread of disease due to lack of clean water. A recent example that displays the enormity of increasing power of storms and the lasting effects on the water supply is the damage dealt by hurricane Katrina.

We rely on water heavily, without it there would be no life. As early as 100 years ago, our ancestors had no problems dealing with the water situation, so why are we having a crisis now?

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<sup>9</sup> <http://www.nasa.gov/centers/goddard/news/topstory/2003/1023esuice.html>

This crisis is, in part, due to the increasing population and temperature rise as noted above, but there are also a number of other reasons.

One is the areas in which the populations are increasing. Due to innovative technological increases water can now be transported for thousands of miles quite efficiently. This allows places that were previously only hospitable to a small number of people, to support a much larger population. Two good examples of this phenomenon are Las Vegas (NV) and Los Angeles (CA). When initially settled, these arid cities were not suitable for a large population, but are now some of the most populated and fastest growing cities in the US as there have not been substantial efforts to limit development to the availability of the water supply.

Another problem is the current trend of water usage. We are not using water efficiently, especially in places where efficiency is very much needed. If we go back to the example of Las Vegas, one may note that it uses a massive amount of Arizona's water supply. It is also surprising to note that much of this water is not used on the famous "Strip" but rather on the golf courses. The grass used for golfing is incredibly sensitive and needs to be watered constantly. Not only are golf courses unnecessary for survival, but they are being maintained in the worst places possible, deserts. A golf course could be much more efficiently and cheaply maintained in places where the rainfall is much higher and an excess of water is available through a reliable source of water, such as a river, is close by (although the Colorado River is such a source, it does not have an excess of water as will be shown later).

However, golf courses are not the only inefficient uses of water that are occurring today. Irrigation for “cash foods” such as nuts, fruits and livestock being raised in arid areas has not only greatly increased the water demands of these areas but has also exacerbated the problem by contaminating water sources through poor soil management and pollution from chemical fertilizers. In the Western states, irrigation uses as much as 80% of the total water consumption for this area<sup>10</sup>. The lack of low-water usage facilities such as toilets, lack of education on how to reduce water usage on a personal level, industrial waste resulting in pollution in the groundwater and a high amount of pollution in the air which contaminates rainwater, and complex water rights have all contributed to the existing water crisis.

One of the regions most affected by this crisis is Southwestern USA, specifically California, Colorado, Arizona, New Mexico and Utah. As a result, competition for the water rights to the Colorado River, which runs from Colorado through the southwest to Mexico and is the major source of water for this region, has been steadily increasing. Now, even this source of water is becoming insufficient to supply all of these states. These states are now looking at other ways in which to keep supporting their growing demands. However, the best way forward may be to look at the ways to decrease the need for water and to increase the efficiency of what is being used.

One element of this report is to examine the history of water in the western US and how, not only the situation, but the mentality towards water has changed over the course of the years. The current situation will be assessed: how much each state requires, what they are receiving, how they are using the water they have, where they are looking to acquire more water, how they have

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<sup>10</sup> <http://www.ucowr.siu.edu/hydro/h03.html>

handled previous negotiations and how much water they made need in the future. From there the various options on how to better address the water problem, will be discussed and evaluated. Finally, a list will be displayed showing small things which each person can do, to reduce the effect of the water crisis and global warming. Individually it may have a negligible effect on the situation, but if a large number of people abide by the rules, it will have a positive and noticeable effect on the problem at hand.

# HISTORY

As mentioned previously, water has always been a coveted resource in the world and due to the increasing demands, needs to be managed carefully. To understand the growing water crisis and what we should do to fix the current problems, it's helpful to review the past and understand how we got where we are today. This section will present how people, especially those in the American Southwest, have dealt with water and its issues in the past.

All one has to do is look at the older cities of the world to see how difficult it was to acquire a steady source of fresh, clean water. An excellent example of this is Egypt. Ninety-Seven percent of Egyptians live in close proximity of the Nile<sup>11</sup>. They depend on the Nile, a very reliable and predictable river at this point as it is so far from its original water sources, to supply them with drinking water, irrigation water and a convenient form of transportation. If this river had not been so reliable, then an entire civilization might have ceased to exist. Nowadays it might be possible to supply a population of Cairo's scale, 15,750,000<sup>12</sup>, without the Nile, although the cost and magnitude of such a project would be staggering. As few as a hundred years ago, it would have been unthinkable.

How did this change in possibilities come to pass? The answer is the development of water transportation systems (such as the aqueduct) that allowed water to be moved and stored for later use. This led to settlement of areas that previously could not have supported a larger population

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<sup>11</sup> <http://www.geology.ucdavis.edu/~cowen/~GEL115/115CH17oldirrigation.html>

<sup>12</sup> <http://www.demographia.com/db-cairo.htm>

without the possibility of water storage and crop irrigation. As early as 6000 years ago<sup>13</sup> irrigation has been an integral part of survival. Though there is time and effort involved to build and maintain an aqueduct, the advantage of having water easily accessible by letting gravity do its work far outweighs the initial investment. Having to manually carry water to its destination is much more strenuous and uses up precious time that might be spent better elsewhere.

## **Ancient Rome**

Probably the most well known example of a water transportation system is the Roman Aqueduct. The Romans built a very extensive aqueduct system that spanned a large area of their Empire. Their longest aqueduct was approximately 59 miles long, a massive engineering feat accomplished by the Romans. This system provided more than a cubic meter of water per day for each inhabitant when their population reached roughly 1 million<sup>14</sup>. This happens to be more than what the average person today uses, which is very impressive considering the technological gap between our engineers and the Romans. Their system worked by using the land to their advantage, using the slope of the land to carry water to where it was needed. The gradient of this slope was very slightly tilted downwards and gravity was allowed to work. In most cases, the aqueduct was molded along the natural landscape to make it easier on the engineers. In some cases it was necessary to build bridges across ravines or to have arches to reduce the gradient of the slope, otherwise the water would move too quickly and some of the precious resource would be lost.

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<sup>13</sup> <http://www.geology.ucdavis.edu/~cowen/~GEL115/115CH17oldirrigation.html>

<sup>14</sup> <http://id-archserve.ucsb.edu/arhistory/152k/water.html>

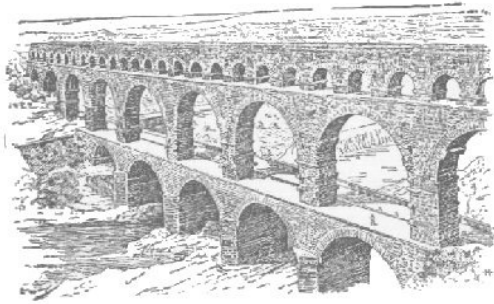


Figure 3 - Roman Aqueduct<sup>15</sup>

The immense size of the Roman Empire was the motivating factor behind the development of the aqueduct. A large portion of their populated land was not near a reliable source of water and therefore vulnerable to the weather. Instead of forcing their people to live only in those areas which could readily sustain them, they built these incredible aqueducts to supply those areas with water. The major problem with such an extensive network of irrigation was its vulnerability. An earthquake, high winds or attack from a rival could easily destroy or disrupt the flow of water. The community that would normally be supplied by this constant source of water would quickly have to look for an alternative or perish.

## **American Southwest**

There are strong parallels between the population changes due to the Roman aqueduct system and what our society is doing today with areas such as the American Southwest. We are supplying areas, such as the Southwest desert, that would normally not be able to support high density populations or food crops, with an acceptable amount of water for today's standards, 10

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<sup>15</sup> <http://www.usgennet.org/usa/topic/preservation/science/inventions/chpt2.htm>

gallons per person per day, and then some. As a result, the population in these areas has continued to grow and the need for even more water has increased. Though it might make good sense ecologically to reduce the amount of water and decrease the population of such areas, it is not realistically feasible. Places such as Las Vegas are considered artificial oases where one can have the heat of the desert, but the comfort of a cooler and wetter climate. Granted, supporting a limited number of these cities would not necessarily have a profound adverse affect on the water resources of the areas, but the majority of the Southwest is already developed and is continuing to grow. To understand the reason behind this mentality and how this happened in what was originally an inhospitable area, we must go back to the 19<sup>th</sup> Century, just as the large migration west was happening.

## **The Move Westward**

Back in 1869, in what is now known as Colorado, Utah, Arizona, New Mexico and Nevada, the Plateau Province was mostly unexplored except by Native Americans. For most travelers heading west, the Plateau Province was a place to be avoided when traveling as there was very little vegetation or water to support travelers. The mapping of this area is mostly credited to John Wesley Powell, who Lake Powell is named after. Powell, along with 9 other men, set out on 4 wooden ships on the Green River in Utah. After about 3 months, Powell finally showed up at the Grand Walsh Cliffs located towards the end of the Grand Canyon, with a couple of casualties and minus a boat. At the same time that Powell was mapping this area, many people had already begun to move west. By the late 1870s small farms were beginning to sprout up around Denver a

small town used by those searching for gold and beaver pelts which was supplied with fresh water by the Platte River.

There were a number of reasons for this rush to the west. There was the California Gold rush in 1848 that brought people from all over the world. Even though gold was becoming scarcer by 1870, people still believed that they could “make it big” in the West. The West had become associated with richness and profit to anyone who moved there. Adding to this fever were the newspapers, especially the publisher for the Herald Tribune, Horace Greeley, who pushed for young men go to west and populate the area<sup>16</sup>. Now that there was a better picture of how large the Southwest was as well as what the geography was like, people were more likely to migrate there. It was no longer viewed to be quite as dangerous, instead it was viewed as an opportunity to expand the nation. Added on to this was the thought of “why not?”. If there was an area of land open, it should be used to its fullest extent, not left to waste. There were 38 million<sup>17</sup> people that could be spread out across an entire nation, instead of being holed up along the coasts.

The migration was further encouraged by the unusual precipitation level at the time. The late 1870s and 1880s saw an increased precipitation level in areas that usually received little, to no, precipitation yearly<sup>18</sup>. This allowed farmers to explore and experiment with different types of farming methods and crops in areas which they would not have been able to do if the precipitation levels had been normal and gave them a false sense of confidence. The long

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<sup>16</sup> Cadillac Desert, pg. 35

<sup>17</sup> <http://www.census.gov/population/www/documentation/twps0029/tab01.html>

<sup>18</sup> [http://www.cas.sc.edu/geog/hrl/Hazard\\_Pubs/2000\\_RainfallInTheGardenOfTheUSGreatPlains.pdf](http://www.cas.sc.edu/geog/hrl/Hazard_Pubs/2000_RainfallInTheGardenOfTheUSGreatPlains.pdf), pg. 1

growing season, and hot climate, combined with an adequate water source resulted in high yield crops especially in Southern California. Before the 1880s, Los Angeles had been a less than desirable place to live, until people began to realize the full potential of such a climate. Probably the most lucrative crop to grow was the orange, a cash crop. Oranges sold for a lot more than wheat, which was traditionally grown in places such as Nebraska, and the California climate was perfect for such an orchard. Los Angeles and its surrounding areas began to increase in population, limited only by the amount of easily available fresh water.

Unfortunately this increased precipitation level had yet another consequence; it gave rise to the “Rain follows the Plow” mentality of the late 19<sup>th</sup> Century<sup>19</sup>. In fact, Kansas’ Board of Agriculture recorded that there was an average of 44.17 inches of rain in 1888 and 43.99 in 1889<sup>20</sup>. If one compares this to the average rainfall level from 1931 – 1976, which was roughly 19 inches<sup>21</sup>, there is a difference of about 25 inches of rain. This is an incredible difference in rainfall levels and completely changes how one tackles farming in that area. The Rain follows the Plow mentality was very dangerous, especially in areas where rainfall can be so fickle. Farmers were taking the farming methods used in New England, where the annual precipitation levels vary from 35 to 55 inches<sup>22</sup>, and applying it to what was essentially a desert. In only a

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<sup>19</sup> [http://econ.arizona.edu/downloads/working\\_papers/dryfarm8drafts.pdf](http://econ.arizona.edu/downloads/working_papers/dryfarm8drafts.pdf)

<sup>20</sup> Cadillac Desert, pg. 40

<sup>21</sup> <http://links.jstor.org/sici?sici=0022-8443%28197723%2F24%2980%3A3%2F4%3C89%3APPIWK1%3E2.0.CO%3B2-9&size=SMALL&origin=JSTOR-reducePage#abstract> (Abstract, Precipitation Patterns in Western Kansas, 1931-1976)

<sup>22</sup> <http://www.necci.sr.unh.edu/Nera-products/NERA-Climate-2pager-6.99.PDF>

decade or two these areas, much of what was the Great American Desert, were rapidly being populated by people lulled into a false sense of security. Obviously back then, meteorologists did not have as much information or knowledge as we do today about climate change, but nonetheless this rapid increase in population and inappropriate mass farming caused significant damage to this area in the long run.

## **The Dustbowl**

One of the most severe results of this over-farming in unsuited areas, was the Dustbowl of the 1930s. It is ironic that there was a large increase in rainfall, in some places causing floods, a year before the drought, accompanied by the dust storms of September 1930, began. The floods were followed by blizzards in the winter of 1930-1931. Following this winter, there was a dramatic decrease of precipitation resulting in a drought. It was not until that following September that it was even worth planting crops, there was so little moisture in the ground. Due to the late planting, much of the crop, mostly wheat, did not survive, or was very weak. In 1932, the winds began to blow, bringing with it large amount of dust. This cycle of dust storms, heat waves during the summer, blizzards during the winter, continued for about 10 years carrying away 300 million tons worth of topsoil<sup>23</sup>, with the worst ending around 1938. Millions of people migrated away from the plains<sup>24</sup> as crops failed, livestock were killed and houses were made uninhabitable due to the large amount of dust settled in and around them. By this time, however, the damage to the land had already been done.

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<sup>23</sup> <http://www.bookrags.com/history/america-1930s-government-and-politics/sub27.html>

<sup>24</sup> <http://www.drought.unl.edu/whatis/dustbowl.htm>

If a farmer continues to grow crops in the same area, year after year, without allowing the land to recharge, a number of things happen. One is that the soil loses its nutritional value and therefore produces fewer crops. This causes the farmers to plant even more, in hopes that more crops will grow, causing a vicious circle as the soil will lose even more nutritional value from the added stress of more crops. If the soil is not allowed to rest, it becomes dry and light, perfect conditions for a dust storm. In order to plant the crops, the farmers plowed up the indigenous grasses, further damaging and changing the land. In addition to extensive inappropriate crop farming, the land was overgrazed by cattle. Again, the farmers tried to get too much out of the land and allowed their cattle to graze on the same areas, rather than rotating to a less utilized area. The cattle would eat all of the grass down to the roots, leaving the soil vulnerable to the winds that would sweep the plains. If the grass had not been continuously eaten away, the soil may have been more stable and less likely to create a dust storm.

There are multiple theories as to why the Dust Bowl disaster occurred. Some believe it may have been a shift in the oceanic temperatures that, in part, caused the drought and Dust Bowl<sup>25</sup>.

Changes in ocean temperature do cause shifts in normal weather patterns. If these temperature variations are great enough, it is more than likely that even areas far removed from the ocean, such as the Mid-West would have been affected. It is probable that the drought was caused by climatic shifts. The dust that came along with the high winds was likely a combination of the dryness, poor farming methods and lack of soil conservation leading to soil erosion.

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<sup>25</sup> <http://www.nasa.gov/centers/goddard/news/topstory/2004/0319dustbowl.html>

It is worth noting that, after the Dust Bowl disaster, the government took measures to prevent this from happening again. They began to launch programs to promote soil conservation. These programs included paying farmers to grow a specific type of crop that would fertilize the soil, or to not grow any crop at all. There were programs that paid farmers to follow the contours of the land or plant trees along their farms, to prevent widespread erosion from occurring. These programs solved two problems at once. First, it allowed the soil to recharge and yields to reach their previous peaks, as well as prevent erosion so that the soil would stay on the ground and not get swept up by every wind that blew by. The second problem solved was that of economics. This Dust Bowl had caused many of farmers to go bankrupt and switch professions or find a new place to begin farming. Those that were left in the plains did not have a lot to work with. The promotion of soil conservation and paid programs gave the farmers enough money to start over and encouraged good farming methods. As one farmer put it, the programs, “helped us get back on our feet... When I came to York, this one time they was giving us about \$50 or 60\$ on 80 acres.”<sup>26</sup>

Just before and around the time of the Dust it become obvious that in order for the population in the Los Angeles area to grow, a reliable source of water was needed, which sometimes happened at the expense of someone else. The rainfall, which was so abundant at the end of the 19<sup>th</sup> century, was merely part of the cycle of increased rainfall followed by drought. A drought, like the one from 1890-1896, did and would cause a significant amount of damage to a city without a reliable source of water to fall back on.

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<sup>26</sup> [http://www.livinghistoryfarm.org/farminginthe30s/crops\\_09.html](http://www.livinghistoryfarm.org/farminginthe30s/crops_09.html)

Unfortunately, the majority of the cities in the Southwest which had been settled during times of high precipitation now had no sources nearby from which they could easily draw on. They therefore had to look further away and pipe the water to where it was needed which led to the rise of water rights.

Water rights were the source of a great deal of controversy and the laws surrounding water rights were and continue to be, complex and varied. The initial settlers of the Southwest brought with them water rights based on the riparian system. In the riparian system, the owner of the land on the bank of the stream or lake also holds the right to the water as long as they do not adversely affect other users who also hold rights to the same body of water.<sup>27</sup> In the East, where most of the settlers came from, there was usually enough water that the riparian system worked well. However, in the arid Southwest, settlement and land development would have been severely restricted if water use was limited to the people who owned the land that the water flowed through. A common practice at that time was for miners during the California Gold Rush, to divert and transport water from its natural course to other areas for processing the ore. The end result was that this custom of claiming and using water led to the “prior appropriation doctrine”, also known as the Colorado Doctrine and “first in time-first in right”, becoming law.<sup>28</sup> Under the appropriation doctrine, though the water in a river, lake or stream is not actually owned, the right to use the water was granted if it was proven that the water was used for beneficial use and if that person or corporation had a way to access the water. It is important to note that, in contrast to the riparian system, the owner of appropriation water rights can be different from the owner of the

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<sup>27</sup><http://www.waterinfo.org/colorado-water/colorado-water-rights>

<sup>28</sup> <http://www.blm.gov/nstc/WaterLaws/appsystems.html>

land through which the water runs. In addition, the first person to receive water rights to a stream had seniority over anyone else with rights on that same stream. This meant that the owner with the most seniority had priority over the use of the water. Once granted, these water rights could be bought and sold similar to property, and could even be forfeited if it could be proven that the owner had not been using the water allocated whether based on flow rate or storage volume. To make matters more complex, even up to the present, the laws vary within the western states.<sup>29</sup>

Several states in the West are now taking steps to make changes in the laws which have often resulted in a combination of riparian and appropriation doctrines in order to address the issues of water rights based on the present situation.<sup>30</sup> However, back in the 1800's, the appropriation doctrine was used. Since water could be bought and sold separately from the land, it was not uncommon for a powerful outside entity, either a city or a group of farmers, to obtain appropriation water rights, leaving the locals fearful that the outsiders would take their water and leave none for them, which is exactly what happened with Owens Valley.

## **Los Angeles and Owens Valley**

Los Angeles' first boom in population began in 1880, mostly due to the agricultural possibilities associated with that region. This was compounded by the discovery of oil in the Beverly Hills region. In about 20 years, Los Angeles went from a small shifty town that housed anyone trying to avoid the law, to a sprawling metropolis. The population became so large, that there was no

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<sup>29</sup> <http://library.findlaw.com/1999/Jan/1/241492.html>

<sup>30</sup> <http://www.blm.gov/nstc/WaterLaws/appsystems.html>

way the Los Angeles River would support the city. Not only was the population growing, reaching 300,000 in 1910 and 1.2 million in 1930<sup>31</sup>, but the annual flow of the river was dropping, going from 100 cubic feet per second (cfs) in 1880 to 45 cfs in 1902<sup>32</sup>. To compensate, Los Angeles began drawing water out of the ground, but the governing body knew this would not last and a long term solution was needed. By 1904 they knew that something had to be done immediately.

Owens Valley on the other hand, was full of potential. It is a unique little valley located between the Sierra Nevada and White Mountain ranges, about 250 miles away from Los Angeles. This valley had an underused river, Owens Valley River, as well as a lake, Owens Valley Lake. Not only was the geography perfect for increased irrigation, the soil was also very rich and was suitable for any number of crops. Owens Valley Lake was also the perfect spot of migratory waterfowl due to the large numbers of flies and shrimp living in the lake. However, the Los Angeles administration had their eye on the extra water.

Around the same time Los Angeles began to look at Owens Valley, the Reclamation Service (later to be known as Bureau of Reclamation) also decided that this would be a great region to prove their worth. As stated before, the valley would be perfect for irrigation and the farmers were all well-versed in land management, somewhat of a rarity this far west. To the people of Owens Valley, the agent of Los Angeles, Fred Eaton<sup>33</sup>, was just another engineer associated with the Reclamation Service, but this was not the case as he realized the potential of Owens Valley to

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<sup>31</sup> <http://www.census.gov/population/www/documentation/twps0027.html>, Population Division Working Paper No. 27

<sup>32</sup> Cadillac Desert, pg 60

<sup>33</sup> <http://www.usc.edu/libraries/archives/la/scandals/owens.html>

benefit Los Angeles and was instrumental in making this potential a reality. Around the year of 1905, Los Angeles slowly and somewhat secretly began to buy out key parts of land and water rights so that an aqueduct could be built. During the course of buying up these rights, Los Angeles also had to come up with a way to convince the government that their project took precedence over the Reclamation Service's. Their argument was that, "it is a hundred or a thousand fold more important to the state and more valuable to the people as a whole if used by the city than if used by the people of the Owens Valley"<sup>34</sup>. In 1906, President Theodore Roosevelt granted that this was the case and Los Angeles had the right to build the aqueduct. In 1907, when Los Angeles finally had enough land and rights to the river, the votes endorsed the decision to build an aqueduct.

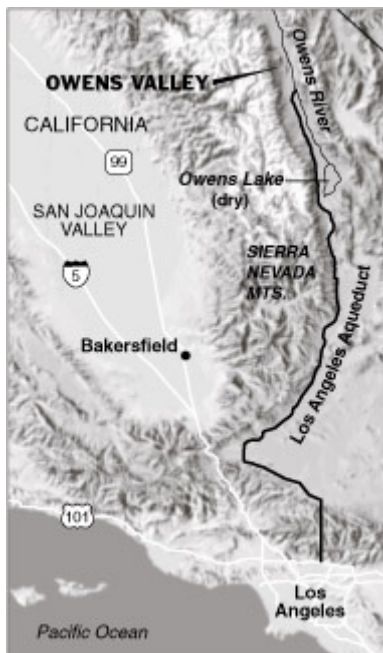


Figure 4 - Los Angeles Aqueduct from Owens Valley<sup>35</sup>

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<sup>34</sup> <http://wsoweb.ladwp.com/Aqueduct/historyoflaa/hundred.htm>

<sup>35</sup> [http://www.nytimes.com/2007/01/01/us/01water.html?pagewanted=2&\\_r=1&ei=5087&em&en=74176d876d406106&ex=1167800400&adxnnl=1&adxnnlx=1209146647-80h24/imxpUo8HmHA0KXNw](http://www.nytimes.com/2007/01/01/us/01water.html?pagewanted=2&_r=1&ei=5087&em&en=74176d876d406106&ex=1167800400&adxnnl=1&adxnnlx=1209146647-80h24/imxpUo8HmHA0KXNw)

It took 6 years to build the aqueduct. On November 5, 1913 the Owens Valley aqueduct was opened. It is interesting to note, that the aqueduct would run through and had the capacity to supply the San Fernando Valley, a region full of potential, with a steady supply of water. When the aqueduct was first introduced, the San Fernando Valley was not a part of Los Angeles. To prevent the land surveyors of this area from receiving all of the benefits of this project, Roosevelt stated that the water could only be used by the city of Los Angeles. In response to this ruling, Los Angeles promptly annexed the San Fernando Valley<sup>36</sup> to realize additional benefit from the aqueduct.

Even though there was a vocal opposition to the aqueduct, for about a decade, everything went relatively smoothly. There were no conflicts on how much water would be used by each source, since that had been set in stone before the aqueduct was built. Los Angeles was using up the excess water and still staying well within its rights. This did not last as Los Angeles continued to grow and the amount of water allotted to them by the aqueduct was no longer sufficient to supply the population. Adding to this problem was a lack of snowmelt from the Eastern Sierra in 1923, meaning that both Los Angeles and their primary water source could very well be facing shortages. Los Angeles dealt with this problem by buying up a number of ranches in the area and not only using their river water, but also pumping up all the nearby groundwater. The ranchers adjacent to these pumps were severely affected since they also relied on that groundwater, especially in times of reduced river flow, as was happening at the time. In 1924 a number of men blew up parts of the aqueduct in retaliation to Los Angeles' underhanded moves.

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<sup>36</sup> [http://www.kued.org/productions/desertwars/kahrl\\_william.php](http://www.kued.org/productions/desertwars/kahrl_william.php)

By 1927, it became an all out war between the two parties involved, the first order to shoot coming on May 28, 1927<sup>37</sup>. This war did not last long though, as the two people (the Watterson brothers, owners of the town bank) responsible for supplying the rebellion against Los Angeles, had also committed a number of crimes. When the Los Angeles authorities revealed this information, the men were arrested and the rebellion was finished<sup>38</sup>. As one can see, water will not always keep its predetermined route, but instead may flow towards the greatest source of power.

Owens Valley never developed as much as was originally intended. Instead, it stayed a small town with very little industrial power. Recently, Los Angeles has been releasing some of its hold on the water from Owens Valley and is trying to slowly refill Owens Valley Lake, which was destroyed once the aqueduct was built. Although Owens Valley never reached the peak of its potential in terms of industrialization, it did allow the wildlife to continue relatively unaffected, some silver lining to a very dark cloud.

## **The Colorado River**

As Los Angeles continued to grow, water rights and control of the Colorado River became increasingly important. The Colorado River has always been a source of controversy as it is a large, reliable source of water close to a number of thirsty states. Currently, the Colorado River

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<sup>37</sup> Cadillac Desert, pg. 95

<sup>38</sup> [http://www.kued.org/productions/desertwars/kahrl\\_william.php](http://www.kued.org/productions/desertwars/kahrl_william.php)

supplies about 13.5 million acre feet per year<sup>39</sup>. One acre foot is roughly equal to 1,233,500 liters or 325,851.4 gallons. This is a large amount of water that, theoretically can supply about 27 million homes<sup>40</sup>. Of course the Colorado River is not the only source of water available in these areas, the Ogallala Aquifer being a major source of groundwater from Texas to South Dakota<sup>41</sup>, but it is certainly attractive to any state that wishes to develop.

In 1921, California and the six other Colorado River Basin States, Arizona, Nevada, Utah, New Mexico, Colorado and Wyoming, formed the Colorado River Compact to apportion the water supply of the Colorado River and its tributaries. This gathering of states produced the Colorado River Compact of 1922<sup>42</sup>. It was a way for the six states to protect themselves against monopolization of the river to enable rapid development in California. The Compact, though it was not ratified until later by Arizona, was signed into law by President Herbert Hoover in 1922. This act changed the way that water rights were determined and the states no longer had to be concerned about losing their water rights due to non-use.

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<sup>39</sup> <http://www.drainit.org/campaigns/drought/summary.cfm>

<sup>40</sup> <http://westernwaterblog.typepad.com/westernwaterblog/2007/12/index.html>

<sup>41</sup> [http://southwestfarmpress.com/mag/farming\\_water\\_management\\_local/](http://southwestfarmpress.com/mag/farming_water_management_local/)

<sup>42</sup> <http://www.usbr.gov/lc/region/pao/pdfiles/crcompct.pdf>



Figure 5 - Colorado River Basin<sup>43</sup>

The Compact divided the river system and its water rights between the Upper Basin and Lower Basin states. The boundary between the two basins was defined as the “Lee’s Ferry” which refers to the “point in the main stream of the Colorado River one mile below the mouth of the Paria River”<sup>44</sup>. This point was chosen as it was determined based on the annual rainfall and river flow of the Colorado River. The Upper Basin states consist of Colorado, New Mexico, Utah and Wyoming. The Lower Basin states consist of California, Arizona and Nevada. The Compact gave, in perpetuity, to these states, the exclusive rights to 7.5 million acre-feet of water annually and the Lower Basin states also received the right to increase their consumption annually by 1

<sup>43</sup> <http://geochange.er.usgs.gov/sw/changes/natural/codrought/>

<sup>44</sup> <http://www.usbr.gov/lc/region/pao/pdffiles/crcompct.pdf>

million acre-feet. Included in the Compact was a stated preference for agriculture and domestic uses over water use for power generation. A flaw in the compact was the estimate of the annual flow of the Colorado River at 17 million acre-feet. It is now thought that the estimate, which was based on the annual flow of the river from 1896 to 1921, was done during a time of increased water supply. Recent estimates indicate that the actually average flow is closer to 15 million acre-feet.<sup>45</sup> It is easy to see how an over-estimate of a resource could lead to poor planning and use of that resource.

In the Upper Basin, Colorado is allotted 3.88 million acre feet, Utah 1.73 million acre feet, Wyoming 1.05 million acre feet, and New Mexico 0.84 million acre feet. The Lower Basin states' water is distributed according to the Boulder Canyon Project Act<sup>46</sup>, which was passed in 1928. According to this contract, California is allotted the most at 4.4 million acre feet, followed by Arizona with 2.8 million acre feet and Nevada with 300,000 acre feet. From there, the states are allowed to distribute the water as they see fit. It is interesting to see how the Lower Basin distributes its water within the states. California and Arizona use the Colorado River for both irrigation and domestic purposes<sup>47</sup>, which is to be expected since they are both quite large food producers. Nevada on the other hand only uses its water for domestic purposes, with close to 70% of southern Nevada's water going to sprinklers that water lawns and golf courses<sup>48</sup>.

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<sup>45</sup> <http://www.water.utah.gov/interstate/thecoloradoriverart.pdf>

<sup>46</sup> <http://crc.nv.gov/ProjectAct1928.htm>

<sup>47</sup> <http://www.usbr.gov/lc/region/g4000/contracts/wateruse.html>

<sup>48</sup> <http://www.uswaternews.com/archives/arconserv/3toplas4.html>

## The Boulder Canyon Project



Figure 6 - Boulder Canyon<sup>49</sup>

The Boulder Canyon Project Act of 1928 was the next step taken in managing the waters of the Colorado River. This Act authorized the construction of the Hoover Dam and Power Plant to increase hydro-electric power, and the All-American Canal. Previously, water was delivered to California's Imperial Valley by a canal that went through Mexico. The construction of the All-American Canal was a way for California to prevent Mexico from having any control over California's water supply. This Act also gave Arizona, California and Nevada the opportunity to agree how to divide up their 7.5 million acre-feet of water. The three states could not come to an agreement on this until 1963.

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<sup>49</sup> [http://www.nps.gov/history/history/online\\_books/dams/boulder\\_dam2/chap2.htm](http://www.nps.gov/history/history/online_books/dams/boulder_dam2/chap2.htm)

One issue that was not resolved until later was how much water Mexico was allotted. When the Colorado Compact was implemented, the states began to use the water to the fullest extent, meaning there was very little left over flowing into Mexico. In 1944, 22 years after the water from the Colorado River was first distributed between states, the Mexican Treaty of 1944 was signed between the United States of America and Mexico, designating the rights Mexico had to a number of rivers, including the Colorado River. In Article 10, it is stated that the USA is obliged to supply Mexico with 1.5 million acre feet from the Colorado River, except in times of drought, in which case Mexico is subject to the same proportional reduction as the US states<sup>50</sup>. This was definitely a much needed treaty to keep good relations with Mexico as it was felt that it was not equitable to allocate to Mexico only whatever was leftover after the Upper and Lower Basins had taken their fill of water. In 1962, due to a protest from Mexico, Minute 242 was adopted in 1973 which obligates the US to provide nearly the same quality of water to Mexico as that used in the U.S.

Construction was authorized for a number of dams and other water development projects on the Colorado River by the Colorado River Storage Project Act of 1956 and the Colorado River Basin Project Act of 1968. These Acts addressed the transportation of water to Arizona. The Act of 1968 was also the first time that there was an acknowledgement that previous estimates of the river's capacity were incorrect and that additional measures would need to be taken as the Act instructs the Secretary "to prepare long-range water resources studies directed toward the augmentation of the Colorado River, to prepare criteria for the coordinated long-range operation

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<sup>50</sup> <http://www.usbr.gov/lc/region/pao/pdfiles/mextrety.pdf>

of the Colorado River reservoirs, and to undertake programs for water salvage and groundwater recovery along and adjacent to the mainstream of the Colorado River.”<sup>51</sup>

## **The Federal Agencies**

In addition to the agreements made by the Colorado River Basin States, two federal agencies, the U.S. Army Corps of Engineers and the Bureau of Reclamation, also have a long history in how water has been used and distributed in the West. The Army Corps of Engineers (ACoE) was formed on March 16, 1802<sup>52</sup>. The Corps was initially formed to supervise various coastal constructions such as lighthouses, piers and docks. Beginning at the start of the 20<sup>th</sup> century however, their role changed quite drastically. They became the top federal flood controller and recovery agency. From there, they broadened their civil works to include hydroelectric power, respondents to a broader number of natural disasters, not just floods, and the country’s leading provider of recreation<sup>53</sup>.

The Bureau of Reclamation (BoR) was founded in 1902<sup>54</sup>. Its purpose was to increase the efficiency of water usage, especially in areas where efficiency was most important, most notably, the Southwest. Over the course of the years, the Bureau has built over 600 dams in 17 different countries, is the second biggest producer of hydroelectric power in the US, providing over 40

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<sup>51</sup> [http://www.azwater.gov/dwr/ColoradoRiverManagement/Law\\_of\\_River.html](http://www.azwater.gov/dwr/ColoradoRiverManagement/Law_of_River.html)

<sup>52</sup> <http://www.hq.usace.army.mil/history/Brief/index.html>

<sup>53</sup> <http://www.hq.usace.army.mil/history/Brief/index.html>

<sup>54</sup> <http://www.usbr.gov/main/about/>

billion kilowatts a year, brings water to 31 million people and supplies 10 million acres worth of farmland that produces 60% of our vegetables and 25% of our fruits and nuts<sup>55</sup>.

Both of these agencies were appointed by the government to control the waterways of the US. Having two agencies working towards the same goal, with two very different approaches, the BoR wishing to provide irrigation and hydroelectric power and the ACoE focused mainly on preventing floods, was a breeding ground for competition. One should note, that it was not until later in the 20<sup>th</sup> century that either of these agencies had much regard to the wildlife situation in the areas they wished to work on. Both of these agencies essentially wanted to do the same thing, build dams, even if they were for different reasons. Dams would supply a huge amount of hydroelectric power, as well as control floods to some extent and promote irrigation. Unfortunately, it became a struggle for domination between the two organizations. When one would find a place that was suitable for a dam, the other would rush in and try to take over the project, suggesting a similar project, but highlighting different attributes of what the dam would do.

This competition is embodied in the Kings and Kern River Projects. In 1937, the BoR was just beginning to detail the possibility of damming the Kings and Kern Rivers in California. There was a lot of unused water “going to waste” and a dam would produce a storage facility for this excess water until it could be piped to the needed farmers. Once the ACoE got wind of this project, it was decided that a dam should be built, but it was to be used primarily for flood

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<sup>55</sup> <http://www.usbr.gov/main/about/>

control. Flooding usually occurred every 10 to 15 years<sup>56</sup> and was very hard on the inhabitants downstream. For five years, both organizations jockeyed for the right to build their dam.

As stated before, the BoR was mostly focused on the viability of irrigations and making sure that not one drop of water went to waste. They had a lot of support from the small-time farmers, since this would give them the water they needed to develop and at a relatively cheap price. The ACoE on the other hand, did not mention irrigation much and when they did it was directed towards the larger agricultural businesses that were located closer to the site of the dam. The ACoE stated that the Californians needed the flood control desperately. Illustrating this point was their “emergency flood diversion” structure<sup>57</sup> on the lower section of the Kings River. Congress could not seem to decide which project was the right one to choose, so they authorized both projects, whoever found the funding first would be allowed to build their project. On May 28<sup>th</sup>, 1947 the Army Corps of Engineers began construction on the Pine Flat Dam.

Even though the Bureau of Reclamation first laid claim to the river, the ACoE were able to persuade enough rich and powerful bodies to finance their works instead of allowing the BoR to go ahead with their plans. It was not until 1984 that a hydroelectric plant was constructed to produce power<sup>58</sup>. Currently the Pine Flat Dam is in good working order with its primary purpose being flood control, followed by irrigation, recreation, and hydroelectric power<sup>59</sup>. It would be

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<sup>56</sup> <http://kingsnet.kings.k12.ca.us/kcoe/curric/history/resources/kingsriver.html>

<sup>57</sup> Cadillac Desert, pg. 177

<sup>58</sup> <http://www.spk.usace.army.mil/organizations/cespk-co/lakes/pineflat.html>

<sup>59</sup> [http://www.krkd.org/power/pine\\_flat\\_power](http://www.krkd.org/power/pine_flat_power)

interesting to see how the land would have developed had the BoR taken the job instead of the ACoE.

The feud between the BoR and ACoE is a prime example of how the geography of the land became obsolete in terms of where water would flow, to the point where the water flowed where the more powerful entity told it to, not necessarily where it was originally intended. There is a famous saying “Water flows uphill towards money”<sup>60</sup> that captures the events around the acquisition of water rights at that time.

As one can see throughout history, the distribution and use of water has been dictated by those in places of power; whether that being was one of the Roman Emperors, Los Angeles Water Department, The Colorado River Basin States, Bureau of Reclamation or Army Corps of Engineers. The alteration of the natural distribution of water, wasteful water usage and poor population planning and land management has resulted in dire consequences, as demonstrated by the Dust Bowl of 1930s and other situations that are now affecting us in the present. The lessons have not always been learned from these consequences. Even though we now have more advanced technology as well as a greater understanding of the consequences of misused land and water, poor practices are still in place and are exacerbating the growing water crisis.

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<sup>60</sup> quoted by Ivan Doig in Marc Reisner’s, *Cadillac Desert*, 1986

## CURRENT SITUATION

Now that we have looked at the history of water and the issues that have led to the present water crisis, it is time to look at and evaluate the current situation of the water. The area that will be concentrated on mainly encompasses the states of Arizona, Nevada and the southern part California and their relationship to the Colorado River contract and those who have signed it.

Although the various contracts allocating water rights of the Colorado River were a step in the right direction, there are some very serious problems that still need to be addressed. As stated before, the Colorado River currently supplies roughly 13.5 million acre feet per year. If one sums the amount of water allocated by the Compact and the Treaty, it will come out to 16.5 million acre feet; 15 million acre feet for the states and 1.5 million for Mexico. This means that there is a deficit on 3 million acre feet, about 6 million homes worth. Granted, at the time the Compact and Treaty were signed, the Colorado River may have had a larger flow, but we are currently going through an extended drought that has no foreseeable end. Due to the current drought situation, it would be much more feasible to re-evaluate the flow of the Colorado River and make an amendment based on the findings. A possible conflict with this solution is the potential that all the states involved would then be jockeying for a higher percentage of water than they previously had, especially those who have developed more than expected, such as Nevada. Unless the states were willing to work together on a compromise rather than looking out for individual interests, the resolution could be delayed indefinitely, when immediate action is needed.

## Positive Developments across the States

In December of 2007, the 7 states that signed the initial Compact, reconvened at the Colorado River Water Users Associations annual meeting in Las Vegas to deal with the water issue. They all came to realize, “a simple fact that the Earth is warming”<sup>61</sup>, that this had had an adverse affect on their water supply and that a solution needed to be found. The states had been draining the water out of the two reservoirs, Lake Mead and Lake Powell, so quickly that they are currently half-empty<sup>62</sup>. The result of this meeting was a new compact, the Record of Decision<sup>63</sup>. This compact was hailed as a, “a truly historic moment”<sup>64</sup>, the fact that every state got together and agreed upon a pact is a great achievement and gives hope for the future.

As quoted from a press release from the U.S. Department of the Interior, The Record of Decision adopts four key elements of river management:

“First, new guidelines establish rules for shortages – specifying who will take reductions and when they take them. This is essential for prudent water planning in times of drought.

Second, the new operational rules for Lake Powell and Lake Mead will allow these two massive reservoirs to rise and fall in tandem, thereby better sharing the risk of drought.

Third, the new guidelines establish rules for surpluses, so that if the basin is blessed with ample runoff, the Department of the Interior will have rules in place to distribute the extra water.

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<sup>61</sup> <http://westernwaterblog.typepad.com/westernwaterblog/2007/12/index.html>

<sup>62</sup> <http://www.iht.com/articles/2007/12/09/america/10water.php>

<sup>63</sup> <http://www.usbr.gov/lc/region/programs/strategies/RecordofDecision.pdf>

<sup>64</sup> <http://westernwaterblog.typepad.com/westernwaterblog/2007/12/index.html>

Fourth, the new rules will address the ongoing drought by encouraging new initiatives for water conservation.”<sup>65</sup>

This new agreement now allows for storage of water in Lake Mead and Powell by California, Nevada and Arizona. In the case of excess water, these states will be allowed to store water in these reservoirs for later use. It is hoped that this will raise the level of the lakes to a more acceptable level. The compact has already established guidelines for use of surplus water in order to prevent disagreements when and if it is time to draw on the excess water. However, one might be a little skeptical considering that there might not ever be an excess of water and the governments may have been optimistic about the future water supply. As John Weisheit, the conservation director for Living Rivers stated, “There is more water on paper than there actually is on the landscape. They are looking at this in a way that will allow more development even though the water is not theoretically there.”<sup>66</sup>

## **State Programs**

Another positive development has been the formation of agencies and programs within the states specifically dedicated to dealing with the use of water as well as making sure the quality of the water is at an acceptable level. An example of one such program that has been successfully implemented is the Drought Busters program in Los Angeles.

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<sup>65</sup> [http://www.doi.gov/news/07\\_News\\_Releases/071213.html](http://www.doi.gov/news/07_News_Releases/071213.html)

<sup>66</sup> <http://www.iht.com/articles/2007/12/09/america/10water.php>

Los Angeles is a large city of about 10 million people, roughly a quarter of California's total population<sup>67</sup> located in the southern part of California. Since the early 1900's, Los Angeles has been a city that has always needed more water, as illustrated by the aforementioned Owens Valley River conflict. In fact, Los Angeles was probably one of the major reasons that California was allocated any of the Colorado River. Eighty-seven percent of Los Angeles' water supply comes from either the Colorado River or the Owens Valley River<sup>68</sup>. In 2000, there were 3.8 million people supplied by the Los Angeles Department of Water and Power that used 220 billions gallons of water, of which 191 billion gallons were imported<sup>69</sup>. This shows the true reliance of the Los Angeles population on imported water. The percentage of water used that is imported will only go up as the population increase, since the amount local water available is unlikely to increase.

The Drought Buster program has had a very positive impact on reducing the amount of water used in Los Angeles. The Drought Buster program was implemented in 1990 to enforce the Prohibited Water Use Ordinance. This ordinance banned a number of, what were deemed unnecessary, water usages such as: allowing leaks to go unattended, stop serving water to customers in eating establishments unless requested, allow excess water from sprinklers to flood gutters. The result was a water use reduction of 34%<sup>70</sup>.

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<sup>67</sup> <http://quickfacts.census.gov/qfd/states/06/06037.html>

<sup>68</sup> [http://www.lacity.org/ead/EADWeb-WNR/drinking\\_water.htm](http://www.lacity.org/ead/EADWeb-WNR/drinking_water.htm)

<sup>69</sup> [http://www.lacity.org/ead/EADWeb-WNR/drinking\\_water.htm](http://www.lacity.org/ead/EADWeb-WNR/drinking_water.htm)

<sup>70</sup> <http://www.ladwp.com/ladwp/cms/ladwp009949.jsp>

At the moment, Los Angeles water is relatively safe to drink<sup>71</sup> and with the measures currently in place, it can support its large population. However, with Los Angeles' population growth hovering around 1.5% a year<sup>72</sup>, either new sources of water will have to be found or the restrictions on water usage will have to become more stringent.

Though Los Angeles is making progress, not all policies put in place to conserve and redistribute water have been implemented. For example, California has been ordered by the U.S. Department of the Interior to gradually reduce its draw of the Colorado River from 5.2 million acre-feet to 4.4 million. At press time, a proposed transfer of water from the farming communities of the Imperial Valley to the densely populated and underserved city of San Diego to offset the loss of the Colorado River water had not been completed<sup>73</sup>.

Arizona is another area that has also acknowledged the need for a long-term solution. In the past Arizona has not used all of its 2.8 million acre feet of water from the Colorado River. However, with their increasing population, length and severity of droughts, as well as recognizing that the Colorado River is in danger of being overused due to over allocation, Arizona has begun to take action now to prevent problems in the future. The epitome of this thinking was the introduction of The Arizona Water Banking Authority (AWBA) in 1996 with the goal to “increase utilization of the state’s Colorado River entitlement and develop long-term storage credits for the state.”<sup>74</sup>

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<sup>71</sup> <http://www.ladwp.com/ladwp/cms/ladwp000486.jsp>

<sup>72</sup> [http://www-rcf.usc.edu/~pgordon/pdf/Portl\\_LA\\_Figures.pdf](http://www-rcf.usc.edu/~pgordon/pdf/Portl_LA_Figures.pdf)

<sup>73</sup> <http://www.memagazine.org/contents/current/features/notadrop/notadrop.html>

<sup>74</sup> <http://www.azwaterbank.gov/awba>

The AWBA works with the 2007 contract that wishes to re-hydrate the Colorado River. Arizona, although not going through a severe water crisis itself, is preparing for the worst and helping the environment at the same time. For instance, in 2007, the AWBA recharged approximately 388,000 acre feet of the Colorado River, by storing it in reservoirs<sup>75</sup>. That is more acre feet than Nevada is allocated. This means, that in times of drought, Nevada could be supplied purely off of the reserves that Arizona has stored.

Unlike Arizona, Nevada has a serious water problem. It is known as the driest state in the nation, where its rivers consistently go below average 6 out of 10 years<sup>76</sup>. Nevada was also only allotted 300,000 acre feet of the Colorado River, a very small amount. The reason for this being, that in 1928 Nevada had very little political clout and no need for a large percentage of the water available. For 60 years, 300,000 acre feet of water was sufficient for the state<sup>77</sup>. More recently though, due to a population increase of 3.5% as compared to the nation's 0.9% increase between the years of 2004-2005<sup>78</sup>, as well as the recognition that the climate is becoming more arid in areas heavily populated (southern Nevada).<sup>79</sup> Nevada has looked to securing more water as well as efficiently using what it already has.

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<sup>75</sup> [http://www.azwaterbank.gov/awba/documents/2008/2008-1\\_Final.pdf](http://www.azwaterbank.gov/awba/documents/2008/2008-1_Final.pdf)

<sup>76</sup> <http://water.nv.gov/WaterPlanning/wat-fact/issues.cfm#drought>

<sup>77</sup> <http://www.npr.org/templates/story/story.php?storyId=10939792>

<sup>78</sup> <http://www.census.gov/Press-Release/www/releases/archives/population/006142.html>

<sup>79</sup> [http://www.cpc.ncep.noaa.gov/products/expert\\_assessment/season\\_drought.gif](http://www.cpc.ncep.noaa.gov/products/expert_assessment/season_drought.gif)

As aforementioned, Las Vegas is the biggest consumer of water in Nevada, not due to “The Strip” which consumes about 3% of Nevada’s water<sup>80</sup>, but the golf courses and lawns that surround the inner city. According to the World Water Report, irrigation accounts for 70 percent of all water usage. In 1989, Las Vegas was consuming 340-350 gallons per capita, or 350 gallons per person per day, which is close to 10 times more than the average New Yorker would consume<sup>81</sup>. Not only does Las Vegas have a lower precipitation level, roughly 4 inches a year<sup>82</sup> compared to New York’s 48 inches a year<sup>83</sup>, but they also were consuming ten times the amount of water. Instead of using roughly ten times less water as guided by precipitation levels, Las Vegas had gone the other way, meaning they were using 100 times more water than they should be if they wished to use the same percent of water that New York was. It is a little better presently, largely due to Patricia Mulroy, the general manager of the Southern Nevada Water Authority. Since she has been in office, there have been a number of reductions in water usage, not only in Las Vegas, but in Southern Nevada in general. Nevada has begun moving in the right direction to reduce the water problems, but a number of major changes to water management and use need to be done before self-sufficiency is achieved.

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<sup>80</sup> <http://www.npr.org/templates/story/story.php?storyId=10939792>

<sup>81</sup> <http://www.npr.org/templates/story/story.php?storyId=10939792>

<sup>82</sup> <http://www.lvol.com/lvolog/hist/weather.html>

<sup>83</sup> <http://www.worldweather.org/093/c00278.htm>

As one can see, many people are waking up the realization that not only is there a water crisis, but it will only get worse as the world continues to heat up. There have already been a number of measures taken and there are still more planned, that will reduce the water crisis down to a manageable level. There are so many options however, that they need to be categorized, evaluated individually on their feasibility, and coordinated in order to achieve the maximum efficiency.

## SOLUTIONS

The importance of the water in the southwest region in the United States has become one of the most discussed subjects in the past few years due to the combination of the devastating results of global warming, increased demand and decreasing resources. Projections of climate change caused by human activities conducted by 19 different climate modeling groups around the world, using different climate models, show widespread agreement that southwestern North America, and the subtropics in general, are heading toward a climate even more arid than it is today<sup>84</sup>. The combination of finite Colorado River water supplies, increasing demands, warmer temperatures and the prospect of recurrent droughts point to a future in which the potential for conflict among those who use the river will be ever-present.

There is not just one easy solution to solving the Southwest's water crisis. This is instead, a task that will require changes on all levels ranging from individual every-day changes to putting in place international policies and strategies to reduce the effects of global warming with the goal of achieving better water conservation and management in order to prevent an ever worsening water crisis. These responses will need to be coordinated so that both supply and demand achieve a better balance. Though reduction of greenhouse gases and global warming are an important part of the ultimate solution, the recommendations that will be outlined in this paper will focus on the more limited and specific goal of lessening the growing water crisis in the Southwest.

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<sup>84</sup> <http://www.ens-newswire.com/ens/apr2007/2007-04-05-01.asp>

The solutions can be broken down into several categories:

- **Individual efforts**
- **Technological solutions**
- **Policies**

## **Individual Efforts**

Though initially the benefits may appear minor, individual changes to reduce water usage will make a positive difference, especially as more and more people adopt them. To be effective, this effort will require people to be educated about the water crisis and to understand why and how changes must be made. It will also involve setting realistic expectations based on water availability versus water demand. People will need to change their habits, some of which may be small matters such as not letting tap water run during brushing, whereas others are more drastic such as re-landscaping with indigenous drought resistant plants.

There are a number of excellent resources already available to educate people on improved water usage and which offer a variety of approaches. One of the most complete documents for the general public that provides water use information and solutions on water conservation practice at home comes directly from the Colorado State University Extension service. This fact sheet, which is reproduced in its entirety below, offers information and practical, relatively easy, effective and inexpensive solutions designed to cut down on water usage. Though this

publication specifically targets Colorado, the information and recommendations would be appropriate to implement in any of the western states:

### **Water Conservation In and Around the Home Fact Sheet number 9.952<sup>85</sup>**

#### **Quick Facts...**

- Water supply planners estimate that a typical household needs 0.4 -0.5 acre feet of water per year (approximately 150,000 gal) to satisfy the demands of a home and landscape.
- The installation of low-flow plumbing fixtures can save up to 30 percent of indoor water use.
- Outdoor water use accounts for about 55 percent of the residential water use in the Front Range urban area, most of which is used on turf.
- During drought or times of restricted landscape watering, most lawns, including bluegrass, will withstand reduced watering regimes by going dormant.

Colorado's semi-arid climate is punctuated with multi-year droughts, reminding us of the value of plentiful water supplies. Fortunately, most of our water supply is renewed annually as snowpack in the Rockies. Water supply planners estimate that a typical household needs 0.4 to 0.5 acre-feet of water per year (approximately 150,000 gal) to satisfy the typical demands of a home and lawn. However, we can get by on far less.

Outdoor water use accounts for about 55 percent of the residential water use in urban areas along the Front Range, most of which is used on turf. As a percentage of total water use in the urban Front Range, outdoor water accounts for about 40 percent of all urban water use. Many Colorado residents use over 200 gallons of water per capita per day. In contrast, residents in Arizona use 160 gallons per capita per day (20 percent less than most Colorado residents). Water conservation is vital to enhancing the efficiency of how we use water. This fact sheet describes ways to reduce water consumption in and around your home.

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<sup>85</sup> <http://www.ext.colostate.edu/pubs/consumer/09952.html> *Water Conservation In and Around the Home* by R.

*Waskom and M.Neibauer, number 9.952*

## Water Conservation in the Home

Home water use varies considerably, depending upon the number of people in a household, plumbing fixtures,

appliances, and other factors. The largest water users in the home are toilets, clothes washers, faucets, and showers.

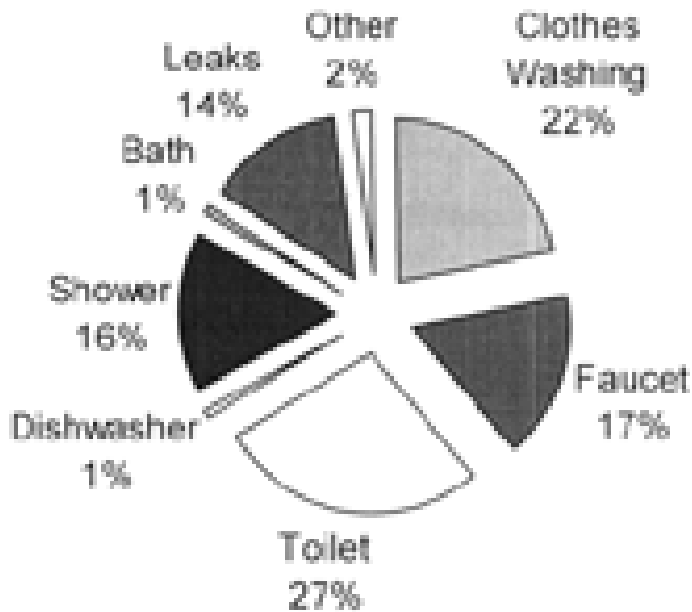


Figure 7 - Average household water use

### Bathroom Water Efficiency

Toilets made before 1993 use 3.5 to 8 gallons per flush (gpf). High efficiency toilets manufactured after 1993 use 1.6 gpf or less. The date of manufacture of most toilets is on the underside of the tank lid. A family of four can save 14,000 to 25,000 gal/yr by switching from conventional toilets to the newer, more efficient ones. Your water utility may even offer rebates for replacing conventional toilets. Additional water savings can occur by making sure your toilet is not leaking and that the flapper is working properly. Here are other suggestions for increasing your toilet-use efficiency.

- Install vacuum assisted, low-volume toilets.
- Consider not flushing the toilet unless absolutely necessary.

- Regularly check for toilet leaks by placing food coloring in your toilet tank. Repairing leaking toilets can save more than 600 gallons of water per month.
- Do not use your toilet as a wastebasket.
- Make sure your toilet flapper does not remain open after flushing.
- Avoid using toilet bowl cleaners such as toilet tank tablets. These products affect the pH of water in your toilet tank and can cause leaks by damaging the rubber and plastic parts of your toilet.

## **Showering Efficiency**

Showerheads currently manufactured in the U.S. have a flow-rate of 2.5 gallons per minute (gpm) or less. Here are some suggestions for increasing shower-use efficiency.

- Install a low-flow showerhead if you do not already have one.
- Keep your showers brief. A shower that lasts for five minutes using a low-flow showerhead uses 12 gallons of water. If possible, use a watch to time yourself while you are in the shower.
- Turn off the water while you lather up with soap and shampoo.
- Irrigate your indoor plants by placing a bucket in the shower to collect the water while waiting for it to warm up.
- Check the flow rate of your showerhead by using a 5-gallon bucket and a clock. Turn the shower on full and place a 5-gallon bucket under the shower for two minutes. A 2.5 gpm showerhead will fill the bucket up in that two-minute time frame.
- Check the flow rate of your showerhead by using a 5-gallon bucket and a clock. Turn the shower on full and place a 5-gallon bucket under the shower for two minutes. A 2.5 gpm showerhead will fill the bucket up in that two-minute time frame.
- Check and repair leaks in the tub diverter valve.

## **Faucet Efficiency**

- Install low-flow faucet aerators on all your household faucets. Some aerators can restrict flow to less than 1.0 gpm.

- Do not run the faucet continuously while washing dishes and hands, shaving, or brushing your teeth.
- Checking and repairing faucet leaks can save up to 140 gallons of water per week.
- Estimated Facet Leakage Rates (# of drips)
- 60 drops/minute = 192 gallons/month
- 90 drops/minute = 210 gallons/month
- 120 drops/minute = 429 gallons/month

### **Clothes Washing Efficiency**

Conventional washing machines use between 35 to 50 gallons per load (gpl). The newer front-loading machines are more efficient and use between 18 to 20 gpl. Below are suggestions for reducing water use while clothes washing.

- Run the washing machine only when you have a full load of clothes.
- For lightly soiled laundry loads, use the shortest wash cycle.
- To avoid redundant washing, pre-treat stains on your clothes.
- Select the minimum water volume per load if your washer has a variable water volume setting.
- Regularly check washing machine hoses for leaks.

### **Dishwasher Efficiency**

- Install a high efficiency dishwasher machine.
- Running the dishwasher only when it's full can save 1,000 gallons of water per month.
- Running a full dishwasher usually uses less water than washing the same number of dishes by hand.
- Because the drying cycle of most dishwashing machines uses 1,500 watts per cycle, air or hand drying the dishes is more efficient and less expensive.

### **Additional ways to conserve water in the home:**

- Check your water meter and bill and talk to family members about setting water conservation goals for indoor water use.
- Use the garbage disposal less often. Compost organic matter from your kitchen.

- Collect the water you use for rinsing fruits and vegetables and reuse it to water houseplants and/or shrubs.
- When buying a new appliance, remember that certain models offer different cycles that are more water and energy-efficient.
- If you have an evaporative air conditioner, direct the water drain to a flower bed, tree, or your lawn.
- Collect rainwater in a bucket for watering indoor plants.
- If your local water utility offers incentives or in-home water audits, take advantage of these programs.
- Keep drinking water in the refrigerator during the summer instead of letting the faucet run until water is cool.

## **Water Conservation around the Home:**

### **Improving Lawn Irrigation Efficiency**

Urban lawn watering is the single largest water demand on most municipal supplies. However, there are many ways to conserve water on the home landscape.

First, create an irrigation schedule relative to the types of plants in your landscape. Second, learn the water requirements of your landscape plants and water accordingly, avoiding over-watering as much as possible. Over-watering is not only wasteful, it is also unhealthy for plants. Third, make a habit of manually operating your irrigation system and rely less on the automatic controller. Fourth, do not irrigate on a set schedule, since daily plant water use can vary greatly according to the weather. Finally, take into account recent rainfall amounts before watering your landscape.

During drought or times of restricted landscape watering, most lawns, including bluegrass, will withstand reduced watering regimes by going dormant. In these situations, adjust mowing, fertilizing, aeration, and weed control practices appropriately to the watering schedule. Most lawns can be revived with good management and care after the drought breaks. Changing landscape plants and lawn grass species during drought is not a good idea, as it generally takes more water to establish new plants than to keep old plants alive.

Keep in mind the variety of water needs among various landscape plants. For example, certain types of lawns may need water every three or four days during a hot, dry summer. However, trees and shrubs may only need water every few weeks, while flowerbeds may need to be watered once a week. Trees, shrubs, and flowers may rot if you water them on the same watering schedule as your lawn.

### **Guidelines for when to water:**

- Irrigate when footprints or mower tracks become visible and/or large areas of the lawn become blue-gray in color.
- Slowly apply irrigation water at rates that replace evaporation (ET) so runoff and puddling do not occur. Water less in cool spring and fall weather and more (3/4 to 1 inch) during hot summer months.
- Move your sprinkler around the yard in cycles to let the water thoroughly and evenly soak in.
- Water dry spots instead of the entire lawn.
- Water between 9 p.m. and 9 a.m. to avoid evaporation losses from hot and windy weather conditions.

### **Additional Ways to Conserve Water for Landscaping**

- Make sure the irrigation system is operating properly.
- Replace broken or missing sprinkler heads.
- Make sure the spray heads turn properly.
- Adjust heads so that water does not reach streets and driveways.
- Check nozzles for plugging.
- Place straight-sided containers (such as tuna fish cans) around the yard during irrigation and measure water depth so that you know how long it takes to apply ¼ to ½ inch of water.
- Place containers on persistent dry spots to determine if poor sprinkler coverage is the problem.
- Never water if the soil is still wet.

### **Managing the Water Needs of Plants**

- Reset automatic controllers according to the seasonal needs of plants. Inspect controls at least once a month to adjust run times.

- Winter watering will minimize stress to trees, shrubs, flowers, and turf in areas receiving low winter precipitation. Apply water once a month during dry winter periods.
- Drip irrigation installed at the base of large transplanted trees will need to be moved as the tree root system expands. At maturity, tree roots spread outward two to three times the width of the tree canopy.
- Shaded plants use less water than plants in full sun.

### **Mulching for Water Conservation**

Mulching reduces evaporation from the soil surface and reduces irrigation needs by approximately 50 percent. The following is a list of suggestions for using mulch in the home garden.

- Use an organic mulch to a depth of approximately 4 inches, depending upon the particle size of the mulching material.
- Grass clippings can be used as mulch in the vegetable garden. Do not use clippings from lawns treated with herbicides or other pesticides in the past month.
- For general landscape applications, use spun or woven permeable landscape fabrics rather than solid sheet plastics.
- Black or dark-colored plastic mulch conserves moisture and increases soil temperature in vegetable gardens.

### **Conserving Water in the Vegetable Garden**

- Plant in blocks instead of rows to create shade for the root systems and reduce evaporation.
- Group plants with similar water needs together.
- Check the soil for moisture before you water and do not water until the soil has dried out to a depth of at least 4 inches.
- Control weeds that compete with vegetables for water.

### **Additional ways to conserve water around the home:**

- Check your water meter and bill so you can set conservation goals for your family's outdoor water use.
- Have a family discussion on ways you can work together to reduce outdoor water consumption.
- Collect the water you use for rinsing fruits and vegetables and reuse it to water houseplants and/or shrubs.

- Use a broom instead of a hose to sweep your driveway and you can save between 50 and 80 gallons of water.
- Use porous materials for patios and walkways to reduce runoff.
- Accept having a dirty car and a brown lawn during drought.
- If you must wash your car, use a car wash that recycles water instead of washing your car in the driveway. If that is not possible, wash your car on the lawn so you can simultaneously water your grass.
- Set a kitchen timer when watering your lawn or garden, to keep track of the time.
- Direct downspouts or gutters toward shrubs or trees.

<b>Water used in normal home activities.</b>						
<b>Area</b>	<b>Activity</b>	<b># of times</b>	<b>Circumstances</b>	<b>Water Used</b>	<b>Total</b>	
<b>BATHROOM</b>	Toilet	4 flushes/ day	Conventional toilet	3.5 - 7.0 gal/flush	14-28 gal/day	
			ULV toilet	1.6 gal/flush	6 gal/ day	
	Shower	5 min. once/ day	Conventional showerhead	3-8 gal/minute	14-40 gal/day	
			Low-flow showerhead	2.5 gal/minute	12 gal/day	
	Bath	once/day	Full tub	30-45 gal	30-45 gal/day	
			Tub 1/4 to 1/3 full	9-12 gal	9-12 gal	
	Shaving	once/day	Open tap	5-10 gal	5-10 gal	
			One full basin of water	1 gal	1 gal/day	
	Brushing teeth	twice/day	Open tap	2-5 gal	4-10 gal/day	
			One full basin of water	¼ to ½ gal	½ to 1 gal/day	
	Hand washing	twice/day	Open tap	1 gal	2 gal/day	
			Soap and then rinse	¼ gal	½ gal/day	
	<b>KITCHEN</b>	Cooking	Washing	Open tap	5-10 gal	5-10 gal/ day

		produce once/day	One full kitchen basin	1-2 gal	1-2 gal/day
	Dishwasher	once/day full load	Standard cycle	10-15 gal	10-15 gal/ day
			Short cycle	8-13 gal	8-13 gal/ day
	Dishwashing by hand	once/day	Open tap	30 gal	30 gal/day
			Full basin/wash and rinse	5 gal	5 gal/day
	Laundry	once every 3 days	Conventional top-loader	35-50 gal	70-100 gal/week
			Front-loader	18-20 gal	36-40 gal/week
<b>MISC.</b>	Car washing	twice/month	Hose w/shut-off nozzle	50 gal/wash	100 gal/month
			5 full, 2 gal. buckets	10 gal/wash	20 gal/month
<b>LAWNCARE</b>	Kentucky bluegrass	½" every third day	5000 sq. ft.	1,500 gal/watering	18,500 gal/month
	Turf-type tall fescue	½" twice/week	5000 sq. ft.	1,500 gal/watering	12,500 gal/month
	Buffalo grass	½" every 2 weeks	5000 sq. ft.	1,500 gal/watering	3,000 gal/month
Source: Denver Water, 2003					

Figure 8 - Water used in normal home activities.

As shown in the chart above from the Fact Sheet, even a relatively small change, such as closing the tap when brushing teeth, has the potential to save 3 to 9 gallons of water/day/person. A more drastic measure, such as re-landscaping a lawn with drought resistant grass could save as much

as 15,500 gallons of water/month. If every household adopted at least the majority of the measures listed above, the potential decrease in water demand becomes quite sizable.

## **Technology**

There are a number of technologies currently available that would lead to both a decreased need for water, more efficient use of water including recycling, and an increased ability to store water. However, more needs to be done to make sure these solutions are cost effective and conversions from old systems to new systems are actually being put in place if the maximum benefit is to be gained.

Desalination - This is the process of removing of dissolved solids from water. The majority of the solids are made up of salts and mineral. Due to advancements in reverse osmosis technology, desalination is now becoming much more affordable and efficient which is making it an attractive option for costal communities, especially those in Southern California, which are dependent upon using water from the Colorado River. The cost, however, is still a factor as the cost to desalinate is \$800 per acre-foot, while the cost of importing water is about \$500<sup>86</sup>. However, five large municipal water agencies, all based in California, have joined together to form the United States Desalination Coalition. Its goal is to ask Congress to approve legislation aimed at providing financial incentives and grants for the development of desalination treatment facilities.

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<sup>86</sup> <http://www.newwatersupply.org/issue/desal.htm>

Aquifer storage and recovery (ASR)<sup>87</sup> - Aquifer storage and recovery is a process by which water is forced into an aquifer by injection through wells or by surface spreading and infiltration. The water is stored in the aquifer and then pumped out when needed. The aquifer functions as a storage tank. Water is deposited during times of excess and removed during drought.

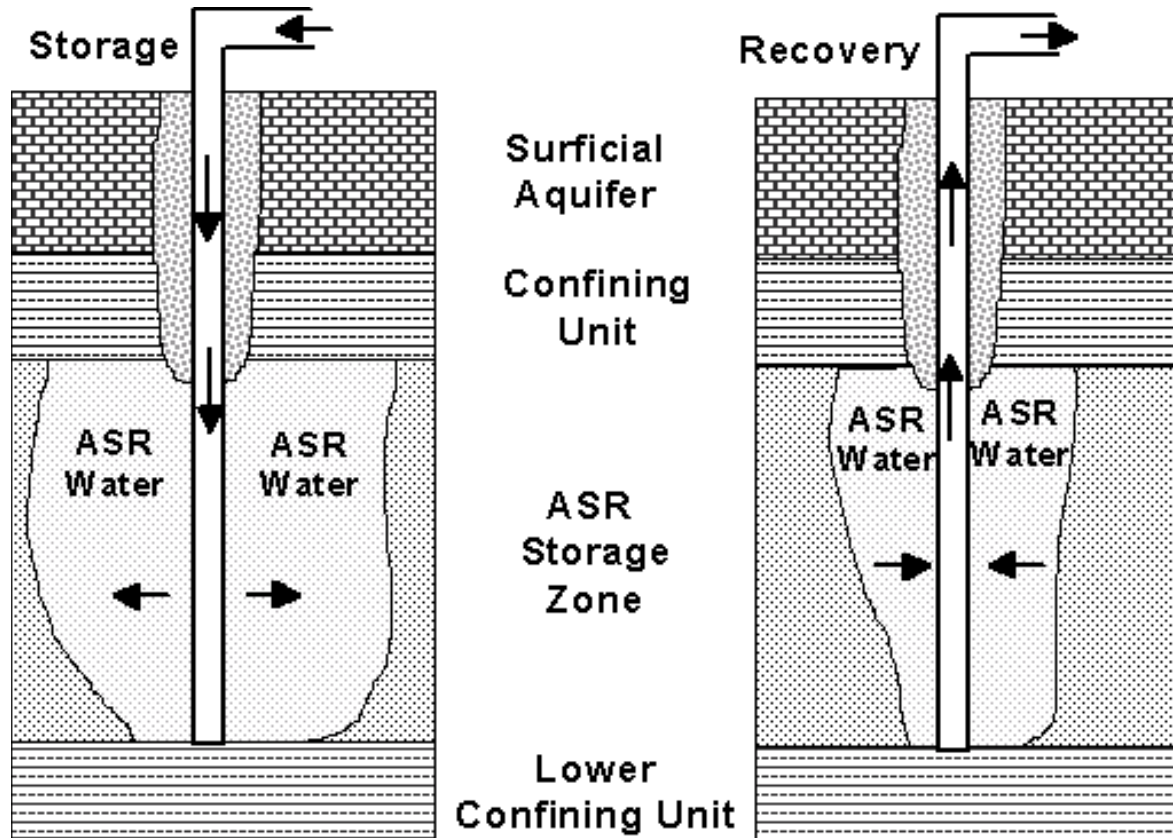


Figure 9 - ASR Storage Diagram<sup>88</sup>

<sup>87</sup> [http://www.gwpc.org/meetings/meetings\\_forum/AF04/Attachments/Abstracts/Shrier-Catherine-FP.pdf](http://www.gwpc.org/meetings/meetings_forum/AF04/Attachments/Abstracts/Shrier-Catherine-FP.pdf)

<sup>88</sup> <http://www2.dnr.state.wi.us/org/water/dwg/Uiw/ASRTFinal.pdf>

Though ASR has traditionally been used mainly for drinking water, this method is increasingly being used to store water for industrial use, irrigation, livestock and aquatic habitat. There are a number of benefits to this method of water conservation including:

- The ability to store substantial amounts of water deep underground versus large and often expensive surface reservoirs;
- It also minimizes loss due to evaporation;
- ASR systems are thought to have less of detrimental affect on the environment than surface reservoirs and also more protection from tampering;
- Natural aquifers that have been depleted may be used as for ASR.<sup>89</sup>

There are numerous regulations and permit processes governing the use of ASR at local, state and federal levels. These regulations include such issues as groundwater protection, water rights, water resource management and drinking water regulation. However, in spite of the number of regulations, this technology is showing growth as the number of ASR facilities has increased from only three states in 1985 to operation ASR facilities in 16 states by 2004. A technical memorandum summarizing case systems of operating ASR in the US put forth by the East Bay Municipal Utility District, California, in 2005 draws the conclusion that “ASR projects are in use throughout the United States. They are a tested and relied upon method of water supply, particularly in the role of providing citizens with much-needed supplemental and/or drought

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<sup>89</sup> <http://www.asrforum.com/what.html>

supply. “This technology has great potential to take advantage of excess water and preserve it for use during times of drought.”<sup>90</sup>

Water recycling and reuse<sup>91</sup> - Water recycling is the safe reuse of treated wastewater. Various technologies are in use including sand filtration, water chlorination, micro filtration and membrane filtration. Such water is currently being used for ecosystem restoration, landscape and agricultural irrigation, industrial cooling and groundwater recharge. The cost of recycling varies from a minimal amount to over \$2,000 per acre-ft, with the highest cost assigned to the highest treatment for the highest use.

Advantages to water recycling include the ability to access a drought resistant and reliable local water supply, reduction in use of imported water, preservation of limited potable water supplies for drinking, a method for safe wastewater disposal, and is a sustainable water source.

Additionally, water recycling is a well-established technology and is already an integrated part of public policy in a number of states, especially those of limited water supply, especially in the Western US.

Water recycling is growing. Approximately 3.4 billion gallons per day is reused in the US but this is only a fraction of the total wastewater generated. For this technology to become more widely used and accepted, more work needs to be done with public education to offset negative

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<sup>90</sup>[http://www.ebmud.com/water\\_&\\_environment/water\\_supply/current\\_projects/bayside\\_groundwater/feir/Attachments.pdf](http://www.ebmud.com/water_&_environment/water_supply/current_projects/bayside_groundwater/feir/Attachments.pdf)

<sup>91</sup> <http://www.niph.go.jp/soshiki/suido/pdf/h19JPUS/abstract/r14.pdf>

perceptions along with better documentation of the economics of water reuse. This would be helped if there were consistent national regulations throughout the US enabling the protection of public health.

Improved irrigation practices and methods - According to the World Water Report, irrigation accounts for 70 percent of all water usage. However, many of the irrigation systems in use are so inefficient that less than half of the water used for irrigation actually results in a benefit to the crops. The water evaporates before reaching the crops, seeps out of canals as it is being transported or too much water is being applied at the wrong times<sup>92</sup>. With irrigation accounting for such a high percentage of water usage, it is critical that irrigation practices are used to the maximum benefit for water conservation while still providing the necessary crop yields.

In a world of unlimited water, crops could be fully irrigated in order to achieve maximum crop yield. However, when water is restricted, alternatives to full irrigation must be considered. The goal in this case is to manage the irrigation process in order to achieve the greatest crop yield. There are a number of options to consider when crops are grown in areas with restricted water limits<sup>93</sup>:

- ***Reduce irrigated acreage*** - If, due to the type of crop being grown, full irrigation is required, then the irrigated acreage must be reduced. If a finite amount of water is available, then a smaller area to be irrigated means that proportionally more water can be used for the areas that have been planted in order to obtain high crop yield.

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<sup>92</sup> <http://oregonstate.edu/~muirp/irrigati.htm>

<sup>93</sup> <http://www.ianrpubs.unl.edu/epublic/pages/publicationD.jsp?publicationId=194>

- ***Reduce the amount of water used for irrigation*** - Crop yield would be lower in years that have normal or low precipitation but could have good yield in years of above normal rainfall.
- ***Substitute crops so that more low water crops are planted:*** Corn, for example, is a high-water crop but is still widely grown across the U.S. Southwest. Low-water crops, such as soybean, winter wheat and sunflowers, are better suited to this environment. Specific information on current crops and irrigated acres is available by state from the Department of Agriculture 2002 Census and illustrates the extent of our reliance on irrigated crops<sup>94</sup>.
- ***Irrigate only when needed*** - Plants do not necessarily need the same amount of water throughout their growth period. Less water may be needed during initial stages of growth with more water needed during the reproductive stage. This strategy requires in-depth knowledge of the crop and might also require changes to be made in furrows for planting in order to obtain the maximum benefit from what water is used. Furrows that are dry will not transport water well, so the type of plowing and planting would also need to be considered.
- ***Use of crop residue to capture and retain precipitation*** - Covering the soil with residue after planting is one of the most effective means of both conserving soil moisture and preventing soil erosion. Residue decreases the amount of run-off from irrigation and natural precipitation and also reduces evaporation. Less water would then be required for irrigation.

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<sup>94</sup> <http://www.nass.usda.gov/census/census02/volume1/>

- **Improved irrigation systems** - Irrigation systems in the Southwest are often inefficient, losing volumes of water through evaporation during the hottest times of the day. Over watering also occurs, leading to puddling and contamination of ground water. The two major types of irrigation in place are gravity-flow systems and mechanized sprinkler systems. In gravity flow systems, water is transported and released at the upper end of the fields. Furrows are then used to channel water across the fields. Mechanized sprinkler systems spray water and usually need pressure to do this. Center-pivot sprinkler systems are widely used in the West and accounted for up to 79% of totaled US sprinkler acreage in 2003<sup>95</sup>. These systems have metal frames with sprinklers along the length of the arms, supported by wheeled trusses. Water is pumped in at the center (the pivot) and is pumped out along the arms. The entire system moves in a circle to irrigate the crops. In high-pressure center-pivot systems, significant water is lost due to evaporation and/or wind as water is shot up into the air. To cut down on water loss and increase efficiency, center-pivot systems can be fitted with low-pressure sprinklers that point down instead of up. This system has the additional advantages of also requiring less energy and labor.<sup>96</sup>



Figure 10 - Low-Pressure Center-Pivot Irrigation System<sup>97</sup>

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<sup>95</sup> <http://www.ers.usda.gov/Publications/AREI/EIB16/Chapter4/4.6/>

<sup>96</sup> <http://ga.water.usgs.gov/edu/irsprayhigh.html>

<sup>97</sup> [http://attra.ncat.org/attra-pub/irrigation\\_water.html#intro](http://attra.ncat.org/attra-pub/irrigation_water.html#intro)

Low-flow systems such as drip, micro and trickle-sprinklers offer even higher efficiency though they are currently used mainly only in orchards and vineyards. In addition to the technologies mentioned above, the use of remote sensing and accurate water-flow measurement, and hydrodynamic gates on irrigation canals to set an irrigation schedule appropriate for the crop's needs, all have the potential of improving the efficiency of irrigation.

<b>Attainable Irrigation System Application Efficiencies</b>	
<b>System Type</b>	<b>Efficiency (percent)</b>
<b>Surface Systems</b>	
Level border	60-80
Furrow	60-80
Surge	65-80
Graded burrow	55-75
Corrugate	40-55
Wild flood	25-40
<b>Sprinkler Systems</b>	
Linear move	75-90
Center pivot (low pressure)	75-90
Fixed solid set	70-85
Center pivot (high pressure)	65-80
Hand move or side roll laterals	60-75
Traveling gun	60-70
Stationary gun	50-60
<b>Micro-irrigation systems</b>	
Surface/subsurface drip	85-95
Micro spray or mist	85-90

Figure 11 - Efficiency of various irrigation methods<sup>98</sup>

<sup>98</sup> [http://attra.ncat.org/attra-pub/irrigation\\_water.html#intro](http://attra.ncat.org/attra-pub/irrigation_water.html#intro)

Excessive and poorly managed irrigation has multiple negative impacts in addition to depleting the fresh water supply when water use is great than water recharge. Poor irrigation management decreases agricultural productivity and profitability. It degrades soil quality through erosion and nutrient depletion. This in turn will require more potentially polluting fertilizers in order to maintain crop productivity levels. The addition of more chemicals further degrades water quality by leaching contaminated water from irrigated fields into the water supply. It destroys wildlife habitats<sup>99</sup>.

As noted in a recent publication by the USDA Economic Research Service<sup>100</sup> there is even greater potential for increasing agricultural water conservation with the combined use of conserving water-management practices and irrigation systems. More work needs to be done so that farms follow water conservation and irrigation practices that will increase efficiency of irrigation, decrease the amount of water needed, enhance crop yields, protect the soil and protect the environment. As irrigation accounts for such a high percentage of water use in the western states, it is critical that plans for improvement in this area are implemented.

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<sup>99</sup> [http://attra.ncat.org/downloads/water\\_quality/irrigation.pdf](http://attra.ncat.org/downloads/water_quality/irrigation.pdf)

<sup>100</sup> <http://www.ers.usda.gov/Publications/AREI/EIB16/Chapter4/4.6/>

## Policies

It is not always enough to recognize a problem, nor is it always enough to have a variety of solutions available to resolve the problem. There needs to be cooperation among all those affected by the issue including a clear statement of the problem, steps to be taken towards resolution and agreement of all parties. Though policies may seem far removed from the individual, they are also necessary if true progress is to be made on a large scale.

Population growth control - It's simple mathematics. An increase in population leads to increased water use which leads to decreased resources. However, as stated by Peter Gleick, of the Pacific Institute, "As critically important as population is, it isn't the whole picture. Population rarely, if ever, acts alone to produce water scarcity and looking at it in isolation shifts attention from policies that may be equally or more effective. By ignoring the related roles of consumption levels, the form of resource use, and the role of economics, technology, and culture, such an approach often misses many of the most important and effective policies for solving problems."<sup>101</sup>. Population control is one of the more effective ways to reduce the growing water demands. It has a clear, relatively quick (if we deal with non-residents, such as limiting the number of tourists) and noticeable reduction on the demands, as well being a safe process and one that the government could control with relative ease. The difficulty with this situation is the very stringent opposition. It would be improbable to get the general population to agree that curtailing the population growth is a necessity. A number of lifestyles all agree that a family is entitled to as many children as they please. And this is only dealing with one section of the

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<sup>101</sup> <http://www.aaas.org/international/ehn/fisheries/gleick.htm>

opposition. If any attempt was made to limit the tourism to a place such as Las Vegas, there would be a colossal outcry of protest. The amount of profit available would become a fixed number, instead of allowing the entrepreneurs their chance at profiting as much as possible. The question then becomes, what is a reasonable number of residents and tourists, and who is the right person to decide that number? In theory, population growth control is an excellent idea to reduce the growing demands. Practically, it is much more complicated to implement than one would first think.

Reduce the use of beef as a source of food - Beef in the US is big business though in the past several decades, there have been increasing health concerns including an increased risk of heart disease, high blood pressure and increased cholesterol levels. Growth hormones and antibiotics added to the feed have also been raised as potential health issues<sup>102</sup>.

Added to these concerns are the environmental costs associated with raising cows. These include environmental pollution from farm animal waste on factory farms, use of fossil fuels to raise and transport animals, and the production of methane from livestock<sup>103</sup>. Last but not least, is the use of valuable water resources to produce a product that isn't necessarily good for us?

To raise cows requires a tremendous amount of water, as will be illustrated. The majority of water is used not to hydrate cattle, but to grow their feed. On big beef ranches, in order to make the greatest amount of profit, free range grazing is limited. Cattle are crowded into holding pens

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<sup>102</sup> <http://www.sustainabletable.org/features/articles/beef/>

<sup>103</sup> <http://www.earthsave.org/globalwarming.htm>

to prevent them from burning off their food. Rather than being fed grass, a cow's natural food, they are fed high-protein soybeans and corn to gain weight faster which allows them to be "harvested" sooner. Corn, in particular, is a high-water crop yet is being grown in areas of low natural precipitation as animal feed. Half or more of our harvested acreage (corn, soybeans, etc.) goes to feed cattle, but the microorganisms in a cow's rumen work best when the cow eats grass. Statistics on the water usage for livestock vary. According to the National Sustainable Agriculture Information Service, livestock needs the following amount of water daily just for drinking<sup>104</sup>:

- 1000 lb dairy cow 30 gallons
- Dry beef cow 22 gallons
- Beef cow-calf pair 20 gallons
- 600 lb beef heifer 12 gallons
- 2000 lb beef bull 19 gallons
- Sheep or goat 2 gallons

Statistics, including water and other resources as well the resulting negative environmental effects listed below, needed to produce 1 lb of beef the way it's done on typical US beef farms as cited directly from *Diet for a Small Planet* and/or *Diet for a New America* submit even stronger arguments for reducing the amount of beef produced and consumed<sup>105</sup>:

- 16 lb. of corn, soy, or other high-protein feed: Sixteen pounds of corn or soy would provide food for much longer than the 1 lb of beef.

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<sup>104</sup> [http://attra.ncat.org/downloads/water\\_quality/water\\_mgmt.pdf](http://attra.ncat.org/downloads/water_quality/water_mgmt.pdf)

<sup>105</sup> Lappé, Francis Moore. 1991. *Diet for a Small Planet*. 20th Anniv. Ed. Ballantine Books, New York, Robbins, John. 1987. *Diet for a New America*. Stillpoint Publ., Walpole, NH.

- 2500 gal. H<sub>2</sub>O: This is an enormous amount of water for just 1 lb. of beef.
- 20000 KCal of fossil fuel: Among other things, this is used to run the tractor, supply electricity, and as an ingredient from which to manufacture insecticides, fertilizers, drugs, etc. In contrast, 1 lb. of beef gives 500 KCal of food energy.
- Soil erosion is associated more with corn and soy production than any other crops. Certain areas of the country are losing more soil now, due to erosion, than during the “Dust Bowl” back in the 30s.
- As topsoil erodes and nutrients in the remaining soil become depleted, farmers are becoming increasingly dependent on artificial fertilizers. These, in turn, are so strong that they kill the good bacteria, earthworms, and other “critters” that help build good soil. Also, unlike in previous generations, organic material (compost, manure) is not put back into the soil to help build it up.
- Market demands are such that, to make a living, farmers are forced to plant more and more marginal land despite the ecological consequences. For example, hillsides that formerly would have been left untouched to stop erosion are being tilled and planted.
- Our country is increasingly making use of imported, foreign beef. Typically, this beef is produced in Third World countries and is often done in association with slash-and-burn clearing of rainforest. This has also sent a message to the peoples in many of these countries that it is necessary to eat beef. However, many countries’ standards for domestic sale are much lower than standards for sale to the US (because of what the USDA will let in). Typically the meat eaten by people in many of these other countries contains drugs, insecticides, and/or hormones at levels that would not be permitted in the

US. There have been numerous instances of young girls showing signs of puberty due to hormones in beef.

- 2/3 of our agricultural exports go to feed cattle, not hungry people. Most of those cattle are destined to come back here as meat.
- Feedlot manure is not composted. A typical feedlot of 20,000 cattle produces the same amount of manure as a city of 320,000 people. The sewage from the people is sent to a sewage treatment plant where at least some of it is treated before being released into our water supplies. The sewage from feedlots isn't treated, but often just let run into local rivers and lakes.
- As seen above, based on the negative effects on the environment and the amount of energy put in versus the amount of energy produced, it is clear that cows do not give a good return on investment. Educating people to look for alternative sources of protein and to reduce the amount of beef in their diet has great potential of offering noticeable health and environmental results.

Limit development and land use to available water resources - In February of 2003, several organizations, including the American Planning Association and the Environmental Law Institute, cosponsored a forum to discuss the need to link growth and land usage to water supply and to review effective ways this is currently being addressed<sup>106</sup>.

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<sup>106</sup> <http://www.lincolninst.edu/pubs/PubDetail.aspx?pubid=794>

As noted in the history section of this paper, water in the West is a commodity that can be bought and sold separate from land<sup>107</sup>. This has led to the formation of Water Markets. Since water can be bought it sold, it can be relocated to the highest bidder. For example, it is legal to transfer water rights from agriculture to urban areas. The ability to buy water facilitates growth into areas where a natural lack of water would prohibit or limit growth.

There are, however, methods of linking water availability and development that are gaining in interest and potential. Public Trust Doctrines, which hold that public natural resources are held in trust by the State for the benefit of all, are in the constitutions of most western states<sup>108</sup>. The states are instructed to take into account the conservation of water for future generations when developing plans for land development and use. By applying the public trust doctrine, it has been possible to use the political process to limit unrealistic growth or establishment of inappropriate land use based on water availability.

Another positive sign that this concept of limiting growth to water availability was a conference, *Wet Growth: Should Water Law Control Land Use?* held in February 2003 sponsored by the Center for Land Resources at Chapman University School of Law in California. The Environmental Law Institute and the American Planning Association were among the organizations that attending. At this conference, various state policies, specifically requiring a link between water availability and development were discussed. A good example of exactly this

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<sup>107</sup> Getches, David H. 1984. *Water law in a nutshell*. St. Paul, MN: West Publishing Co

<sup>108</sup> Sax, Joseph L. 1993. Bringing an ecological perspective to natural resources: Fulfilling the promise of the public trust. In *Natural resources law and policy: Trends and directions*, Lawrence J. MacDonnell and Sarah F. Bates, eds. 148-161. Washington, DC: Island Press.

type of policy is Colorado Senate bill 221. Signed into law in October 2001, this bill requires that developers have to prove they have obtained water rights before they are given approval to build subdivisions of more than 500 units. Though this is not comprehensive, Bill 221 is a positive step in linking growth to the availability of water.

Arizona's Groundwater Management Act (GMA), signed into law in 1980, is an even more comprehensive framework that ties water supply to growth. Groundwater supplies as much as forty percent of Arizona's water needs<sup>109</sup>. The GMA designated four active management areas (AMAs) around the most populated Arizona cities; Phoenix, Pinal, Prescott and Tucson. The GMA has a statutory management goal of ensuring a balance between groundwater withdrawals and natural and artificial recharge in these four AMAs. Mandatory water conservation requirements and incentives to increase existing water supplies are the cornerstones of this legislation. The GMA also prohibits the approval for new subdivisions in AMAs unless the developers can prove that renewable water supplies are available for 100 years.

Water rate structure - Water rate structure operates on a simple principle: the more water you use, the higher the cost. By placing a greater cost on higher levels of water use, it provides a financial incentive to conserve water as well as emphasizing the need to conserve water.

Numerous towns and cities throughout the West have implemented tiered water rates for municipal use of water. As an example, Las Vegas has a four-tiered system. Normal indoor use of water by the majority of customers generally falls under the first and least expensive tier. The

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<sup>109</sup>[http://www.idswater.com/Common/Paper/Paper\\_143/Securing%20Sustainable%20Water%20Supplies%20in%20Arizona.htm](http://www.idswater.com/Common/Paper/Paper_143/Securing%20Sustainable%20Water%20Supplies%20in%20Arizona.htm)

rates for the remaining tiers become increasingly higher as water usage at these levels is considered to be increasingly discretionary rather than a necessity<sup>110</sup>.

**Las Vegas, Nevada, Single-Family Residential Meter Sizes, Thresholds and Rates:**

<b>Meter Size (inches)</b>	<b>Daily Service Charge</b>	<b>Tier</b>	<b>Threshold (x 1,000 gallons)</b>	<b>Rate (per 1,000 gallons)</b>
<b>5/8</b>	\$0.2021 X 30 days = \$6.06	1	0 - 5	\$1.16
		2	5.01 - 10	\$2.08
		3	10.01 - 20	\$3.09
		4	20.01 and over	\$4.58
<b>3/4</b>	\$0.2327 X 30 days = \$6.98	1	0 - 6.8	\$1.16
		2	6.81 - 13.5	\$2.08
		3	13.51 - 27.0	\$3.09
		4	27.01 and over	\$4.58
<b>1</b>	\$0.2940 X 30 days = \$8.82	1	0 - 10.1	\$1.16
		2	10.11 - 20.32	\$2.08
		3	20.33 - 57.5	\$3.09
		4	57.51 and over	\$4.58
<b>1.5</b>	\$0.4470 X 30 days = \$13.41	1	0 to 18.6	\$1.16
		2	18.61 - 37.2	\$2.08
		3	37.21 - 175.7	\$3.09
		4	175.71 and over	\$4.58
<b>2</b>	\$0.6309 X 30 days = \$18.93	1	0 to 28.71	\$1.16
		2	28.72 to 57.43	\$2.08
		3	57.44 to 385.26	\$3.09
		4	385.27 and over	\$4.58

Figure 12 - Las Vegas Water Rates and Thresholds<sup>111</sup>

<sup>110</sup> [http://www.lvwd.com/html/cust\\_serv\\_rates.html](http://www.lvwd.com/html/cust_serv_rates.html)

<sup>111</sup> [http://www.lvwd.com/html/cust\\_serv\\_rates\\_thresholds.html](http://www.lvwd.com/html/cust_serv_rates_thresholds.html)

Education on water conservation - As noted previously, the Drought Buster program from the Los Angeles Department of Water and Power is one of the programs that has seen great success in raising awareness of the need to conserve water. It was first implemented during the severe drought in 1990 to enforce the Los Angeles Prohibited Water Use Ordinance and had a success rate of 34%. The Drought Buster program has recently been re-launched in response to the growing water crisis in the LA Basin. Six customer service employees will disperse within communities across the city. Though this time they are not charged with enforcing current water use ordinance, they do have procedures in place to inform and educate customers who are out of compliance.

The Drought Busters will be looking for the following violations against the Los Angeles' Prohibited Water Use Ordinance (LADWP). As quoted directly from the LADWP website, customers cannot:

- Use water on hard surfaces such as sidewalks, walkways, driveways or parking areas (with the exception of water brooms)
- Water lawns between 10 a.m. and 5 p.m. during April through September, and between 11a.m. and 3 p.m. during October through March.
- Allow excess water from sprinklers to flood gutters.
- Use water to clean, fill or maintain decorative fountains unless the water is part of a recirculation system.
- Serve water to customers in eating establishments, unless requested.
- Allow leaks to go unattended.<sup>112</sup>

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<sup>112</sup> <http://www.ladwp.com/ladwp/cms/ladwp009949.jsp>

The combination of providing clear ordinances limiting water usage along with water conservation education and reminders to violators of the ordinances has proven to be effective. More programs such as this should be implemented in other cities as the 34% reduction in water usage attributable to this program is sizable.

Regional cooperation on water management - As noted previously, water rights have not always been determined based on best water management practices. However, the increasing stress due to current drought conditions combine with increased urban sprawl has led the western states to take further steps to work together to come up with solutions that are fair and equitable in order to reduce conflicts and ensure increased efficiency. The February 2007 Report issued by the National Academies<sup>113</sup> further states that “In addition to interstate cooperation, enhanced communication and collaboration between the scientific and water management communities will be vital.” This publication stresses the point that though the Colorado River hydrology knowledge base is extensive, it is not necessarily incorporated into legal and operational interstate decisions to its optimal extent that this is necessary for effective improvements. It also points out that though states and municipalities that are part of the Colorado River Basin have numerous conservation, landscaping and educational programs, that there is nothing in place to document and coordinate these efforts.

What is encouraging is that there are steps being taken to do exactly this. The Colorado River Compact and the Western States Water Council are two such organizations that promote interstate use of resources, information and agreements. These and other similar organizations

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<sup>113</sup> [http://dels.nas.edu/dels/rpt\\_briefs/colorado\\_river\\_management\\_final.pdf](http://dels.nas.edu/dels/rpt_briefs/colorado_river_management_final.pdf)

will likely be called upon to play in increasingly important role in water management as resources continue to decrease and demands increase.

## CONCLUSION

As stated before, there is no one perfect solution to the growing water crisis in the western USA. There is an abundance of solutions that one can choose from. It is no longer an issue of what solutions are available, but rather which ones would be best suited for this particular situation. Each solution has to be individually evaluated and the best from those selected and implemented. No single solution will be sufficient. A combination of short-term and long-term solutions is needed as well as a balance between economic feasibility, practicality and benefits.

Population growth control is an excellent example of a solution that in theory is sound but is close to unrealistic. It is a sure, definite way to reduce the demand for water. Though results would not be seen immediately, it has the benefit of being a long term solution. If we could control the population, we could theoretically put a limit on the need for every increasing water usage. Unfortunately, this is a drastic and impractical solution. It would be exceptionally difficult to implement as a number of ethical issues would rise such as: who controls what the “necessary” population is and what reasoning do they use? Who gives that organization the right to decide whether or not I have children? What repercussions would there be for not following the regulations? All of these questions could perhaps eventually be answered, but we find it hard to believe that the answers would be satisfactory for a large portion of the population.

Implementing and managing population control to the degree necessary to realize benefits, though theoretically possible, is not practical and also does not provide much needed immediate, short-term solutions.

Another example of a solution that is good in theory and might work in practice, but is not immediately effective is reducing the amount of beef we eat. It has been shown that beef is detrimental to not only our health (in some cases), but requires a massive amount of water to maintain, and is responsible for environmental problems such as land degradation through excessive grazing, excessive waste production that in turn needs to be treated, and the emission of methane. Some of these issues would be more easily dealt with in areas where rainfall is abundant, but in an arid area such as the Four Corner States, supporting the current numbers of cattle is a severe waste of a valuable resource. Although awareness of this dire situation can be brought to the public, the effect that it will have is likely minimal without financial incentives and/or legal enforcement. It is unlikely for people to stop eating beef merely because someone told them it could cause a water crisis. There are those who will take the message to heart and make dietary changes, but it is probable the majority will see no need to change their lifestyle. There would also be follow-on economic implications as beef is big business. Programmes and support would also need to be put in place to assist the former cattle farmers in finding alternative ways to best utilize their resources. Though there is potential for positive impact of reducing the number of cattle and their feed, this is at best a long-term solution that may only be able to be implemented over an extended period of time.

As noted previously, irrigation is responsible for the greatest amount of water usage, up to approximately 70 to 80% in the western US. Poor irrigation practices, poor crop management, old technology and economic factors continue to place a huge drain on water resources in the western US as well as other parts of the world. The potential for decreasing the amount of water usage by irrigation is tremendous and must be addressed. The technology for more efficient low-

pressure and low-flow irrigation technology, such as drip and micro-sprinkler which have application efficiencies of approximately 90 to 95% <sup>114</sup>, is already available. Programs for educating farmers on water conservation, irrigation and crop management already exist from a number of sources including local, state and federal levels as well as through numerous agricultural agencies and universities. Implementing changes to the irrigation process has the added benefit of reducing the negative environmental impact on soil and additional water contamination as well as reducing water usage and improving crop production.

This is a viable solution that would show both short and long-term benefits. The technology and methods are established, economically feasible, practical and assistance is readily available to the farmers for implementation. Decreased water consumption would be seen immediately and the cumulative effects of decreased consumption would have additional long term benefits as ground water and rivers were replenished. However, as noted by the USDA through various surveys <sup>115</sup>, these practices have not yet been implemented across the board. Poor current practices need to be changed and there needs to be economic and/or legal pressure to ensure compliance in order to better realize the benefits of this solution.

Desalinization, ASR, and recycling plants are additional technological solutions that have great potential: they have only a slight impact on the general population, create jobs, and have minimal impact on the environment. The technology is known and works well. Numerous plants are already established and though regulations are not yet consistent, they are a strong start to ensure

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<sup>114</sup> <http://www.ers.usda.gov/Publications/AREI/EIB16/Chapter4/4.6/>

<sup>115</sup> <http://www.ers.usda.gov/Publications/AREI/EIB16/Chapter4/4.6/>

public safety and high water quality. Re-using water is a very effective way to reduce the strain placed on surrounding water resources. Imagine if everyone was entitled to exactly the same amount of water they are entitled to today, but the net use was reduced to half the acre-feet. This would be safe, clean, immediate and long-term solution to the situation at hand. Building and up keeping the facility would create a bounty of jobs. It would also help spread awareness of how serious the situation is, as all of the employees would be faced with the circumstance every day. The biggest drawback at this point is that the plants are expensive to implement and cheaper resources are, at the moment, still available. However, as technology continues to improve, there will be an increased cost and environmental benefit to implement these plants. This is a solution that bears consideration and will likely become increasingly feasible as the costs are reduced.

Though individual household usage of water would not lead to as dramatic a difference as irrigation practices and water recycling plants, it is still a solution very much worth consideration. A combination of continued education on the need for water conservation as well as economic sanctions and incentives to encourage decreased water usage will be necessary to encourage people to change their habits. Additionally, the simplicity of making day to day changes makes this solution a feasible one. Small changes multiplied by many households would result in a cost effective and noticeable difference in decreasing water consumption both long and short-term and should be pursued.

Policies and legislation limiting land use and development to water availability are still in the infancy stage but have become more widespread in recent years. Passing legislation is a slow process but continued efforts in this area have great potential for long-term benefits. The laws

currently in place are only a first step and will need to go further in order to gain the full benefit of determining appropriate land use based on water resources. This is a long-term solution that bears consideration.

There needs to be more communication and cooperation between the various states and agencies responsible for water management in the western US so that cohesive short-term and long-term plans can be formulated. These organizations need to come together, understand what options are available to them and together determine the best way forward for water conservation for all states concerned. Each western state has agencies set up to monitor and manage water but this is being done primarily on a state level. Though all states benefit whenever one state decreases water usage, it does not necessarily decrease the overall water consumption by the area as any excess water could be used other states. The Basin Plan in Los Angeles and the GMA in Arizona are good examples of in-state agencies that have seen success in managing water consumption. The Colorado River Water Users Association is a good example of the type of cross-state cooperation that is needed. Though this is only a first step, the potential of long-term benefits from such synergy is enormous. The western states must make their commitment to improving water management and distribution throughout the west instead of just looking out for their own state. As mentioned, these agencies are being formed and meetings have been taking place as people are beginning to realize what a dire situation we are in, but still more needs to be done.

In conclusion, there are programs, tools and technology already available to ameliorate the effects of water shortage in the western US due to global warming. What is necessary now is the commitment and cooperation to take action at all levels to achieve this common goal.

# LIST OF FIGURES

Figure 1 - Increasing Melt Period ..... 6

Figure 2 - Arctic Sea Ice Extent..... 8

Figure 3 - Roman Aqueduct..... 14

Figure 4 - Los Angeles Aqueduct from Owens Valley..... 24

Figure 5 - Colorado River Basin..... 28

Figure 6 - Boulder Canyon ..... 30

Figure 7 - Average household water use..... 47

Figure 8 - Water used in normal home activities..... 54

Figure 9 - ASR Storage Diagram..... 56

Figure 10 - Low-Pressure Center-Pivot Irrigation System ..... 61

Figure 11 - Efficiency of various irrigation methods..... 62

Figure 12 - Las Vegas Water Rates and Thresholds..... 71

# BIBLIOGRAPHY

## Periodicals

- Archibold, Randal C. "A Century Later, Los Angeles Atones for Water Sins." The New York Times 1 Jan. 2001: 2. 23 Apr. 2008 <[http://www.nytimes.com/2007/01/01/us/01water.html?pagewanted=2&\\_r=1&ei=5087&em&en=74176d876d406106&ex=1167800400&adxnnl=1&adxnnlx=1209146647-80h24/imxpUo8HmHA0KXNw](http://www.nytimes.com/2007/01/01/us/01water.html?pagewanted=2&_r=1&ei=5087&em&en=74176d876d406106&ex=1167800400&adxnnl=1&adxnnlx=1209146647-80h24/imxpUo8HmHA0KXNw)>.
- Ehrenmann, Gayle. "Not a Drop to Drink." Mechanical Engineering 2003. 18 Feb. 2008 <<http://www.memagazine.org/contents/current/features/notadrop/notadrop.html>>.
- "Federal pact would allocate Colorado River water to Western States." International Herald Tribune 9 Dec. 2007. 4 Feb. 2008 <<http://www.ihf.com/articles/2007/12/09/america/10water.php>>.
- "Global Warming Brings Perpetual Drought to the U.S. Southwest." Environment News Service [New York, New York] 5 Apr. 2007. 8 Feb. 2008 <<http://www.ens-newswire.com/ens/apr2007/2007-04-05-01.asp>>.
- McKinney, Matthew. "Linking Growth and Land Use to Water Supply." Land Lines 15.2 (Apr. 2003). 12 Mar. 2008 <<http://www.lincolnst.edu/pubs/PubDetail.aspx?pubid=794>>.
- Powell, William E. "Precipitation Patterns in Western Kansas 1931-1976." Transactions of the Kansas Academy of Science 80.3-4 (Fall-Winter 1977): 89-106. JSTOR Archives. 2000. JSTOR. 6 Jan. 2008 <<http://links.jstor.org/sici?sici=0022-8443%28197723%2F24%2980%3A3%2F4%3C89%3APPIWK1%3E2.0.CO%3B2-9&size=SMALL&origin=JSTOR-reducePage#abstract> (Abstract, Precipitation Patterns in Western Kansas, 1931-1976)>.
- "Record Increase in U.S. Greenhouse Gas Emissions Reported." Environment News Service [Washington D.C.] 18 Apr. 2006. 8 Feb. 2008 <<http://www.ens-newswire.com/ens/apr2006/2006-04-18-02.asp>>.
- Robbins, Ted. "Stakes High for Las Vegas Water Czar." National Public Radio 13 June 2007. 8 Feb. 2008 <<http://www.npr.org/templates/story/story.php?storyId=10939792>>.
- Smith, Ron. "Water Management: Local control remains key in all plans." Southwest Farm Press 21 May 2002. 22 Apr. 2008 <[http://southwestfarmpress.com/mag/farming\\_water\\_management\\_local/](http://southwestfarmpress.com/mag/farming_water_management_local/)>.

## Nonperiodicals

- Arizona State. Arizona Water Banking Authority. Annual Plan of Operation 2008. By Herbert R. Gunther. Arizona Water Banking Authority. 1 Feb. 2008. 19 Feb. 2008 <[http://www.azwaterbank.gov/awba/documents/2008/2008-1\\_Final.pdf](http://www.azwaterbank.gov/awba/documents/2008/2008-1_Final.pdf)>.
- California. East Bay Municipal Utility District. "Attachment A." Technical Memorandum: A Summary of Operating Aquifer Storage and Recovery (ASR) Systems. EBMUD Current Projects. 7 Apr. 2005. EBMUD, Oakland, California. 15 Mar. 2008 <[http://www.ebmud.com/water\\_&\\_environment/water\\_supply/current\\_projects/bayside\\_groundwater/feir/Attachments.pdf](http://www.ebmud.com/water_&_environment/water_supply/current_projects/bayside_groundwater/feir/Attachments.pdf)>.
- Diemer, Dennis M. An Overview of Water Recycling in the United States. National Institute of Public Health - Japan. Japanese Government, Saitama, Japan. 14 Mar. 2008 <<http://www.niph.go.jp/soshiki/suido/pdf/h19JPUS/abstract/r14.pdf>>.
- Energy Information Administration. National Energy Information Center. What are Greenhouse Gases? Washington DC: EIA, 2001. EIA. 2 Apr. 2001. Energy Information Administration, Washington DC. 22 Jan. 2008 <<http://www.eia.doe.gov/oiaf/1605/ggcebro/chapter1.html>>.
- Gleick, Peter H. Human Population and Water: To the Limits in the 21st Century. American Association for the Advancement of Science. Sept. 1995. 18 Mar. 2008 <<http://www.aaas.org>>. Path: International Publications; Human Population and Water, Fisheries, and Coastal Areas: Science and Policy Issues; Human Population and Water.
- Glennon, Robert. Water Follies. Washington: Island Press, 2004.
- Lappe, Francis Moore. Diet for a Small Planet. New York: Ballantine Books, 1991.
- Midkiff, Ken, and Robert A Donnelly. Not a Drop to Drink: America's Water Crisis. N.p.: Inner Ocean Publishing, 2007.
- Nevada State. Department of Conservation and Natural Resources. "Drought." Nevada Water Facts. Water Resource Issues in Nevada. Department of Conservation and Natural Resources. 18 Feb. 2008 <<http://water.nv.gov/WaterPlanning/wat-fact/issues.cfm#drought>>.
- Pearce, Fred. When the Rivers Run Dry. Malaysia: Beacon Press, 2007.
- Reisner, Marc. Cadillac Desert. New York: Penguin Books, 1993.
- Robbins, John. Diet for a New America. Walpole, NH: Stillpoint Publ., 1987.
- Sax, Joseph L., Lawrence J. MacDonnell, and Sarah F. Bates. Natural Resources Law and Policy. Washington D.C.: Island Press, 1993. 148 - 161.

- Shrier, Catherine J. “Aquifer Storage and Recovery Regulations and Challenges for the EPA’s Underground Injection Control Program.” Ground Water Protection Council, September 9th, 2004. Ground Water Protection Council. 2007. Oklahoma City, Oklahoma. 20 Feb. 2008 <[http://www.gwpc.org/meetings/meetings\\_forum/AF04/Attachments/Abstracts/Shrier-Catherine-FP.pdf](http://www.gwpc.org/meetings/meetings_forum/AF04/Attachments/Abstracts/Shrier-Catherine-FP.pdf)>.
- U.S. Census Bureau. Population of the 100 Largest Cities and other Urban Places in the United States: 1790 to 1990. By Campbell Gibson. U.S. Census Bureau. June 1998. U.S. Government. 3 Feb. 2008 <<http://www.census.gov/population/www/documentation/twps0027.html>>. Population Division Working Paper No. 27
- U.S. Census Bureau News. Nevada Edges out Arizona as the Fastest-Growing State. By Robert Bernstein. U.S. Census Press Releases. 22 Dec. 2005. U. S. Department of Commerce, Washington DC. 6 Feb. 2008 <<http://www.census.gov/Press-Release/www/releases/archives/population/006142.html>>.
- U.S. Department of the Interior. “Chapter 2.” The Story of Boulder Dam. Lake Mead National Recreation Area. 1 Feb. 2008. U.S. Department of the Interior, Washington D.C. 22 Apr. 2008 <[http://www.nps.gov/history/history/online\\_books/dams/boulder\\_dam2/chap2.htm](http://www.nps.gov/history/history/online_books/dams/boulder_dam2/chap2.htm)>.
- U.S. Department of the Interior. Coping with Severe and Sustained Drought in the Southwest. By Michael D. Dettinger. U.S. Department of the Interior. Oct. 1995. U.S. Geological Survey. 6 Feb. 2008 <<http://geochange.er.usgs.gov/sw/changes/natural/codrought>>.
- U.S. Department of Agriculture Statistics. 2002 Census of Agriculture Volume 1 State Level Data. National Agricultural Statistics Service. 2002. U.S. Department of Agriculture, Washington D.C. 24 Apr. 2008 <<http://www.nass.usda.gov/census/census02/volume1/>>.
- U.S. Global Change Research Group. “Current Climate Change of the New England Region.” New England Regional Assessment. Washington: United States Government, 1999. New England Regional Assessment. 17 Sept. 2001. U.S. Climate Change Science Program/ U.S. Global Change Research Program. 7 Jan. 2008 <<http://www.necci.sr.unh.edu/Nera-products/NERA-Climate-2pager-6.99.PDF>>.
- U. S. Government. U.S. Department of Agriculture. “Chapter 4.5.” Irrigation Water Management. By Glenn Schaible and Marcel Aillery. Economic Research Service. 21 July 2006. U.S. Department of Agriculture. 18 Mar. 2008 < <http://www.ers.usda.gov/Publications/AREI/EIB16/Chapter4/4.6/>>.
- U. S. Government. “Finding System Efficiency.” Measuring and Conserving Irrigation Water. By Mike Morris and Vicki Lynne. National Sustainable Agriculture Information Service. 2006. U. S. Department of Agriculture. 20 Apr. 2008 <[http://attra.ncat.org/attra-pub/irrigation\\_water.html#intro](http://attra.ncat.org/attra-pub/irrigation_water.html#intro)>. Attra Publication #IP280

U.S. Government. Irrigation: Typical sprinkler (spray) irrigation. U.S. Geological Survey. 2000. U.S. Department of the Interior, Washington DC. 20 Apr. 2008 <<http://ga.water.usgs.gov/edu/irsprayhigh.html>>.

U.S. Government. U.S. Census Bureau, Population Division. “Table 1.” Nativity of the Population and Place of Birth of the Native Population 1850 to 1990. By Campbell Gibson and Emily Lennon. Washington DC: U.S. Census Bureau, 1999. 18 Jan. 2001. U.S. Census Bureau. 28 Dec. 2007 <<http://www.census.gov/population/www/documentation/twps0029/tab01.html>>.

U.S. Government. NOAA/National Weather Service. U.S. Seasonal Drought Outlook. Climate Predication Center. 29 Jan. 2008. NOAA/National Weather Service, Washington DC. 6 Feb. 2008 < [http://www.cpc.ncep.noaa.gov/products/expert\\_assessment/season\\_drought.gif](http://www.cpc.ncep.noaa.gov/products/expert_assessment/season_drought.gif)>. Drought prediction is updated every Thursday

U.S. Government. NOAA/National Weather Service Forecast. Monthly Temperature and Precipitation Normals, Las Vegas, Nevada (1971-2000). National Weather Service Forecast Office. NOAA/National Weather Service, Las Vegas. 5 Feb. 2008 <<http://www.wrh.noaa.gov/vef/motemps.php>>.

Utah State. Division of Water Resources. Utah’s Perspective, The Colorado River. By D. Larry Anderson. Salt Lake City: Utah State, 2002. Utah Division of Water Resources. State of Utah. 4 Feb. 2008 < <http://www.water.utah.gov/interstate/thecoloradoriverart.pdf>>.

Villiers, Marq. Water: The Fate of Our Most Precious Resource. Boston: Mariner Books, 2001.

Waskom, R., and M. Neibauer. Water Conservation In and Around the Home, Fact Sheet no.9.952. Colorado State University Extension, 2006. Water Resource Fact Sheets. Jan. 2006. Colorado State University. 8 Feb. 2008 <<http://www.ext.colostate.edu/pubs/consumer/09952.html>>.

### **Web sites, e-sources**

“Aerial Geology - Part 1.” Nevada Seismological Laboratory. University of Nevada, Reno. 6 Feb. 2008 <<http://unrnet.seismo.unr.edu/Aerials/part1.html>>.

“America 1930-1939: Government and Politics: The Dust Bowl.” BookRags. 2005. 6 Jan. 2008 <<http://www.bookrags.com/history/america-1930s-government-and-politics/sub27.html>>.

“Arizona Water Banking Authority Home page.” Arizona Water Banking Authority. 2007. Arizona Government. 18 Apr. 2008 <<http://www.azwaterbank.gov/awba/>>.

Bellows, Barbara. “Irrigation.” National Sustainable Agriculture Information Service. 2004. National Center for Appropriate Technology. 18 Mar. 2008 <[http://attra.ncat.org/downloads/water\\_quality/irrigation.pdf](http://attra.ncat.org/downloads/water_quality/irrigation.pdf)>.

- Bellows, Barbara. "Water, Heat Stress, and Drought." National Sustainable Agriculture Information Service. 2004. National Center for Appropriate Technology. 19 Mar. 2008 <[http://attra.ncat.org/downloads/water\\_quality/water\\_mgmt.pdf](http://attra.ncat.org/downloads/water_quality/water_mgmt.pdf)>.
- "Bureau of Reclamation: About Us." Bureau of Reclamation. 28 Sept. 2007. U.S. Department of the Interior. 12 Feb. 2008 <<http://www.usbr.gov/main/about/>>.
- Carey, Bjorn. "Increase in Major Hurricanes Linked to Warmer Seas." Live Science. 15 Sept. 2005. Imaginova. 22 Jan. 2008 <[http://www.livescience.com/environment/050915\\_more\\_hurricanes.html](http://www.livescience.com/environment/050915_more_hurricanes.html)>.
- Castle, Anne J. "Water Rights Law - Prior Appropriation." FindLaw - Library. 1999. FindLaw. 12 Apr. 2008 <<http://library.findlaw.com/1999/Jan/1/241492.html>>.
- "Colorado River Basin Water Management: Evaluating and Adjusting to Hydroclimatic Variability." The National Academies. Feb. 2007. 18 Mar. 2008 <[http://dels.nas.edu/dels/rpt\\_briefs/colorado\\_river\\_management\\_final.pdf](http://dels.nas.edu/dels/rpt_briefs/colorado_river_management_final.pdf)>.
- "Colorado Water Rights." The Water Information Program. Southwestern Water Conservation District. 20 Apr. 2008 <<http://www.waterinfo.org/colorado-water/colorado-water-rights>>.
- Cowen, Richard, Dr. "Ancient Irrigation." Essays on Geology, History and People. May 1999. University of California, Davis. 17 Jan. 2008 <<http://www.geology.ucdavis.edu/~cowen/~GEL115/115CH17oldirrigation.html>>.
- Department of the Interior. "Sea Level and Climate." USGS FS 002-00: Sea Level and Climate. 31 Jan. 2000. U.S. Geological Survey. 22 Jan. 2008 <<http://pubs.usgs.gov/fs/fs2-00/>>.
- "Drinking Water." City of Los Angeles. 22 Aug. 2007. 16 Feb. 2008 <[http://www.lacity.org/ead/EADWeb-WNR/drinking\\_water.htm](http://www.lacity.org/ead/EADWeb-WNR/drinking_water.htm)>.
- "Drought in the Dust Bowl Years." National Drought Mitigation Center. 2006. University of Nebraska-Lincoln. 7 Jan. 2008 <<http://www.drought.unl.edu/whatis/dustbowl.htm>>.
- "The End of Lake Powell. It's not a matter of if, but when." Living Rivers. 20 July 2004. 2 Feb. 2008 <<http://www.drainit.org/campaigns/drought/summary.cfm>>.
- Flick, Eileen, Linda McCann, and Dennis Thomison. "The Owens Valley Land Grab." Murders, Crimes and Scandals in Lost Angeles. 1996. University of Southern California Libraries. 2 Feb. 2008 <<http://www.usc.edu/libraries/archives/la/scandals/owens.html>>.
- Gisser, Micha. "Water Markets and the Prior Appropriation Doctrine." Universities Council on Water Resources. 6 July 2002. University of New Mexico. 20 Apr. 2008 <[http://www.ucowr.siu.edu/updates/pdfn/V121\\_A4.pdf](http://www.ucowr.siu.edu/updates/pdfn/V121_A4.pdf)>.

“Global Climate Change FAQs.” California Climate Change Portal. 27 Aug. 2007. California State Government. 22 Jan. 2008 < <http://www.climatechange.ca.gov/background/faqs.html>>.

Gordon, Peter, and Harry W. Richardson. “Where Americans Live, Work and Do Business.” Peter Gordon, School of Policy, Planning and Development. 23 May 2002. University of Southern California. 18 Feb. 2008 <[http://www-rcf.usc.edu/~pgordon/pdf/Portl\\_LA\\_Figures.pdf](http://www-rcf.usc.edu/~pgordon/pdf/Portl_LA_Figures.pdf)>.

Hatz, Diane. “Beef.” Sustainable Table. GRACE. 17 Mar. 2008 <<http://www.sustainabletable.org/features/articles/beef/>>.

“A Hundred or a Thousand Fold More Important.” Los Angeles Aqueduct. Los Angeles Department of Water and Power. 2 Feb. 2008 < <http://wsoweb.ladwp.com/Aqueduct/historyoflaa/hundred.htm>>.

“Issue Summary - Desalination.” New Water Supply Coalition. 20 Feb. 2008 <<http://www.newwatersupply.org/issue/desal.htm>>.

Jacobs, Julius L. “The Story of Kings County.” Kings River System. 1955. Kings County Office of Education. 6 Jan. 2008 <<http://kingsnet.kings.k12.ca.us/kcoe/curric/history/resources/kingsriver.html>>.

Joshi, Rashi. “Climate Change: Prioritizing Human Security.” The Henry L. Stimson Center. 2007. 10 Jan. 2008 < <http://www.stimson.org/southeastasia/?SN=SE200707231356>>.

Kahrl, William. Interview. Desert Wars, Water and the West. 2006. KUED - University of Utah. Transcript. 2 Feb. 2008 <[http://www.kued.org/productions/desertwars/kahrl\\_william.php](http://www.kued.org/productions/desertwars/kahrl_william.php)>.

“Law of the River.” Arizona Department of Water Resources. 2007. Arizona State Government. 11 Feb. 2008 <[http://www.azwater.gov/dwr/ColoradoRiverManagement/Law\\_of\\_River.html](http://www.azwater.gov/dwr/ColoradoRiverManagement/Law_of_River.html)>.

Libecap, Gary D., and Zeynep Kocabiyik Hansen. “‘Rain Follows the Plow:’ The Climate Information Problem and Homestead Failure in the Upper Great Plains, 1890-1925.” Eller Collete of Management, University of Arizona. 31 Mar. 2000. 6 Jan. 2008 <[http://econ.arizona.edu/downloads/working\\_papers/dryfarm8drafts.pdf](http://econ.arizona.edu/downloads/working_papers/dryfarm8drafts.pdf)>.

“Los Angeles County Quick Facts from the U.S. Census Bureau.” Quick Facts. 2 Jan. 2008. U.S. Census Bureau. 9 Feb. 2008 <<http://quickfacts.census.gov/qfd/states/06/06037.html>>.

“Los Angeles Drought Busters Program.” Los Angeles Department of Water & Power. 18 Feb. 2008 < <http://www.ladwp.com/ladwp/cms/ladwp009949.jsp>>.

- “Lower Colorado River Water Delivery Contracts.” Bureau of Reclamation, Lower Colorado Region. Mar. 2005. U.S. Department of the Interior. 5 Feb. 2008 <<http://www.usbr.gov/lc/region/g4000/contracts/wateruse.html>>.
- Megdal, Sharon. “Securing Sustainable Water Supplies in Arizona.” IDS. University of Arizona, Tucson. 21 Mar. 2008 <[http://www.idswater.com/Common/Paper/Paper\\_143/Securing%20Sustainable%20Water%20Supplies%20in%20Arizona.htm](http://www.idswater.com/Common/Paper/Paper_143/Securing%20Sustainable%20Water%20Supplies%20in%20Arizona.htm)>.
- Mock, Cary J. “Rainfall in the Garden of the United States Great Plains, 1870-1889.” University of South Carolina, Department of Geography. 23 Apr. 1999. 28 Dec. 2007 <[http://www.cas.sc.edu/geog/hrl/Hazard\\_Pubs/2000\\_RainfallInTheGardenOfTheUSGreatPlains.pdf](http://www.cas.sc.edu/geog/hrl/Hazard_Pubs/2000_RainfallInTheGardenOfTheUSGreatPlains.pdf), pg. 1>.
- Mohr, Noam. “A New Global Warming Strategy: How Environmentalist are Overlooking Vegetarianism as the Most Effective Tool Against Climate Change in our Lifetimes.” EarthSave. 2007. 14 Mar. 2008 <<http://www.earthsave.org/globalwarming.htm>>.
- Muir, Patricia S. “Irrigation Issues.” Human Impacts on Ecosystems. 11 Feb. 2007. Oregon State University. 20 Mar. 2008 <<http://oregonstate.edu/~muirp/irrigati.htm>>.
- “NASA explains ‘Dust Bowl’ Drought.” Goddard Space Flight. Ed. Lynn Jenner. 18 Mar. 2004. U.S. Government. 2 Feb. 2008 <<http://www.nasa.gov/centers/goddard/news/topstory/2004/0319dustbowl.html>>.
- Payne, R. David. “What is ASR?” Aquifer Storage Recover Forum (ASR) Water Resource. ASR Systems LLC. 26 Feb. 2008 <<http://www.asrforum.com/what.html>>.
- “Pine Flat Lake.” Construction Operations - Parks and Lakes. U.S. Army Corps of Engineers, Sacramento District. 4 Feb. 2008 <<http://www.spk.usace.army.mil/organizations/cespk-co/lakes/pineflat.html>>.
- “Pine Flat Power Plant.” Kings River Conservation District. California State. 15 Jan. 2008 <[http://www.krcd.org/power/pine\\_flat\\_power/](http://www.krcd.org/power/pine_flat_power/)>.
- “Proposed Water Rates and Fees.” Las Vegas Valley Water District. Southern Nevada Water Authority. 12 Mar. 2008 <[http://www.lvwd.com/html/cust\\_serv\\_rates.html](http://www.lvwd.com/html/cust_serv_rates.html)>. Path: Proposed Rates and Fees.
- “Recent Warming of Arctic may affect Worldwide Climate.” Goddard Space Flight Center. 23 Oct. 2003. NASA. 6 Jan. 2008 <<http://www.nasa.gov/centers/goddard/news/topstory/2003/1023esuice.html>>.
- Reinhardt, Claudia, and Bill Ganzel. “Conservation Programs Introduced by the New Deal.” Living History Farm. 2003. The Ganzel Group. 5 Feb. 2008 <[http://www.livinghistoryfarm.org/farminginthe30s/crops\\_09.html](http://www.livinghistoryfarm.org/farminginthe30s/crops_09.html)>.

- Schneekloth, Joel P., et al. "Irrigating for Maximum Economic Return with Limited Water." University of Nebraska-Lincoln, Institute of Agriculture and Natural Resources. Jan. 2001. 17 Mar. 2008 <<http://www.ianrpubs.unl.edu/epublic/pages/index.jsp=194LimitedIrrigationManagement>>. Path: Limited Irrigation.
- "7 States, Kempthorne sign Colorado River Water Pact in Las Vegas." Western Water Blog. 14 Dec. 2007. 24 Jan. 2008 <<http://westernwaterblog.typepad.com/westernwaterblog/2007/12/index.html>>.
- Terracycles. "El Nino/La Nina." Terracycles. Ed. David Thomas Volantis. 2004. 22 Jan. 2008 <<http://www.terracycles.com/elninolanina.htm>>.
- "Top Las Vegas-area water users revealed." U.S. Water News Online. Apr. 2003. 3 Feb. 2008 <<http://www.uswaternews.com/archives/arconserv/3toplas4.html>>.
- "The U.S. Army Corps of Engineers: A Brief History." U.S. Army Corps of Engineers. 6 Feb. 2007 <<http://www.hq.usace.army.mil/history/Brief/index.html>>.
- "Water and People." Universities Council on Water Resources (UCOWR). 2005. Southern Illinois University. 22 Jan. 2008 <<http://www.ucowr.siu.edu/hydro/h03.html>>.
- "Water Appropriate Systems." National Science and Technology Center. Ed. Eric Hecox. U.S. Bureau of Land Management. 14 Apr. 2008 <<http://www.blm.gov/nstc/WaterLaws/fedreservedwater.html>>.
- Waterman, Lynn. "Discoveries of the Ancient." USGenNet. 14 Sept. 2007. 23 Jan. 2008 <<http://www.usgennet.org/usa/topic/preservation/science/inventions/chpt2.htm>>.
- "Weather Information for New York City, New York." World Weather Information Service. 31 Jan. 2007. World Meteorological Organization. 29 Dec. 2007 <<http://www.worldweather.org/093/c00278.htm>>.
- White, Kip, and Robert Walsh. "Secretary Kempthorne Signs Historic Decision for New Colorado River Management Strategies." U.S. Department of the Interior - News Release. 13 Dec. 2007. 25 Feb. 2008 <[http://www.doi.gov/news/07\\_News\\_Releases/071213.html](http://www.doi.gov/news/07_News_Releases/071213.html)>.
- Yegul, Fikret. "Water Supply Systems: Cisterns, Reservoirs, Aqueducts." Roman Building Technology and Architecture. 2007. University of California, Santa Barbara. 28 Dec. 2007 <<http://id-archserve.ucsb.edu/arthistory/152k/water.html>>.

## Legal sources

Boulder Canyon Project. Pub. L. 642-70th Congress H.R. 5773. 21 Dec. 1928. Colorado River Commission of Nevada. Nevada State. 9 Feb. 2008 <<http://crc.nv.gov/ProjectAct1928.htm>>.

Colorado River Compact, 1922. 24 Nov. 1922. Bureau of Reclamation, Lower Colorado Region. Ed. Colleen Dwyer. Dec. 2007. U.S. Department of the Interior. 5 Jan. 2008 <<http://www.usbr.gov/lc/region/pao/pdfiles/crcompct.pdf>>.

Record of Decision, Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead. 12 Dec. 2007. U.S. Department of the Interior. 12 Dec. 2007. U.S. Department of the Interior, Washing DC. 18 Feb. 2008 <<http://www.usbr.gov/lc/region/programs/strategies/RecordofDecision.pdf>>.