GENI Global Energy Network Institute

Impacts of Climate Change on California's Water Supply

April 2011

Peter Meisen
President, Global Energy Network Institute (GENI)
www.geni.org

peter@geni.org (619) 595-0139

Natalie Phares
Research Associate, Global Energy Network Institute (GENI)

nataliephares@gmail.com

Table of Contents

Table of Figures

1. Abstract California is in the midst of a water crisis. By consensus estimates, climate change is poised to intensify this crisis in the coming years. Our water delivery and conservation strategies are outdated and structurally failing. Additional new pressure to protect endangered species in the Sacramento-San Joaquin River Delta has prompted mandatory water supply cut-backs to our fertile crescent, the central valleys of California, American's agricultural heartland and the nation's largest supplier of fresh fruits and vegetables. We are currently experiencing one of the most severe droughts in our state's history. Climate change will further aggravate these problems and bring about a whole new set of hardships. In the coming years, as global temperatures rise, our snowpack will decline. This will hinder the capacity of our Sierra Nevada Mountain Range to house water during the dry months: earlier snowmelt at faster rates will cause floods in the early spring and produce droughts during the summer and fall months. The Colorado River and its tributaries, a major water resource for southern California, will experience its own set of changes as precipitation cycles are altered. Sea levels will rise, affecting coastlines, habitats, recreation and freshwater supply. The potential to produce hydropower will decline, and the quality of our water will dwindle as upstream sedimentation and chemicals contaminate water with increased turbidity from larger river flows. California's population is projected to rise at an alarming rate. More people mean less available water.

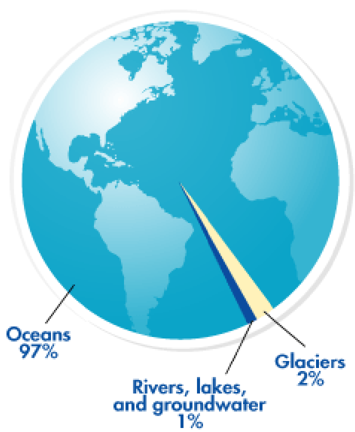
How should policy makers and water planners tackle these issues? Should efforts be weighted towards finding ways to supply water to satisfy our propensity for high water-use levels? Or towards adopting fundamental water-use mentalities that mimic other developed nations which conserve and use less? This paper examines the current situation, possible alternatives for future water management and the associated policies needed. This is the first step to synthesizing a clear picture and solution set.

2. Introduction

THE COMPLEXITIES OF OUR WORLD'S WATER ISSUES are becoming ever more critical as our planet warms and population increases. The delicate and out-dated water infrastructure that currently serves us was developed and implemented during the last century. Since its inception, increasing demand betrays a system seemingly destined for failure as a once abundant resource dwindles. California's large population is a relatively affluent society with associated high demand on all natural resources. Combined with sensitive natural and agricultural ecosystems, this has positioned the state for substantial stress from a neglected water delivery system. Add to this an extensive coastline made vulnerable by global warming-induced rising of the Pacific Ocean, and a potentially devastating scenario becomes obvious. Climate change will bring about multiple complications to an already risky water supply problem which at best is proving difficult to tackle. As temperatures rise, precipitation and runoff cycles are impacted by alterations in the hydrological cycle, secondary to higher atmospheric water holding capacity: snow pack and water storage decline, while sea levels rise.

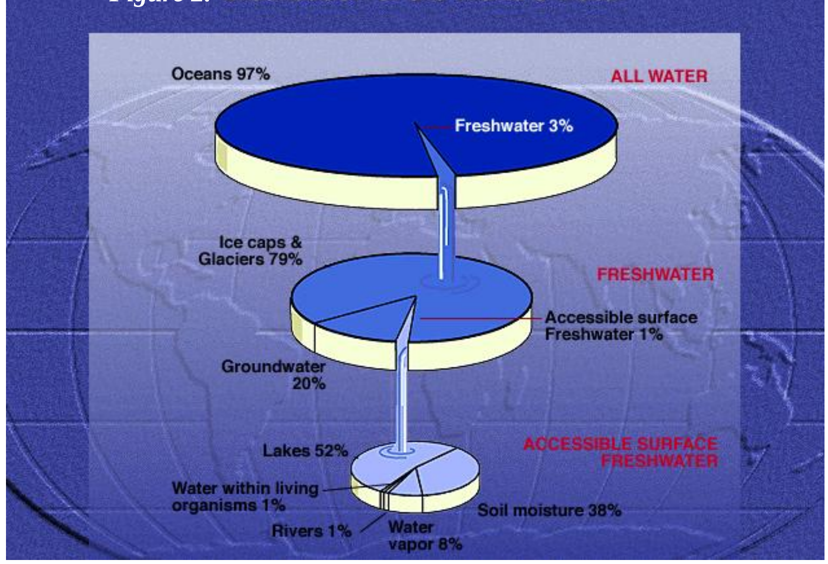
Water is our most precious resource, its prevalence vast in our natural world. When looking at our surrounding stars, planets and galaxies, the first and most critical factor for the possibility of life is the presence of water. Our oceans became saturated via frozen water riding into the atmosphere on meteors and asteroids, colliding with our infant ball of matter over several billion years. Oceans now cover 70% of the Earth's surface. Today, 97% of our water supply is held in the oceans as saltwater. The remaining 3%, and the focus of this article, is considered freshwater and is stored in glaciers, icecaps, freshwater terrestrial sinks and atmospheric systems. This interconnected network of useable water is broken down into a series of systems, shown in Figure 2 below, all determined by the hydrologic cycle. This is the movement of water from the surface and ground reservoirs back into our atmosphere where it is cleaned and re-dispersed. The largest amount of the planets freshwater is locked up in glaciers and icecaps, between 60%-79% according to the data source, while much of our terrestrial water is stored below in groundwater aquifers. Groundwater resides in layers of water-bearing permeable rock or sediment capable of storing liquid, accessible via water wells and the like. The rest resides in surface reservoirs such as lakes and rivers, or incorporated into living systems (United 2010).

Figure 1. **Usable water in the world**



From Salt 2011

Figure 2. **Distribution of the World's Water**



From Rice 2010

It has been apparent over the last few decades that the introduction of fossil fuels during the Industrial Revolution of the 19th century has increasingly introduced a range of problems for our natural world. Global warming, a term coined by scientists as the anthropogenically-induced incremental warming of our atmosphere and oceans due to the addition of harmful greenhouse gases, is considered by some to be at the crux of our dilemma. With many systems on the brink of failure, the issue of water will be one of our most pressing and relevant problems to tackle in the coming years. Our planet, country, and specifically California are now facing severe water shortages due to increasing demand brought on by a growing population and ecological devastation which is already underway. With the number of anticipated climate change impacts on global water supply growing, our world leaders, policy makers and water agencies must be fully knowledgeable about what this means for the future when mapping out next steps in planning the needs of society and the important biological systems we depend on worldwide.

3. Background

The history of climate change, our growing awareness and slow acceptance of it, have been confusing. Although climate change was first formally recognized as an environmental problem by President

Johnson in 1965, it took decades of research beforehand and decades of additional research and awareness efforts after for any substantive policy action to be taken. The first climate summit was held in Rio de Janeiro in 1992. It was the first large-scale acknowledgement of the need to come together on a global level and discuss the issue with all the necessary players; however, a decade and a half later, the Copenhagen Summit of 2009 failed to come to any solutions of adequate consequence (Schmidt 2008). The unrelenting march of time, CO_2 and increased usage of resources makes the challenge all the more ominous. When pondering climate change and considering the impact on water supplies, it is important to understand what global warming actually means, where we in California get our water, and where we stand with water today.

3.1 Global Warming

Global warming is the increase in the average temperature of the Earth's near-surface air and oceans. This increase can be attributed to both natural and anthropogenic (caused by humans) additions of green-house gases (GHG's) released into the atmosphere since the introduction of fossil fuels as an energy source with the onslaught of the Industrial Revolution. The phenomenon is more commonly referred to as climate change, as not all regional habitats will see atmospheric temperature rise; in fact, some regions of the planet may see a more generalized cooling as different ocean current and weather systems are altered (United 2006). By the mid-1700's, weather stations housing temperature measurement devices had begun cropping up, first in European countries and now covering about 80% of the Earth. The first quantitative numbers on record originate from central England, in 1659, then Switzerland in 1755, followed by Stockholm, 1756. Today, we have thousands of meteorological stations contributing data to the overall mean global surface temperature year after year (Schmidt 2008). Weather stations across the Earth are seen in Figure 3, with the largest aggregations in Europe and North America, the most sparse in Africa and across the oceans. The vast array of locations constantly measuring our planet's temperature helps ensure an increasingly reliable estimate of changes in mean global temperature.

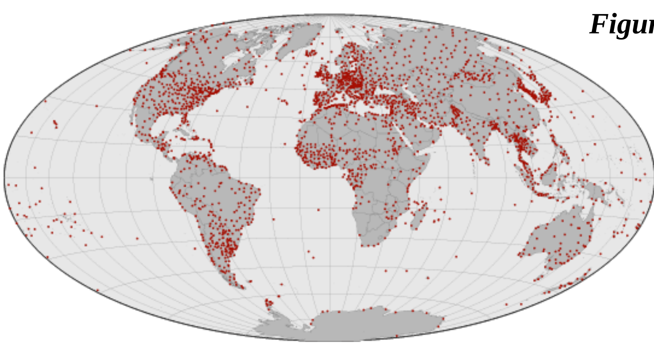


Figure 3. Weather stations across the Earth. From Earth 2007

When assessing climatic temperature variations, temperature changes across time intervals provide the most relevant story. Today, we see that our global average temperature reads just a bit higher than a few decades ago. When compared to base temperatures in Stockholm between 1951 and 1980, we see that a global increase of about 4° F has occurred during the last two decades. On a global scale, an average warming of 1.4° F has ensued over the last century (Schmidt 2008). The trend-line leaves little doubt that this is the warmest climate we've seen since the inception of our temperature records, and much of it can be attributed to a process called the Green House Effect.

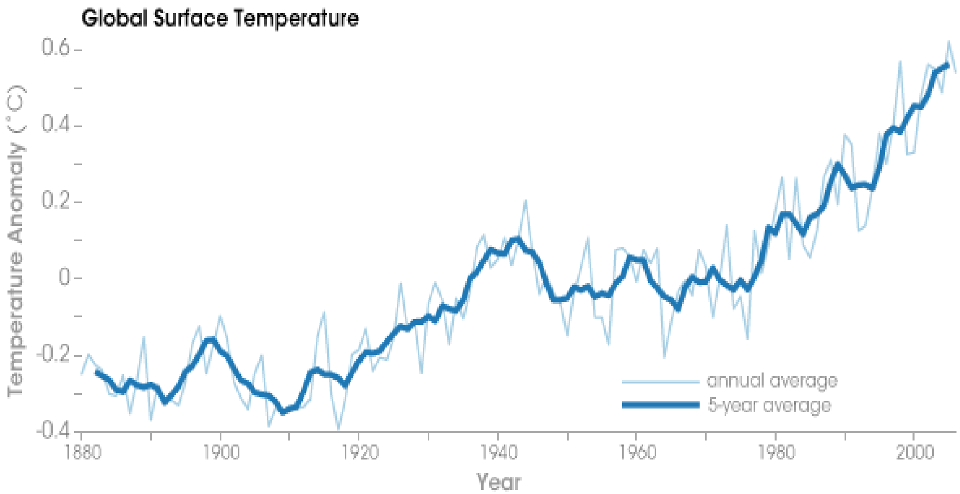


Figure 4. Since the 1800's, our planet has seen a substantial increase in average global surface temperature. From Earth 2007.

The Green House Effect, first described by Joseph Fourier in 1824 and factually reported by Svante Arrhenius in 1896, is responsible for the incubation of our planet and is thus a process we rely upon to sustain a habitable temperature for life. Energy from the sun, (a significant portion transmitted in the form of visible light in the range of 0.2-4 micro-meters), enters the Earth's atmosphere and is absorbed by the surface of the planet. It is then re-radiated in the form of thermal heat back into the atmosphere and dispersed back into space. That radiation which is not lost is absorbed by gas molecules in the stratosphere such as ozone or reflected back down towards the Earth by particulate and molecular (water, CO_2, methane, etc.) material. These are called "greenhouse gases" (GHG's). Consequentially, the emanated energy is locked into our atmosphere as warming energy (United 2006).

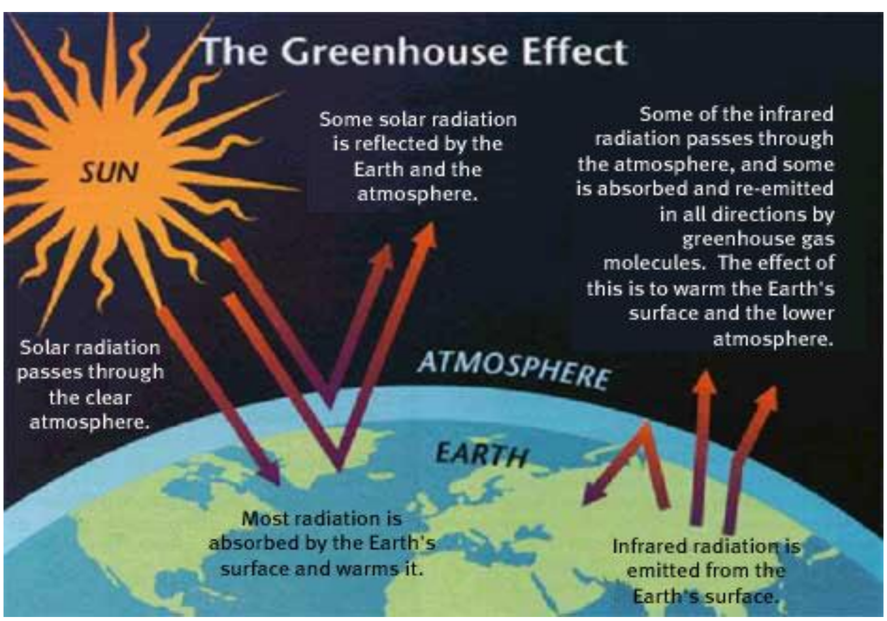


Figure 5. Simplified schematic of how the Green House Effect functions. From BigSky 2010

Although CO_2 is the most commonly mentioned GHG, there are a handful of other chemicals found in our upper atmosphere that have the same effect, some many times more potent than CO_2 (just not as prevalent). A list of the three most common and potent green house gases can be seen in Figure 6. Once emitted into the atmosphere, these heat-trapping chemicals can remain for many years. Some stick around for merely decades, others for centuries. CO_2, for example, will not disperse out of our immediate atmospheric sphere for about 100 years after initial emission. This makes global warming particularly difficult to research as future projections must take into account the varying timelines of chemicals under scrutiny.

Figure 6. Three most common and potent green house gases.

From IPCC 2007

MAIN GREENHOUSE GASES

Greenhouse Gas	Chemical Formula	Pre-Industrial Concentration	Concentration in 2005	Atmospheric Life (years)	Anthropogenic Sources	Global Warming Potential (GWP)
Carbon-dioxide	$C0_2$	280 ppm	379 ppm	Variable	Fossil Fuel Combustion Land Use Conversion Cement Production	1
Methane	CH_4	700 ppb	1774 ppb	12	Fossil Fuel Rice Paddies Landfill Waste Livestock	21
Nitrous oxide	N_20	275 ppb	319 ppb	114	Fertilisers Combustion Industrial Processes	310

Ewings, 2007

Anthropogenic CO_2 is generated mostly by the combustion of fossil fuels and by clearing land for agriculture. Methane is produced during fossil fuel extraction, the raising of livestock, growing rice, burning biomass, and the breakdown of organic matter in landfills and sewage. Third, nitrous oxide is produced by land clearing, fertilizer use and industrial processes, and F-gases (not shown above but ranked as the fourth most common GHG) by leakage from refrigerators, aerosols, air conditioners, aluminum production and the semiconductor industry, electrical insulation, and magnesium smelting (McKeown 2009). In other words, it takes the burning of fossil fuels to power most of our every-day activities, adding GHG's to a stratosphere already a third more CO_2 rich than it was in pre-industrial times.

With that increase comes a rise in temperature. Based on the Keeling Curve of Atmospheric Carbon Dioxide[1] seen below in Figure 7, current projections of warming are in the range of 4-6° C (7.2-10.8°F) for the 21st century, bringing with it devastating consequences. California will need to be ready to face a great number of them and prepare for the roots of our most intricate systems to be shaken (Wilkinson 2002).

[1] This famous image was produced using the findings of Charles David Keeling who started measuring atmospheric CO_2 levels in 1958 at the Mauna Loa Observatory on the big island of Hawaii. Data is still collected under the direction of Charles's son Ralph Keeling. Illustrates the climb of CO_2, which has risen from pre-Industrial times of between 275-285 ppm (parts per million) to today's concentration of between 380-390 ppm. The uniform annual variability in $C0_2$ concentration conforms with the seasonal biological pump of plants as they uptake carbon dioxide in the spring and summer months during their growing season, lowering atmospheric CO_2. During the fall and winter, the world's vegetation dies off and decays, re-releasing the CO_2 back into the atmosphere resulting in a noticeable peak in global concentration. From Climate Central 2010.

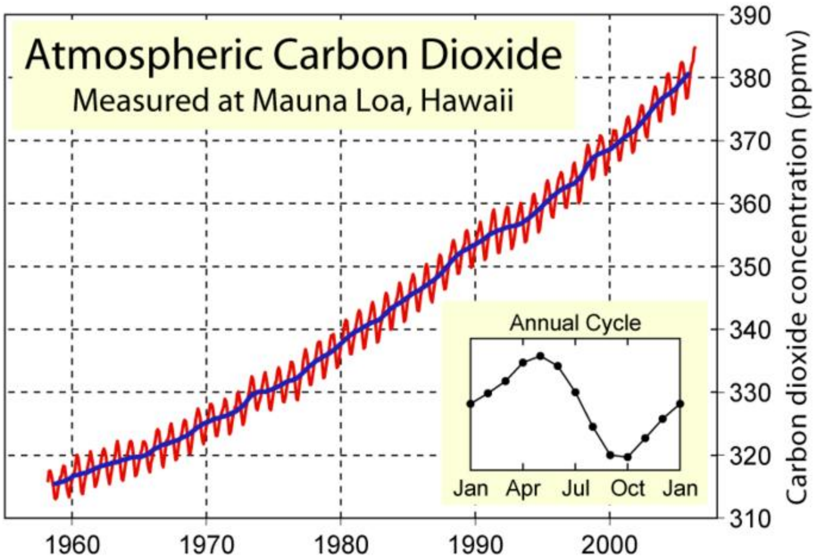


Figure 7. The Keeling Curve From Climate Central 2010

In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) was formed, with a general goal of ***"…considering what could be done to reduce global warming and to cope with whatever temperature increases are inevitable."*** On February 16, 1995, the Kyoto Protocol was implemented, an international and legally binding agreement to reduce greenhouse gas emissions worldwide and reach the same CO_2 ppm levels that pre-dated 1990 by the year 2012 (United 2009). However, it was not until the Thirteenth Conference of the Parties held in Bali of December 2007 that the agreement was ratified by parties. Actions of the UNFCCC have proved slow and overall inadequate to the intensive strategies that must be implemented in order to hold off catastrophic warming effects (Pachauri 2009).

Currently, one of the largest congregating bodies of scientific knowledge on the subject comes from the findings of the Intergovernmental Panel on Climate Change (IPCC), which was formed in 1988 by the United Nations. Their function: to evaluate the risks of human induced climate change. The IPCC has come out with four large-scale assessment reports thus far, (1990, 1995, 2001, 2007), and each is checked and backed by the National Academy of Sciences from multiple countries. Their findings are the general scientific consensus. Their latest report, complete with four volumes covering not only the science behind climate change but also ways that humans can adapt to and mitigate impending temperature changes, took 6 years to produce. Their resounding statement: climate change is in fact occurring, and it will bring with it catastrophic and unforeseen consequences unless we take action now (Intergovernmental 2011).

3.2 Historical Background of Water in California: Where Does Our Water Come From?

The historical background of water supply in the United States has changed drastically over the last couple of centuries, most notably with the increase in state water projects after the Great Depression in the 1930's.

Figure 8. Central Valley Project, a Bureau of Reclamation project devised in 1933 to provide water to the central valley of California From Trager 2010

3.2.1 The State Water Project and the Central Valley Project

Currently, California relies largely upon two water projects, the State Water Project (SWP) and the federal Central Valley Project (CVP). Both take water primarily from northern California tributaries and redistribute it throughout the state; the CVP provides a lot of the farming lands in the middle part of the state with water (up to 6 million acre-feet per year). These complex water storage and delivery systems are controlled, operated and maintained by two governmental bodies, the California Department of Water Resources (DWR) on the state level, and U.S. Bureau of Reclamation on the federal level (Department 2011).

Until 1848, California was still a relatively uninhabited region. With the onset of the Gold Rush in 1849, Californians were forced to begin thinking about the water supply, since watershed until that period were still running their natural courses and were generally adequate to meet the needs of the Native peoples inhabiting the region. As English settlers began making their way across the Eastern states in search of resources and promised riches, substantial settlements were built, initially consisting mostly of missions and ranches owned by the pioneers. The migration intensified over time as thousands of people moved west. California's water resources began to be used and altered in a number of different ways that set up the infrastructure we see today. Because gold was the initial migration lure, water was first used to sluice out the yellow metal from local river systems using waterway set-ups such as flumes. Over time, as the precious metal became harder to find, and population continued to boom, many California settlers turned to farming and other agricultural endeavors, furthering the need for water. Crop irrigation was accomplished using the state's well-endowed aquifers. In 1873, President Ulysses S. Grant ordered the first investigation of California's water resources commissioned by Colonel B. S. Alexander of the U.S. Army Corps of Engineers. His loudest proclamation: development of the Sierra Nevada watershed would be key to the success of California's agricultural and popular growth. Over the next decade, numerous more surveys were conducted, all with the conclusion that development of California's most predominant watersheds was inevitable and necessary. What followed was the birth of the California State Water Project and the Central Valley Project. Construction began on the CVP in 1935, the SWP in the 1950's. For the first time, water was effectively moved from the water-rich lands of the north toward the south where cities were becoming more robust and thirsty (Department 2011).

Figure 9. Proposed routes of the California State Water Project. From Department 2011

California's second Gold Rush took place at the end of World War II, as San Francisco and Los Angeles began to grow at a rate that outpaced local water supplies. Groundwater basins and aquifers began to run low as larger populations required more water for domestic and agricultural support needs. This led to one of the state's largest water surveys to date, conducted by the Division of Water Resources under the Department of Public Works in 1945. From the information gathered, enough was gleaned to propose the state's first water project. Projections took into account waters and land from the northern top of the state down into southern California (Department 2011).

Over the next few years, supplementary surveys were completed that culminated in several revised plans encompassing the Feather River, San Luis Reservoir and a South Bay and North Bay Aqueduct to serve San Benito County. However, feuding parties from the north and south started to highlight the potential complications that would arise when moving water from one region to another. The Metropolitan Water District of Southern California said it needed water from the diluted north to plan for any sort of sustainable water future in its developing urban areas along with sourcing water from the Colorado River. However, its northern counterparts wanted assurance that their waterways and needs would be protected in the future as well. In 1960, the Burns-Porter Act (California Water Resources Development Bond Act), also know as Proposition One, was on the election ballot as a result of special committees that had synthesized information to deduce the areas of compromise on the subject and had come to some sort of functional agreement. The Act barely passed on November 8th (Department 2011).

Today, much of the water moved around in the SWP and the CVP is allocated towards agricultural irrigation and sufficiently saturating the center of our state. Upwards of 20 million Californians rely upon the two for their water supply, as well as 3.6 million acres of farmland. The SWP/CVP produces 10 million acre-feet of water per year (Department 2005).

3.2.2 The Colorado River Basin

Although a significant amount of water is provided by the SWP/CVP to southern regions where the population is considerably more dense, the arid expanses of southern California depend on a substantial quantity of water from the Colorado River (CR) Basin (around 60%). The Basin is estimated to cover an area of more than 244,000 square miles, or about 8% of the land in the United States. 2,000 square miles resides in Mexico (Department 2006). Roughly seven states utilize this huge freshwater source: the "Upper Basin" states, comprised of Wyoming, Colorado, Utah and New Mexico; and the "Lower Basin" states, California, Nevada and Arizona. The dividing point is at Lees Ferry gauging station in Arizona, directly downstream of Lake Powell. These states collectively, along with the river's eighth user, Mexico, are allowed roughly 7.5 million acre-feet (abbreviated 'mac') of water per year. This allocationis per a series of treaties, agreements, laws and court decisions commonly referred to as the "Law of the River." Historically, California alone has received the highest percent of the 7.5 mac, receiving 4.4 mac per year (Legislative 1997). Arizona was allotted 2.8 mac and Nevada 0.3 mac (Department 2006). The state of California has used up to 5.3 mac in the past, made possible due to unused water from Nevada's and Arizona's entitlements. However, as populations bloom in these other lower basin states, California water planners will have to learn to stay within their own entitlement going forward (Legislative 1997).

The Colorado River Basin has been carefully diverted into a network of spider-webbing transfer systems. Two of the most well-known of these diversions are the All-American and Coachella Canals and the Colorado River Aqueduct. The first brings water to the people and crops of the Imperial Valley, primarily agriculture in the Coachella Valley; the latter feeds the population-dense cities on the south coast. Many of the Western United States' and Baja California's largest aggregations of people rely on this water, including Denver, Salt Lake City, Las Vegas, Phoenix, Tucson, Los Angeles and San Diego (Department 2006).

Figure 10. California path of the diverted Colorado River, a major water resource for southern California.
From Metropolitan 2009

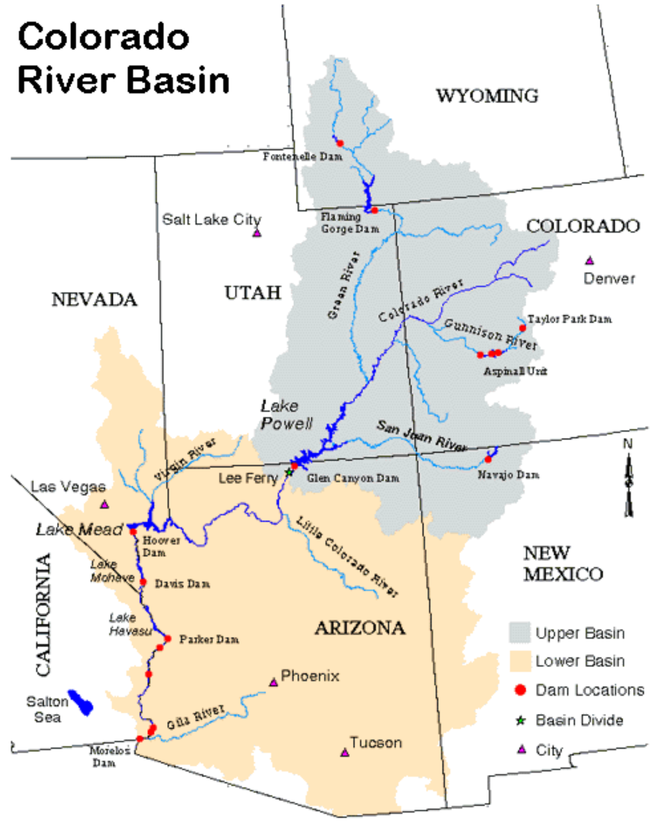


Figure 11. Map of the seven constituent states of the Law of the River agreement that utilize the Colorado River as part of their annual water supply. *From Colorado 2009*

3.3 California's Current Water Crisis

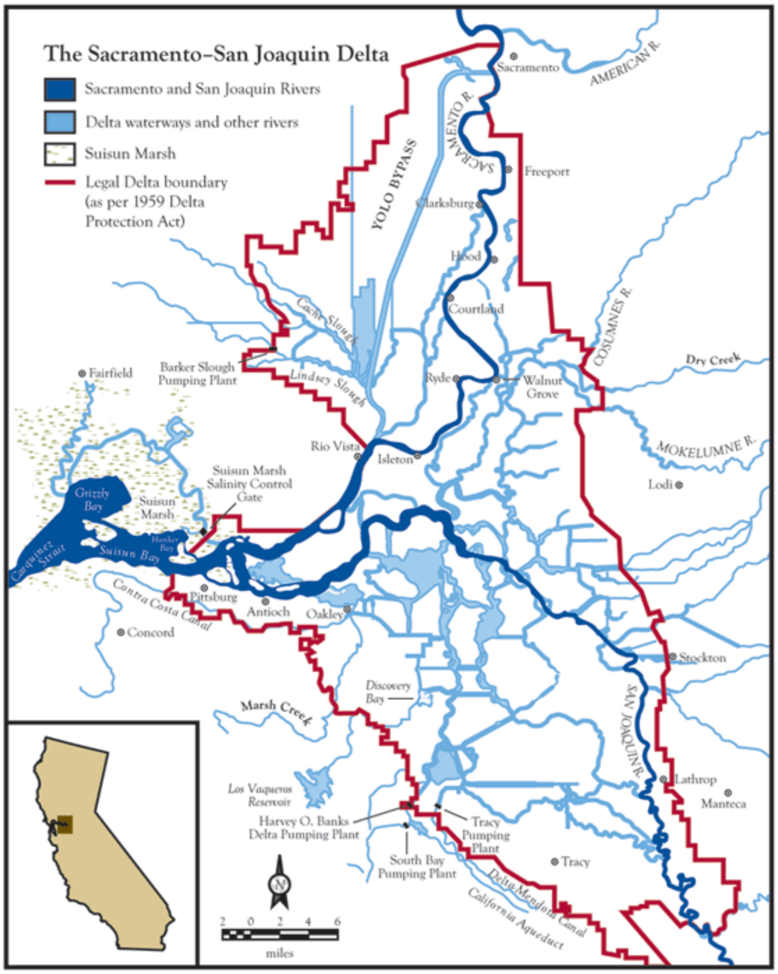
The Association of California's Water Agencies (ACWA), consisting of 450 public water groups statewide, is a coalition of the state's most prominent and informed professionals. Over the last few years, they have put their focus on researching and educating our public and decision makers on the reality we face today: California is on the cusp of a huge water crisis.

A poorly set-up infrastructure accompanied by a changing environment and population explosions put stress on our water supply and demand, which has now brought us to the brink of real calamity. The ACWA has determined the following 6 factors to be the largest contributors:

> (1.) a deteriorating Sacramento- San Joaquin Delta, (2.) water supply cut-backs, (3.) aging infrastructure, (4.) record drought, (5.) climate change, and (6.) conservation constraints.

The first four components are discussed below. Each poses an array of problems, and many of them intricately tie back into the 5th and 6th factors, climate change and conservation constraints. Climate change will be discussed in detail in section 5 (California 2009).

3.3.1 The Sacramento-San Joaquin River Delta



The Sacramento River flows southward and is California's largest naturally flowing water system.

Figure 12. Image of the Sacramento-San Joaquin Rive Delta, the hub of California's local water supply for two-thirds of the state's water. From Latham 2008

Alongside the northward flowing San Joaquin River, our state's second largest river, the Sacramento River provides water to approximately 25 million Californians and 2.5 million acres of farmland via the mutual river delta at the confluence of the two systems. The Sacramento-San Joaquin River Delta (SSJR), seen in Figure 12, is a naturally occurring estuary of 740,000 acres, which includes some 60 reclaimed islands.

The Delta formally forms the eastern portion of the San Francisco Estuary, including the Suisun, San Pablo and San Francisco Bays and stretches from the Coastal Ranges to the Sierra Nevada's (Lund 2007). It consists of thousands of miles of systems held in place and restrained by agricultural levees, channels and sloughs set up decades ago. Today, most are below sea level, which makes them particularly vulnerable as deterioration from storms and aging set in (California 2009).

Levees service the delta as a protector from floods and daily high tides which continually threaten this delicately organized habitat. Unlike the majority of natural deltas which are formed when sediment is deposited from upstream systems, the SSRJ formed because it is a low-lying region where deposited sediment from multiple watersheds was allowed access to substantial amounts of detritus, or organic material, from the multitudes of preexisting marsh plants such as tule (*Schoenoplectus acutus)*. The accumulation of what eventually becomes peat as a result of sedimentation processes occurring over 6,000 years, augmented by tidal processes, produced this unique California delta (Lund 2009). Nearly 750 species rely on the Delta's unique environment as it provides a multitude of distinguished niches that would otherwise be absent in the landscapes of California. In addition, levees serve as a barrier between the salt water of the San Francisco Bay and the fresh water of the out-flowing rivers. Three major state highways, natural gas and electric transmission facilities, a railroad, and 400,000 residents also depend on the levees to maintain the integrity of the Delta as they are in extremely close geographic proximity. It has been estimated that an earthquake of magnitude 6.5 or greater, projected as 75% likely in the next 30 years, would be enough to cause major levee failures resulting in catastrophic statewide water shortages and would prove exceedingly difficult to repair. These failures can be projected to result in substantial flooding/inundation of the local farmlands and fresh water retaining systems that are responsible for providing a large percentage of California's potable and non-potable water (California 2009).

3.3.2 Water Supply Cut-backs

Another prominent player in California's current water supply crisis is the legislation protecting vulnerable species in the Sacramento-San Joaquin Delta, resulting in cut-backs in water availability. Specifically, the Delta Smelt, a fish native to the area, is currently listed as threatened on both the state and federal endangered species lists. Historically, this native fish species has been one of the most prevalent creatures in the unique habitat of the Delta, not placed on endangered lists until 1993 when it was designated as such under the Endangered Species Act. Smelt are a relatively small breed, typically about 2-3 inches in length at maturity with a one year lifespan. Requiring a very narrow salinity range and limited diet, they are considered to be particularly environmentally sensitive and, therefore, reside in the ESA's "critical habitat" designation 1994 (Duke 2010).

Figure 13. The Delta smelt, currently the largest source of controversy regarding SWP/CVP water supply cut-backs. From Duke 2010

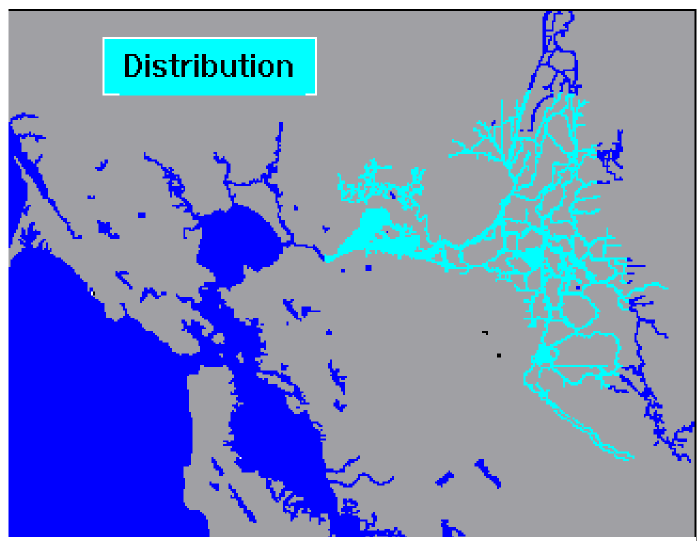


Figure 14. Current smelt distribution in the Sacramento-San Joaquin Delta. From Duke 2010

Over the last 3 years, both voluntary and court mandated cut-backs in pumping regulations have been employed as a response to pressure from environmental groups such as the Natural Resources Defense Council (NRDC) to protect the smelt. This has reduced the amount of water legally allowed to be intermittently gleaned from the Delta. Although the court ruling made on December 14th, 2007 by the US federal District Court Judge under the Endangered Species Act (ESA) is still being analyzed in full, projections assume that water supply from the State Water Project (SWP) and Central Valley Water Project (CVP) could be reduced by as much as 2 million acre-feet annually, or one-third of that currently used. This affects communities in every corner of the state since the SWP/CVP provides water to 25 million residents and accounts for 67% of the state's water supply (California 2009).

3.3.3 Aging Infrastructure

National Geographic estimated that our world population will reach 7 billion people by the end of 2011. California alone is projected to see significant population bursts throughout the next few decades, with projections increasing from around 37 million in 2009 as per the U.S. Census Bureau to upwards of 60 million by 2060. Systems that were constructed years ago when less stress was put on our environment and its precious resources are becoming out-dated and over-extended. A clear example: again the Sacramento-San Joaquin River Delta. California's water usage has directly mirrored its inhabitants. Our levels of water diversion have gone up in direct correlation with the number of people we have housed. The State of California can be commended on some levels for the noticeable increase in conservation efforts over the last few years in regards to water management policy. However, very little effort has been put forth towards infrastructure improvement, which is (arguably) illustrated in the S-SJRD. As more and more people require larger volumes of water to move faster and farther throughout the state, increasing stress is imparted upon an already delicate system on the cusp of failure. The Delta is currently displaying serious signs of deterioration in both its man-made structures as well as the natural ecosystems that depend greatly upon it to endure (California 2009).

This puts California in an extremely vulnerable position as much of our water supply would be cut off should anything significant (i.e. large storm surge) happen to the Delta with its heavy dependence intricate levee and slough systems. The majority of other diverted water systems throughout California, including the All-American Canal and Hetch-Hetchy, are decades old as well, making them out-dated and potentially unreliable (California 2009).

Figure 15. Image taken on June 3rd, 2004, of the Upper Jones Tract levee break. From Romick 2009

From a biological standpoint, the large decline in numerous fish species is a telling sign that the health of the Delta's ecological systems is failing. In addition, decline of native species is paving the way for a large increase of disruptive non-native species which only furthers the ecological imbalances (Lund 2009).

3.3.4 Increased Drought Years

Climate change is becoming a more prominent player for water planners strategize each year as precipitation cycles are altered, snowpack is lessoned, and droughts are more common and prolonged.

Because variation is natural and expected, and certain levels were considered when our water infrastructure was first put in place. However, as infrastructure becomes more antiquated, our precipitation cycles have become less predictable and dehydration of local freshwater systems more prevalent, and thus the gap widens and our capability to respond adequately to drought years lessons.

4. Large-Scale Implications

"If climate is the sum of our expectations, climate change is an alteration in those expectations. However, climate change is not limited to alterations in the global mean temperature or rainfall. For example, global warming describes the ongoing rise in mean surface temperatures across the planet, but global climate change encompasses not only global warming but also the occurrence of drought and the shifts in ocean currents or atmospheric winds. Although climate change cannot be seen in any one particular storm, heat wave, or cold snap, it is found within the changing frequency of such events." - Gavin Schmidt and Joshua Wolfe, authors of Climate Change: Picturing the Science.

As author's Schmidt and Wolfe clearly state, climate change is a science that encompasses all of the different environmental systems. Researchers have found that almost every natural system in place is linked with innumerable others. When one is altered, it can impact other conditions on a much grander scale than might initially be expected.

4.1 Tipping Points

The large-scale implications of climate change are many, but not the focus of this article. However it is important to note that because some of the looming consequences depend on whether certain tipping points are met or not, California will experience a very different future depending on how much we curb our global emissions in the next few years. Many of our organic systems have threshold responses, where amplification will compound beyond norms once a specific threshold is met. One small change, or driver, could lead to a disproportionately large response, meaning these systems could tip precipitously. After bypassing the tipping point it can become exponentially more difficult to turn back. This also means that changes might not be seen until they become dramatic almost instantaneously.

4.1.1 The Amazon Basin

The Amazon Basin is an abundant region with countless different natural systems in place. A certain amount of global warming can be tolerated without much response, but once temperatures reach a certain point and start to really affect one major system, a multiple-system failure response will be seen: less rainfall, resulting in a loss of species diversity, which will disturb the food chain and unravel the natural air filtration, atmospheric circulation and water purification systems via dispersion, extinction or displacement of certain foliage species. The unintended consequences would be many. Researchers say the Amazon Basin could shrink by as much as 50% in the next century should we exceed its tipping point (National 2010).

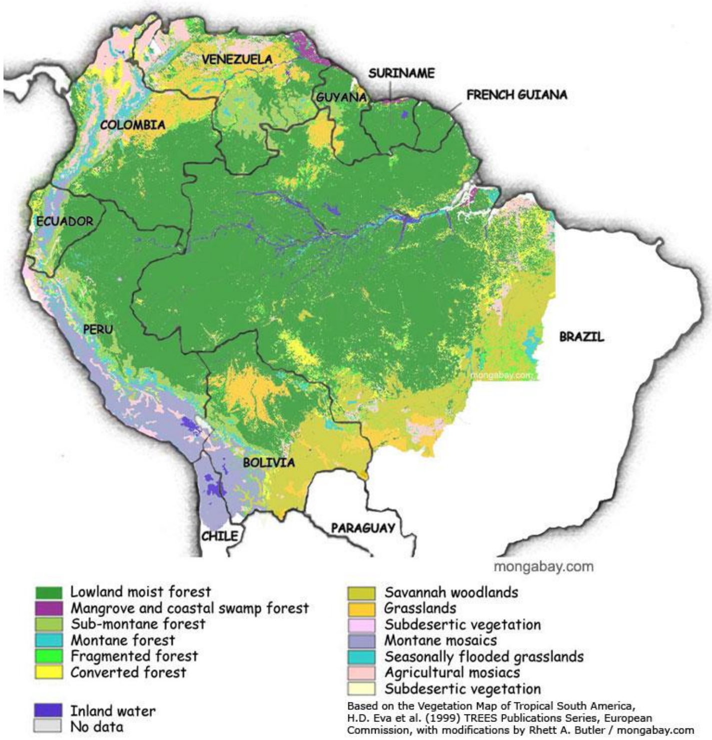


Figure 16. The Amazon Basin, located in Brazil and its neighboring countries in South America. The Amazon Basin is amazingly rich with biodiversity, a hot spot for burgeoning ecosystems. However, the linkage between its natural systems is extremely strong, and the risk of multiple systems failure is large in regards to climate change. From Butler 2010

4.1.2 The Atlantic "Conveyer Belt"

Another example: the Atlantic "Conveyer Belt," or ocean current circulation cycle; also known as thermohaline circulation. The oceans play a critical role in atmospheric behavior and temperatures as they are a vast sink for carbon dioxide and heat. Water has an extremely high heat capacity and absorbs much of the Sun's energy; more heat is held in the top 3 meters (9.8 feet) of the ocean than in our planet's atmosphere. Heat is transferred from the equatorial regions of the Earth, where the largest amount of visible light hits the planet, to the cooler poles via water and atmospheric circulation currents (wind streams). Currently, the Atlantic meridional overturning circulation moves warm water upwards in a northern direction and circulates cooler water south. Salty, warm water from the southern Atlantic Ocean gravitates up towards the North Pole via surface currents like the Gulf Stream. Moving farther north, heat is lost during this near-surface interface to the air. Cooler water, still heavy with salt, then sinks, allowing surface water to replace it and push it down south again, and so the cycle perpetuates (National 2010).

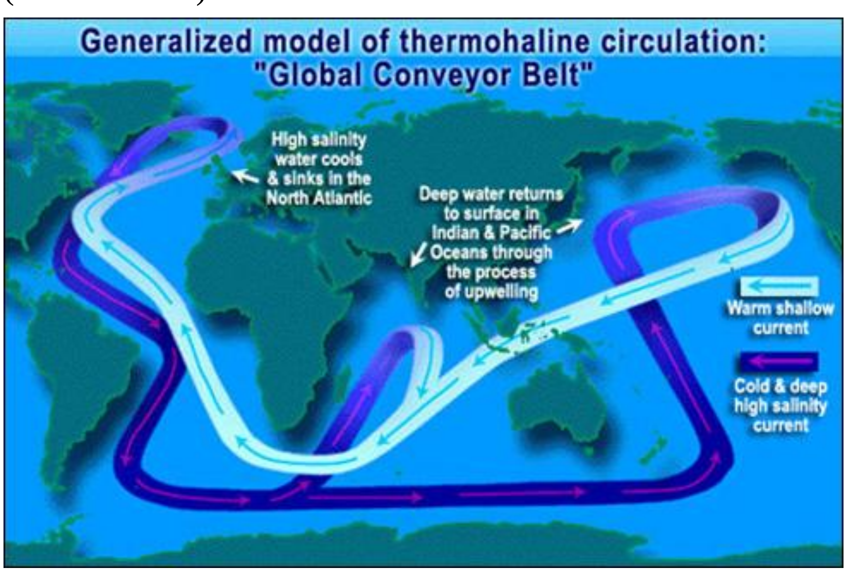


Figure 17. The Thermohaline Circulation "Global Conveyor Belt." From NASA 2010

This general pattern is responsible for the lifecycle of marine species. If global warming continues on its destructive path, glacial and ice cap melt (covered in a latter section) will be releasing multitudes of fresh water into the oceans and potentially disturbing this delicate conveyor belt. The freshwater influx could prevent cold water from moving north if the necessary temperature threshold is met, which would upset the entire system and result in massive changes in everything from ocean salinity to species dispersal and extinction to amplified wave/storm interactions (National 2010).

Alongside these two tipping points, experts agree on three other major systems at risk of reaching their threshold in the coming century, (followed by countless others on varying lesser but substantial scales): melting of the Greenland ice sheet, melting of the Western Antarctic ice sheet, and increased periods of El Nino events (National 2010).

5. Local Implications: Climate Change Impacts on California's Water Supply

California in particular is a high-risk state, and we have much to protect. Biologists consider California to be a special place: it is considered a biodiversity hotspot. The California floristic province is one of the 10 most diverse regions in the world according to Conservation International (www.conservation.org). It has over 2000 endemic plant species, or species that cannot be found anywhere else in nature. San Diego County alone houses over 1500 plant species. There are a lot more species than just humans who depend on a predictable water supply.

Residents in all parts of California will inevitably deal with water shortages in the coming years. Because the majority of our precipitation falls in the northern half of the state in the winter but the largest demand comes from southern California between the months of March thru September, our intricate system of water storage and transmission depends almost entirely on the natural storage system of the Sierra Nevada snowpack, which is expected to greatly diminish in the coming years (Luers 2006). In fact, our water situation is so complicated due to this setup that an estimated 19% of our state's entire energy usage goes towards collection, transportation and treatment of our water (San Diego 2011). As stated by the Department of Water Resources in their report published in June 2007 titled, "Climate Change in California," ***"…Adapting California's water management systems to climate change presents one of the most significant challenges for the 21st century..."*** (Kiparsky 2003).

And our state's water supply will not be the only system to feel the effects of the heat. The health of our people could be in jeopardy as air quality lessons, the frequency and intensity of heat waves climbs, and the range of infectious diseases expands. Ecosystems across the globe will suffer as changes happen at a pace that will prove difficult to adapt. Non-native plant and animal species may find it easy to inhabit areas that at one time had strong, natural defenses. Rising temperatures will force species to migrate towards the cooler poles of the Earth, throwing off food webs and ecosystems in ways we cannot fully understand. While the mean temperature will increase, it will be the increased number of extreme climatic and waether events that will pose the largest threats to the health of our communities. If temperatures reach the highest emissions scenario predictions by the end of the century, southern Californians could experience 100 more days per year of temperatures above 90° F, 95° F in Sacramento. In return we will see a shocking increase in deaths from dehydration, respiratory disease, heat stroke and exhaustion from extreme heat waves (Kiparsky 2003).

Although researches cannot draw concrete conclusions as to exactly how each will be affected, all climate change scenarios agree that each of the areas shown below in Figure 18 will be greatly affected (Kiparsky 2003).

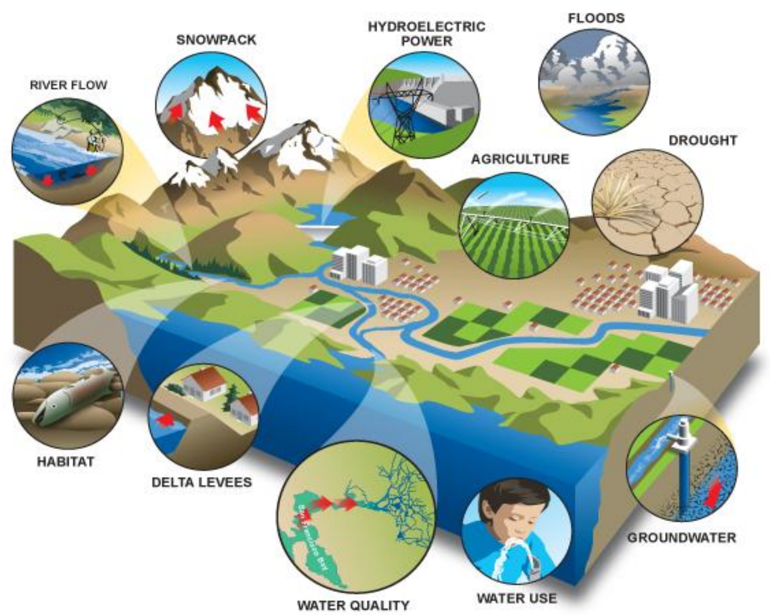


Figure 18. Illustration of the different ways our water use in California will be adversely affected by climate change. From Department 2007

5.1 Future Scenario Modeling Considerations

In order to make future projections, General Circulation Models (GCM) were used that compared different levels of greenhouse gas (GHG) concentrations to produce varying scenarios. The most modest scenarios used the lowest levels of GHG's, both naturally and anthropogenically emitted, that we will accumulate in future marked dates, and the worst scenarios using the highest levels of GHG's. All take into account the expected population growth and correlating increased energy and water usage (Kiparsky 2003). The California Climate Change Center uses three scenarios, seen below in Figure 19, all which have a common 2- 3° F temperature increase over the next few decades, and estimates begin to diverge around mid-century. The lower warming range scenario projects temperature rises between 3-5.5° F, the middle range between 4.5-8.2°F, and the highest a remarkable 6-10.5° F temperature increase by 2100 (Luers 2006).

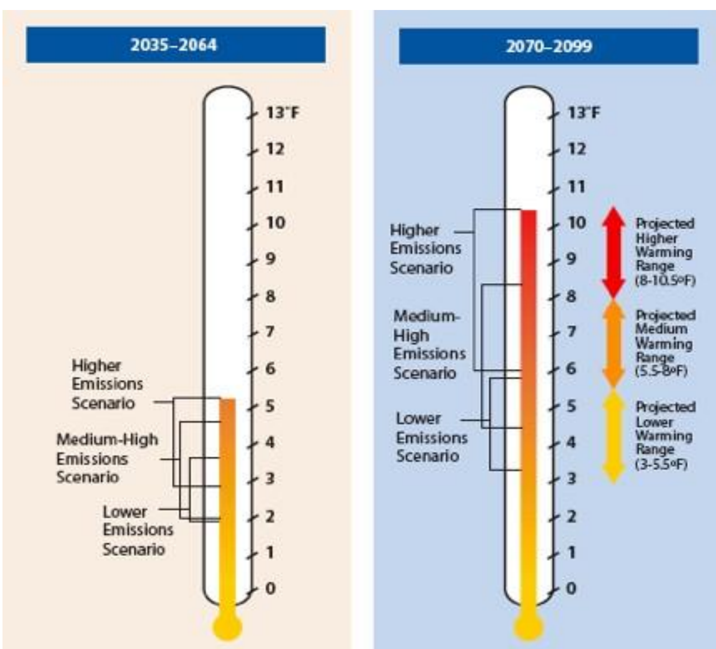


Figure 19. As per the California Climate Change Center, the three temperature increase scenarios as played out by 2064 (left) and 2099 (right). From Luers 2006

Because most scenarios produced by research groups are for large-scale purposes, California's data sets for our hydrological parameters such as precipitation, groundwater resources and local evaporation have been plugged in to finer tune the scope of the scenarios in order to allow water resource planning to take place on a local level. Again, temperature increase is of particular importance to California because of the effects it will have on snowpack and precipitation cycles as much of our annual water supply is held as snow in the Sierra Nevada's and other in-state high-altitude ranges. Precipitation alterations have been considered in accordance with the other two variables, mean global temperature and greenhouse gas concentrations. The latter also took into consideration the different life-spans harmful GHG chemicals have before deterioration or dispersal in the atmosphere after emission. The least understood and most debated, changes in the precipitation cycle will depend on precipitation patterns, timing, and intensity in the area of concern (Kiparsky 2003).

5.2 Precipitation, Transpiration and Evaporation: Changes in the Hydrological Cycle

When atmospheric temperatures increase, the cycle of precipitation and evaporation accelerates.

5.2.1 Precipitation

The maintenance of global fresh-water supply is sustained via the hydrologic cycle, a series of inflows, outflows and storage, as warm air above oceans cause water to evaporate into the atmosphere. It is then carried as water vapor to land where it condenses and falls as rain, eventually returning as run-off to the oceans or evaporated from terrestrial dwellings. When the mean atmospheric temperature goes up, the vapor-pressure difference between the ocean surfaces and adjacent atmosphere enhances which in turn causes even more water to evaporate and so the cycle perpetuates. In biology this is referred to as a positive feed-back loop, one that self-perpetuates. A projected temperature increase of 4° C (7.2° F) would result in a 10% increase in the hydrological cycle. Evidence suggests this increase would be seen in heavier rainfalls as opposed to more frequent downpours or the same number as seen currently but for longer durations. This will have large implications which will be discussed in subsequent sections (Geerts 2011).

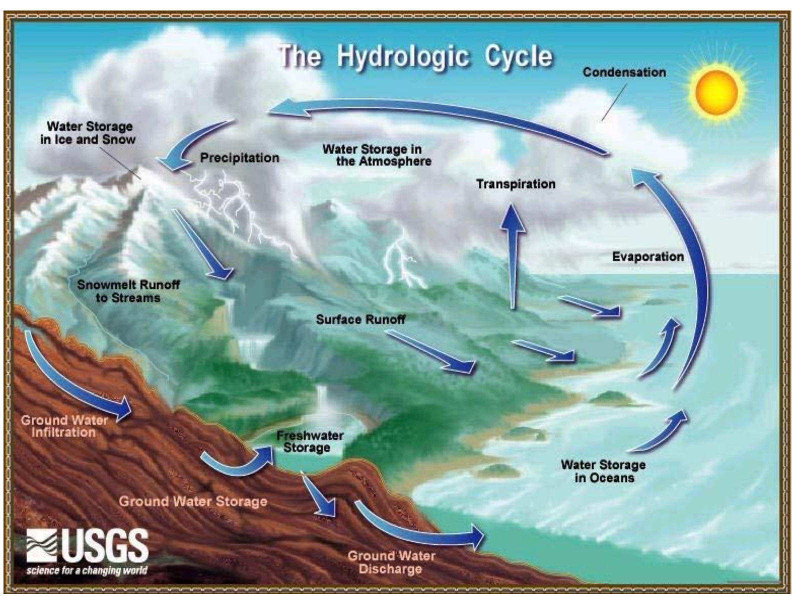


Figure 20. Illustration of the hydrologic cycle. From Solcomhouse 2011

5.2.2 Evaporation and Transpiration

While the potential for evaporation increases with rising temperatures, actual water availability is constrained by the amount of precipitation in the soils, on land, and on vegetation surfaces in any specific area. Vegetation plays a large role in the variability of humidity and precipitation cycles as they intercept H_20 and transpire it back up into the atmosphere, making vegetation cover and plant species important factors to take into consideration. Transpiration, or the loss of water vapor from plants, is a necessary component tied into the photosynthetic cycle via surface openings or stomata, found under the leaves of plants which connect to vascular plant tissues. This enables the diffusion of carbon dioxide gas from the air. An extremely small percentage of the water taken up by a plant is actually used by the living organism, around 1 %, with most of it being lost back up into the atmosphere during gas exchange (Solcomhouse 2011). The actual rate of transpiration is dependent upon the amount of water particles evaporated from plant surfaces and a number of other variables such as root depth, percentage of carbon dioxide in the air, stomatal behavior and density, and plant cover. The general projection for global evaporation increase would be between 3-15% from a doubling of atmospheric CO_2 concentrations (Kiparsky 2003).

5.2.3 Effect on Floods, Droughts and Wildfires

The changes in precipitation we are expecting to see will exacerbate and increase drought and flood intensities and rates. Dissecting paleo-climatic data using tools such as tree-rings and ice cores has already told us these changes are natural; droughts and floods are a widespread and common occurrence. However both have already increased in frequency to non-natural numbers over the past century. The Sierra Nevada snowpack has decreased by 10% over the last 100 years, or 1.5 million acre-feet of snowpack storage per year. Data shows that areas which rely heavily upon surface water, or rivers, streams, and lakes, could be particularly at risk when in comes to water deficits resulting from droughts. Cities in southern California experienced their lowest recorded annual precipitation two times within the past 10 years. At the same time, flood patterns show that peak annual water-flow in our major rivers has increased over the past 50 years due to increased runoff earlier in the year. In addition, scientists expect greater storm intensities, or larger amounts of water dumping over shorter periods of time. During the last decade, Los Angeles has seen its two wettest and driest years ever recorded. To sum it up, more extreme weather conditions will be occurring (Kiparsky 2003).

Precipitation patterns greatly determine wildfire risk in a given area. Fire is not always a negative phenomenon in nature as it is an important ecological “cleanser”, clearing foliage coverage and germinating seeds from time to time. This provides a couple functions; allowing non-competitive species to flourish for small bouts, as well as clearing out deadly amounts of underbrush so larger forest fires do not occur. However, even at the medium temperature increase ranges, the estimates of wildfires in California could increase by as much as 55% (Luers 2006).

In the grasslands and chaparral ecosystems prevalent in southern California, the increase in precipitation during winter months will cause a substantial spurt in plant growth during the winter months, providing more fuel for fires during periods of drought in the summer. Increases of annual wildfires of up to 30% could be seen as a result. In northern California, higher temperatures will increase flammability of forests and underbrush while drying out soils, resulting in up to 90% more wildfires (Luers 2006).

5.3 Annual Snowpack

One of the most potentially devastating shifts we are expected to see in the next century is a substantial loss in our annual snowpack, largely held in the Sierra Nevada mountain range. Roughly a third of the state’s surface water is stored here in the form of snow. This snowpack provides an annual 15 million acre-feet of water (one acre-foot is enough to satisfy the needs of one to three families per year) which is released at a semi constant rate between April and July as the snow melts away (California 2009). Through a vast network of natural and artificial reservoirs and aquifers, or storage and transmission systems, water is transported throughout the state to meet varying demand. Much of the state's demand for water comes from the lower two-thirds of the state during the spring and summer months. Considered a much drier region, southern California has a substantially denser human population and thus requires a great deal more water. The primary reason this system is possible is the extensive natural water reservoir, the Sierra snowpack (Luers 2006).

The major effects warmer temperatures will have on snowpack will include an increase in the ratio of rain to snow, procrastination in the onset of sustained snow season, accelerated rate of snow melt in the spring, and an overall decrease in the snow season leading to later snowfalls with earlier melts (it is important to note that the first of these listed effects will be nullified should the region be at such high altitudes that the mean winter temperatures are so cold that the ration is not affected). The impact this will have on watersheds, local and downstream ecosystems and underground aquifer supplies will be drastic. When looking at agriculture alone, the average Californian farmer is expected to have access to 25% less water than needed to produce the same current annual crop yield. If left untouched, our current rate of emissions would force a 70-90% decrease in Sierra Nevada snowpack by the end of this century; refer to Figure 23 below for a visual representation. Even in the lowest emission scenarios, projections calculate that a decrease of at least 35-45% in annual snowpack will be inevitable by 2100. This means that adaptive measures will have to be put in place; at this point complete mitigation is no longer an option. Not only will water supply be greatly hampered by this loss, but human recreational activities that take place in the direct geographical regions may all but disappear, both winter and summer. Snow sports may no longer be possible, and even activities that make use of the Tahoe Lake basin during summer months, such as water skiing, will most likely be reduced. Water managers will have to make difficult and calculated decisions, deducing the most compromised water level to maintain in reservoirs. They do not overfill reservoirs and then have little capacity to account for possible winter flooding, however they want to sustain levels high enough to provide freshwater year round to all water users (Union 2010).

We are already feeling the effects of a diminished water supply. Water shortages were statewide last year, with the majority of our reservoirs far below their average capacity when compared with an average of previous years.

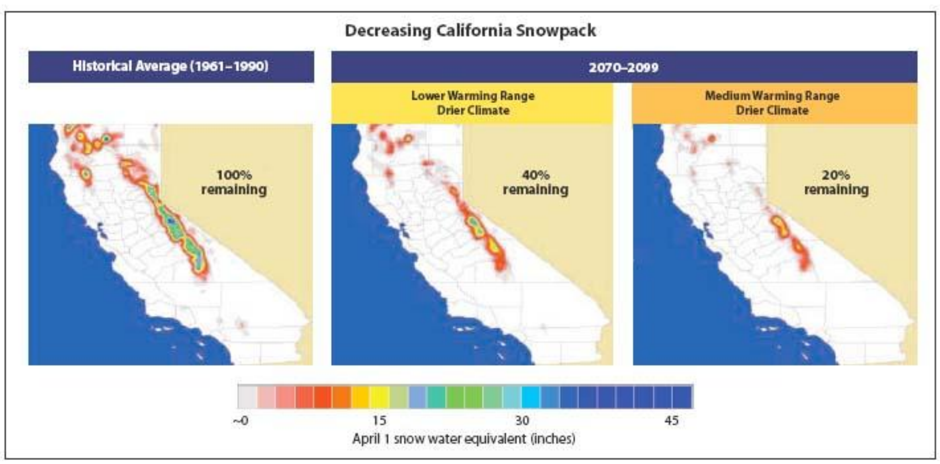


Figure 21. Schematic of annual average snowpack in California over the next century. From Luers 2006

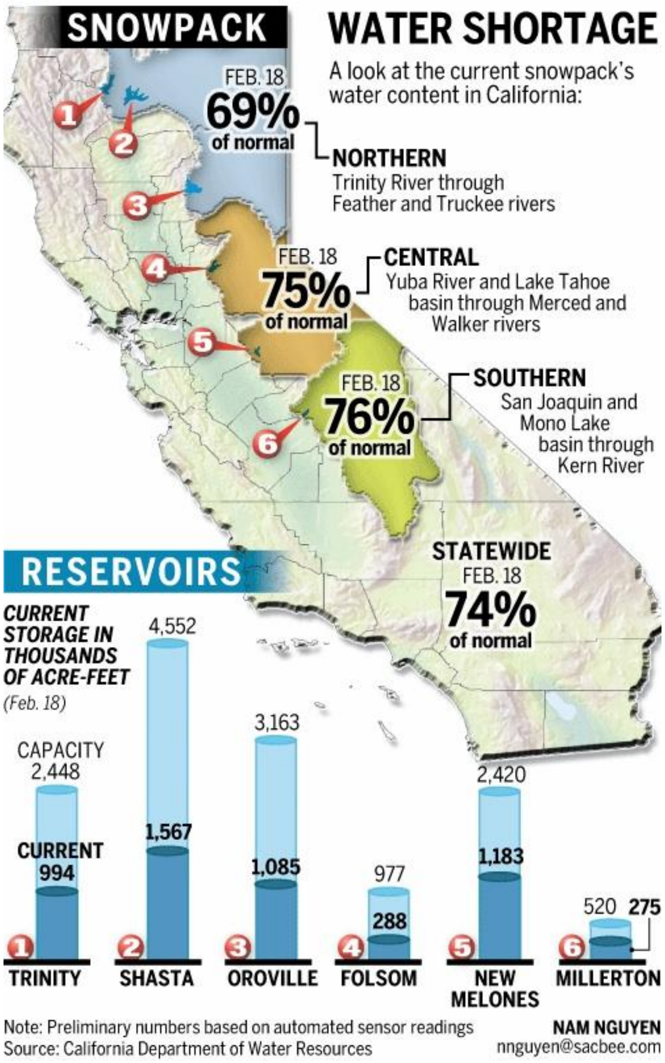


Figure 22. Diagram of California's most prominent reservoirs, showing their decreased levels as a result of diminished snowpack and drought years. Data according to levels on February 18th, 2009. From Sacramento 2009

5.4 Impending Sea Level Rise

The International Panel on Climate Change forecasts a rise of approximately one foot by mid-century and a 3-4 foot ascension by 2100; we have already experienced a 7 inch increase over the last hundred years. Although fluctuating sea levels are a natural process, these estimated increases are the theoretical impact anthropogenic emissions will have on ocean levels. This is yet another factor that makes climate change all the more pertinent an issue for California as our entire Western coast, approximately 1,100 miles, is bordered by the Pacific Ocean. A particularly vulnerable region, the Sacramento-San Joaquin Delta is an extremely perilous region. Levees that are already threatening to fail would be more easily breached, disrupting not only the fragile ecosystems in the area but the large amount of freshwater currently captivated by these levee and delta systems. Were the SSJR Delta allowed to be inundated by saltwater the effects could be catastrophic on California's water supply. Over the last century we have seen an average sea level rise of 1.5 to 2.0 mm/year with an increasing rate as time proceeds. This may sound like an insignificant number, but just a few inches adds up quickly and will eventually greatly affect our coastal cities. Sea level rise can be attributed to three main factors: thermal expansion, the melting of ice caps and glaciers, and loss of ice from the Greenland and Arctic ice sheets (Luers 2006).

5.4.1 Thermal Expansion

Just as air and multiple other fluids act, water expands the warmer it becomes. A hotter atmosphere ultimately results in hotter water temperatures, and thus a correlating expansion. This increase in mass accounts for approximately 2.5 cm of the 15-20 cm rise in sea levels seen in the 20th century. The IPCC's Fourth Assessment projected that we can expect an additional rise of 17-28 cm in the 21st

century due solely to thermal expansion, and many experts consider this a moderate estimate (Luers 2006).

5.4.2 Melting of Ice Caps and Glaciers

Not to be confused with sea ice, glaciers and ice caps exist out of the total pool of ocean water. Technically, ice caps are frozen water masses that cover less than 50,000 km^2 of land area, while anything more than this is considered an ice sheet. A glacier is simply a land mass of ice, which forms when there is an overall greater amount of water freezing, falling as snow and sleet, than there is melting. The actual formation of glaciers is termed "glaciation." Unlike the melting of sea ice, or ice that occurs as the top-most layer on an oceanic body of water, when glaciers and ice caps melt they increase the sea level. This can be easily monitored on a coastline. Much like a glass of ice water, if the ice cubes are already submerged in the water than the melting of those cubes will not cause the level of liquid to rise as it is just a conversion of a solid to a liquid. However, if one allows ice cubes that are not initially accounted for in the measurement of water level to melt *into* the cup, you will see the overall amout of water increase as more liquid is added to the initial amount. About 2.5 cm of rise in the last century was due to melting of glaciers and ice caps, with a projection of 10-12 cm of additional rise before 2100 (Luers 2006).

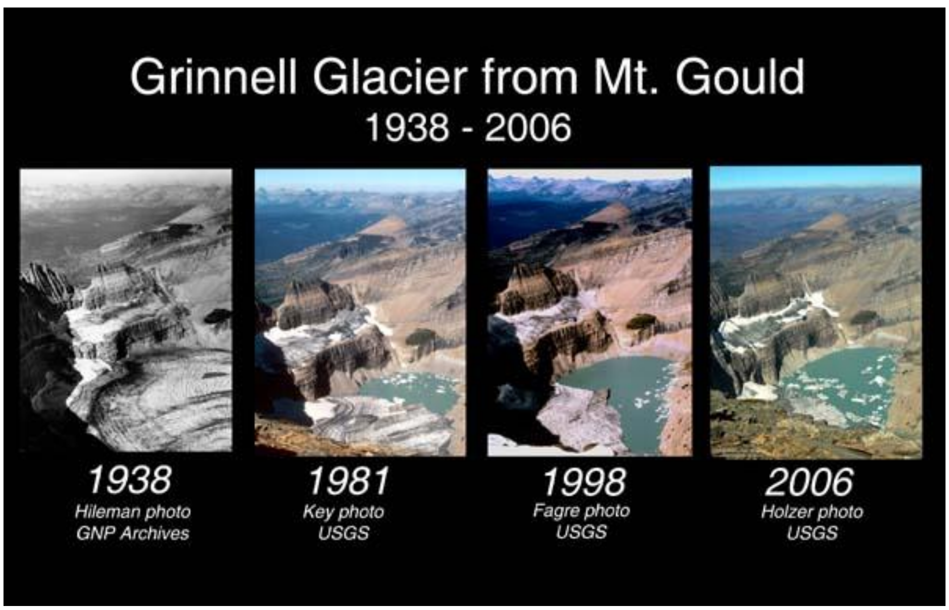


Figure 23. Grinnell Glacier from Mt. Gould in Glacier National Park, Montana. A comparison of glacial coverage taken at the same time of year at the same location almost 70 years. Note vegetation patterns stay relatively stable, suggesting that changes in snow coverage have little to do with alterations in the direct terrestrial habitat and more to do with precipitation cycles. From United 2009

5.4.3 Loss of Ice from the Greenland and Arctic Ice Sheets

The overall amount of freshwater on the Earth is less than 3% of all the water housed on this blue planet, with 60%-79% of that 3% locked up in glaciers and ice sheets. The Greenland and Arctic ice sheets hold a large portion of that, and thus have a huge amount of water to release if they were allowed to flow in the coming years; if completely melted, the Greenland ice sheet would raise sea levels 7 meters, the East Antarctic 5 meters, and the West Antarctic an astonishing 55 meters. The East Antarctic is particularly vulnerable as the majority of this ice sheet is below sea level, meaning any melted water would assuredly find its way back to the oceans (Luers 2006).

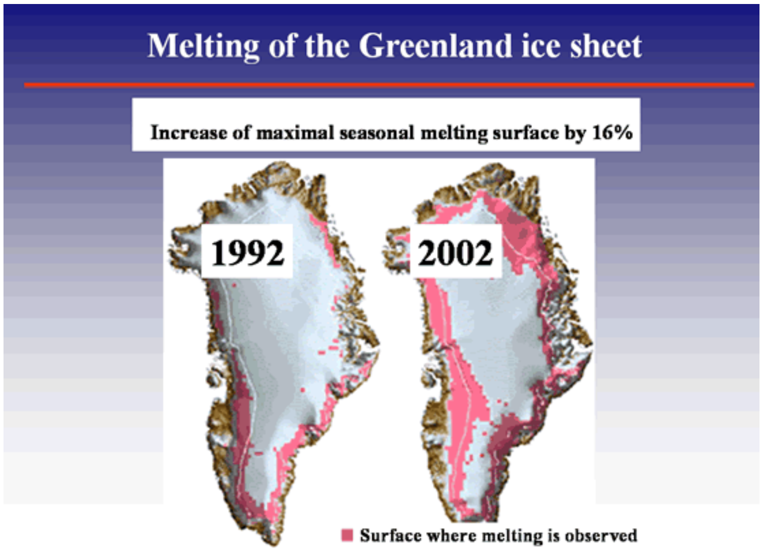


Figure 24. Map of the Greenland ice sheet from 1992 until 2002, depicting the incredible loss of ice sheet coverage. From Sir Alister 2006

Implications of sea level rise on the global scale are enormous. More than 600 million people live in coastal towns that are located 10 meters above sea level or less. Just over two-thirds of the world's cities that have populations exceeding 5 million are included in that coastal population, meaning much of our economic functioning occurs in these vulnerable regions (in general, the central hubs of large corporations and government bodies reside in big cities). With global warming we will see significant alterations in the way our oceans interact with the atmosphere, land, and itself, as ocean currents could be skewed or halted altogether, marine species redistributed and dispersed, and environmental disasters becoming more frequent and intense. Extreme ocean changes could also include ocean acidification and alterations in thermohaline circulation (refer to section 4.1.2), (Climate Institute 2010). Californians will experience a greater amount of flooding on a more frequent scale. This will cause costly coastal erosion that hasn't been considered in the flood-plans of many of our cities. Fragile marine estuaries have already been breached in the San Francisco Bay Delta with increasing frequency due to insufficient levees, and we can expect this to be a more common occurrence. We can expect the shrinking of coastal oceanic beaches. A large majority of the coastline, in southern California especially, is lined by beaches that are a huge tourist draw and thus tie importantly to the region's economic well-being. Well-known areas such as Santa Monica, Venice, and Newport Beach all have sandy destinations which attract people far and wide, and each was created and currently maintained by sand that was brought in from distant beaches and dredging on a yearly basis. Increased sea level rise, storm surges, high tides and flooding will only increase the yearly volume of sand necessary to maintain these sought after vacation destinations. The cost of these beach nourishment programs may become too pricey to sustain (Luers 2006).

5.5 Potential Reduction in Hydropower Production

Depending on conditions (time of day and year) California currently receives between 9-30% of its electricity from hydropower. Hydropower, or hydraulic power, is energy that is harnessed from the movement of water through a series of dams, turbines and generators. Much of our hydroelectric power comes from man-made dams, a majority of which were put in place after WWII, that pool water in a reservoir and allow it to flow out at a specific rate. When released, the water turns a turbine/generator and creates electricty; the principle process can be seen below in Figure 27. A vast array of hydroelectric power plants are built in California (just short of 400), utilizing both state watershed and aqueduct systems with a combined total electric capacity of over 14,000 Megawatts (MW), or 14.5% of our total annual electricity production. The most notable river systems, those with the highest electricity capacity employed by hydropower facilities in our state, are the Pit, San Joaquin, American, Feather, Stanislaus, and Mokelumne rivers (Cubed 2005).

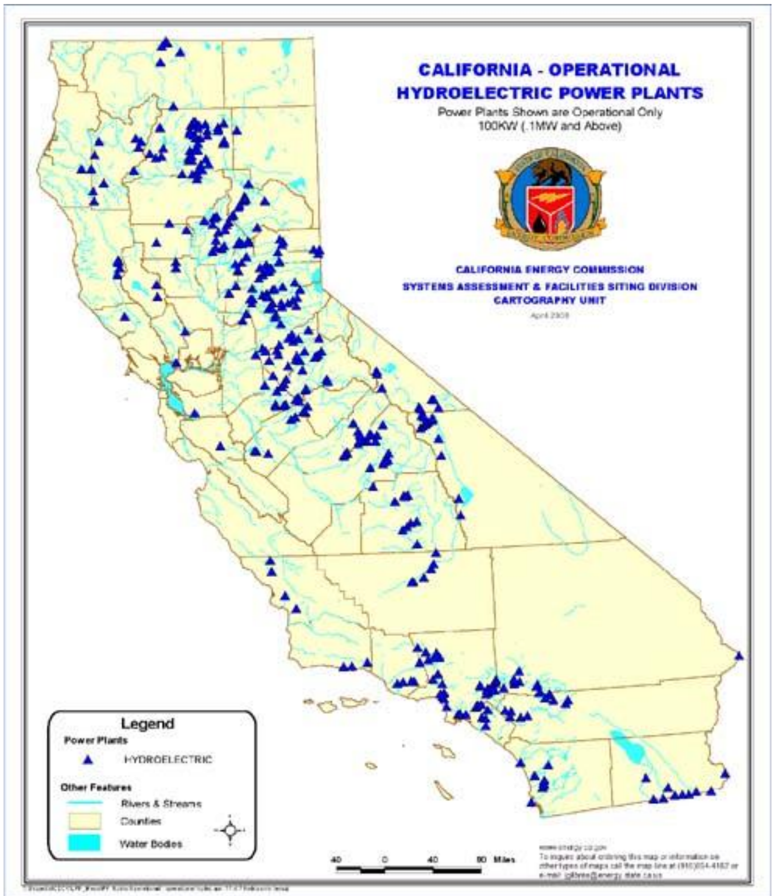


Figure 25. Map of hydroelectric power plants in California. Note- Not all shown. From Animal 2008

Part of a broader multi-use system, much of California's hydropower structures are not only power generation facilities but also serve as water supply reservoirs, flood control mechanisms/overflow storage, and sources of recreation. Although habitats were destroyed in the making of these man-made lakes as valley floors were decimated, now, years later, a plethora of ecosystems are established around these synthesized water sinks (Cubed 2005).

With pending changes in California's precipitation cycles, we could see a substantial decrease in the ability to generate hydropower at critical times during the year. Were the electricity harnessed from water movement easily stored, then increased snowmelt might actually mean more potential hydropower energy each year. However, this increased snowmelt will happen at a quicker rate, earlier in the year, meaning more water moving at a faster rate but for a decreased duration. We have a set capacity and capability of energy capture as our current reservoirs have a limited capacity. Thus, once maxed out we cannot produce more energy even with more flow. Once flow rate reaches its capacity, additional flow doesn't matter; duration of flow is the key to prolonged energy production. In addition, this means that although we will have energy "surges," when snowmelt is high and a lot of water is being moved through our hydropower systems, we have no way of storing this increase in electricity production. In laymen's terms, big amounts of energy produced over short amounts of time don't do us much good without adequate means of storage. Unfortunately, the trend between rising temperatures means less total annual water-electricity production. This has an inverse relationship to the amount of electricity Californian's will demand as our climate gets hotter. Increased daily temperature averages will urge residents and business owners to turn on their air conditioning units more frequently, which of course uses more energy. Without even taking population increases into consideration, researchers say we can expect a 20% rise in electricity use by the end of the century just to counter the oncoming heat (Luers 2006).

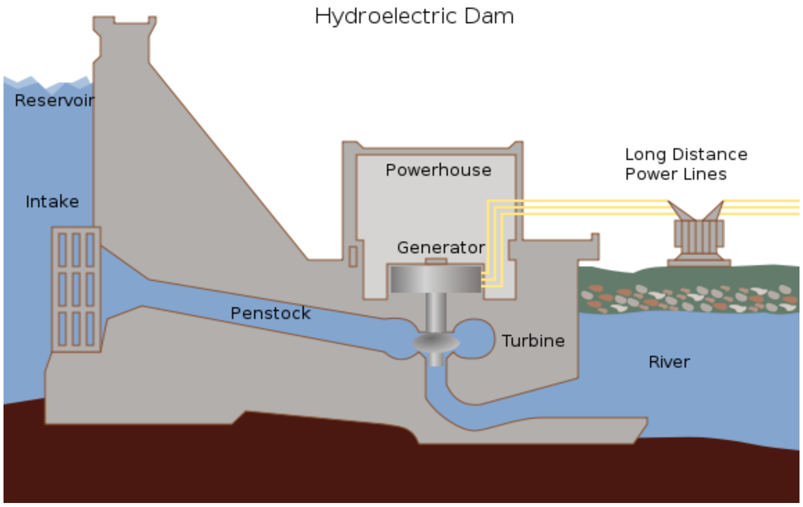


Figure 26. Generalized schematic of how water moves through a dam-system to create electricity. Our man-made dams often utilize a river system that runs through a valley. Captured electricity is then transmitted via power lines which have been hooked up to the generator. From Alternative 2011.

5.6 Water Quality

Dramatic changes in precipitation and runoff will require a different type of water management in the future, especially with regards to water quality. Inundation of freshwater supply will be an increasingly larger problem as climate change causes sea levels to rise and threaten infiltration of crumbling levees. California's Sacramento-San Joaquin Delta is already feeling these side-affects, as high tides bring in ocean water farther inland with each passing year. Water managers will need to manage growing and competing interest in reliable, potable and safe water between residents, farmers, businesses and ecosystems.

There are multiple factors to take into consideration. Boosted flood events will increase flow rates at certain times of year, enhancing the amount of sediment moving downstream and into our reservoirs as soil erosion becomes more prevalent among riverbeds. More water means increased turbidity and movement of pollutants downstream, which as certain times of the year will either be more concentrated or more diluted depending on runoff. Alongside increased sediment, we could experience higher levels of chemical and nutrient loading. In urban areas, more rain and water flow means more runoff and flushing of pesticides and pollutants either to downstream reservoirs or diffusion into groundwater sinks at the water entry point. This can be extremely toxic to ecosystems (refer to section 7.2, "Australia's Water Use," for an example). Reduced water flow during the summer and fall months will likely lead to less dissolved oxygen and larger amounts of detritus and bacterial buildup in streams with longer low-flow conditions, as well as increased salinity and contaminate concentration. Higher water temperatures could accelerate biological activity, such as the growth of algae and micro-organisms (State 2008).

5.7 Water Demand

Water demand will likely increase in the coming years, as warmer temperatures will increase the evapotranspiration rate by as much as 37% (refer to section 5.5.2, "Evaporation and Transpiration") and lengthen growing seasons. An enhanced water exchange rate may also increase salt accumulation on plant and soil surfaces, again resulting in the need for more water. Additional changes in agriculture could exacerbate the demand: e.g. alterations in plant productivity, planting cycles, and crop type (Department 2006).

A lengthened growing season will increase water needs in non-irrigated plants, irrigated plants (both crop and landscape), and environmental sinks alike. Water needs across the state will go up because plants, whether they be crops or wild growth, will require more H_20 for the same amount of mass yield. In addition, domestic water demand has a high positive correlation rate with atmospheric temperatures. Domestic water use could go up as a result of warming temperatures in the following ways: increased laundering of clothing, bathing of humans and animals, increased drinking requirements for all living things as a result of evaporation water loss from surfaces, increased recreational usage of water, and heightened use of evaporative cooling. Increased water demand for industrial use will be largely attributed to an increase in evaporative cooling techniques for facilities and increased drinking requirements for living products such as those involved in the meat production industry (concentrated animal feeding facilities). Evaporation losses from any water surface, especially those in arid regions with low humidity and cloud cover, will increase due to the same factors as listed above as temperatures increase. Water bodies with greater surface to volume ratios will be more largely affected (Department 2006).

Lastly, environmental water regulations could be affected. The amount of water legally required to flow through the Sacramento-San Joaquin Delta will likely increase as more water will be necessary to maintain salinity conditions in response to sea level rise (refer to section 7.2.1, "The Murray-Darling Basin," for another example). Previously established flow standards have already proved too little in the face of increased atmospheric temperatures. Given the Delta's current configuration, water supply facilities and condition of its ecosystems could be negatively affected if salinity levels are not properly maintained. In addition, more water will likely be necessary to keep water temperatures at appropriate levels for sensitive aquatic species, requiring an increased usage of reservoir storage and thermal control releases.

Many variables that are not directly related to global warming will likely alter the demand for water in California as well. These include population growth, changes in agriculture, changes in landscaping practices, changes in environmental water use requirements, water law and policy, and technological innovation (Department 2006).

5.8 Colorado River Supply

Although most of California gets its water from internal sources, a large percentage of the water used in southern California comes from the Colorado River Basin, the single largest source of water outside the Central Valley. Our current legal allotment is 4.4 million acre-feet per year, however we have used as much as 5.3 million acre-feet per year in the past. Roughly half of the water used in our state's southern regions comes from this large river system, which has been carefully diverted in a network of intricate aqueduct transfer systems (refer to section 3.3.2, "The Colorado River Basin.") (Department 2006).

It is not yet fully understood to what extent the Colorado River Basin will be affected by a warming climate, but estimates range between a decrease of 6% all the way up to 50% in annual river flow due to changes in precipitation cycles and snowpack, much like the changes we expect to see in California's Sierra Nevada's (sections 5.2 and 5.3). The IPCC's 4th Assessment projects a warming of 1.1-2°C (1.8-3.6° F) by 2050, with runoff peaking 25 days earlier in the year than in the 1951-1980 historical period (Department 2006). Because the Colorado River hydrates much of the lower half of California and two of its cultivation valleys, it will become increasingly important to learn as much as possible about how global warming will lesson runoff into the Colorado River as our native lands see less water storage capabilities and the desiccation of groundwater supplies. In addition to natural impacts, California, which already uses more water than its legal allocation due to trade agreements, will see less water due to the growing populations of the other two "lower basin" states Arizona and Nevada (California 2009).

More so than timing of snowmelt runoff, impending changes in annual precipitation will be the largest problem for CR Basin water users. As the atmosphere fevers, more water will be expected to fall which will increase sediment inundation, furthered by the fact that more water will fall as rain instead of snow each year and increased wildfire frequency will dry out watersheds. To further complex the issue, the CR Basin has been in a drought state since 1999, with large declines in reservoir storage (Department 2006).

Figure 27. This chart embodies the drought situation experienced by Lake Mead (responsible for housing a large portion of the Colorado River water for the "lower basin" states, capable of holding 28.5 million acre-feet) over the last decade, beginning in 1999 and still underway. Lake Mead is the largest reservoir in the United States, controlled by the Hoover Dam, and is located approximately 30 miles southeast of Las Vegas. Data gathered from a government archive of water height (**http://www.usbr.gov/lc/region/g4000/hourly/mead-elv.html **), updated once per month from 1935 to the present. Vertical axis shows feet above mean sea level, horizontal axis portraying year. [Note: Data gathered after the synthesis of this graph will show that the 2010-2011 snowfall was above average, which may end the drought cycle in Lake Mead for the time being. It is yet to be seen if the above average snowfall experienced in the 2010-11 winter will be a perpetuating cycle in the coming years or if drought levels will still be sustained]. From Arachniod 2011.

5.9 Agriculture

The consequences on our state's food production could become considerable in the coming years, so much so that our Secretary of Energy Steven Chu said we could see agriculture disappear before the turn of the century (Celsius 2011).

The extent to which climate change will affect our agricultural industry in California is somewhat misunderstood as an initial analysis may reveal that global warming will result in longer growing seasons and extended plant growth due to higher carbon dioxide levels and plant water-use efficiency. In some areas, foliage will become more lush, soils more nutrient rich. However the larger picture is not quite as promising for our $30 billion dollar farming industry, which is responsible for providing more than half of our country's entire supply of fruits and vegetables and employing upwards of one million people. Much of the economic output comes down to water, again (Luers 2006).

California farmers cultivate over 300 different commodities, making agriculture one of our most lucrative endeavors. We are the most richly diverse food cultivator in the country, thanks to the extreme variability we have in sub-climates up and down the state. In 2009, 23% of our 81,500 farms brought in revenues of $100,000 or more, compared to the country's average of 17%. We devote more than 25 million acres of land to the growing of cash crops every year, which ranks us the highest-averaging income per acre in the US. Put simply, our economy depends heavily upon the well-being of our crops. Our top agricultural commodities can be seen in Figure 29 below.

TABLE 1. Top 20 California agricultural commodities and 1997 value of production

California rank	Commodity	1997 value of production	U.S. rank	California share of U.S. production
		million $		%
1	Milk and cream	3,626	1	17
2	Grapes	2,819	1	91
3	Nursery products	1,758	1	22
4	Cattle and calves	1,323	5	5
5	Lettuce	1,251	1	72*
6	Almonds	1,127	1	100
7	Hay	1,037	2	6
8	Cotton lint	984	2	14
9	Tomatoes	870	1	94†
10	Flowers and foliage	729	1	22
11	Strawberries	686	1	82
12	Oranges	587	2	23
13	Chickens	473	—	4
14	Broccoli	449	1	92
15	Walnuts	352	1	100
16	Rice	347	2	24
17	Carrots	345	1	76
18	Eggs, chicken	345	2	9
19	Lemons	266	1	89
20	Garlic	262	1	88

Source: CDFA 1999.
* Head lettuce only. California share of U.S. production for leaf lettuce is 81%.
† Processing tomatoes only. California share of U.S. production for fresh market tomatoes is 31%.

Figure 28. California's top 20 agricultural commodities in 1997, with a large percentage produced in the Central and Imperial Valleys. From University 2000.

As temperatures rise, the demand for water will be higher, yet the supply less reliable. Longer and more frequent droughts will become a common occurrence in our largest growing valleys, forcing the relocation of farms, more fallow years, new water sources, or a combination of the three. Our own fertile crescent, the 500 mile Central Valley has experienced a three year drought which has been devastating to many cultivators. This precious section of land is world-renowned for its ability to seed a multitude of different plant species in abundance and is an integral region to the agronomics of California. Sections of the San Joaquin and Central Valleys' were not allotted their normal water deliveries due to water supply cut-backs from the Sacramento-San Joaquin Delta over EPA smelt and salmon protection measures (refer to section 3.3.2, "Water Supply Cutbacks"), furthering the problem, this left thousands of otherwise employed farm workers out of a job (Celsius 2011).

The quality and quantity of crop yields will diminish as less water will be available in a warmer climate that may see increased pest and disease spread. Although warmer temperatures will initially increase plant growth, once a growing threshold is reached the increased temperature will actually have a negative impact, reducing the quality in many of our cash crops. Our hardest hit will be wine grapes, abundant in northern California (the Sonoma and Napa valleys most notably) and the Central Coast as budding wine regions have become more and more prosperous over the last few decades; fruits, nuts and milk fall closely behind. Our state is currently broken up into 17 crush districts, or specific areas of growth, shown in the figure below. Many of them are clustered around the Sacramento-San Joaquin Delta.

Figure 29. The California [wine grape] crush districts in 2006, totaling 17 regions of geographical growth according to administrative code. From University 2008.

California produces more wine than any other state in the country (roughly 90% of the value of wine produced in 2006), taking in about $3.2 billion per year for multiple varietals of fermented juice, and ranks fourth in the world for total volume produced. This makes the health of our wine grapes an important part of our economic well-being. In 2006, over 3.1 million tons of grapes were crushed for wine production, filling more than 2.3 billion bottles for drinkers both in and out of the state (University 2008). Warmer scenarios will induce grape ripening to happen earlier in the year, and affecting quality. Harvest dates could precede the current time of year by up to two months by 2100, altering multiple variables in the intricate science of wine-making. The same principles will affect fruit and nut trees, which are extremely sensitive to temperature changes as ripening will happen faster the warmer it gets. Fruit size and quality will deteriorate as well. This is already happening: in 2004 peaches and nectarines reached maturity prematurely, resulting in an early harvest and placing them in a lower quality category than is usual for these sweet Californian fruits. Lastly, dairy cows will produce less milk the warmer their environment becomes, with waning production happening at temperatures as low as 77° F and substantial impacts occurring at temperatures of 90° F or more. Experts predict that by the end of the century, warming scenarios of the middle to upper ranges will decrease milk production by 20%. Currently, our dairy industry accounts for $3 billion of our state's annual income and provides 20% of the milk consumed in the US (Luers 2006).

Climate change will bring about numerous other problems for our agricultural industry as well. Warmer temperatures will alter the life cycles and breeding seasons of pests and pathogens that already threaten crops yearly and cost millions of dollars to keep under control, enhancing their potential harm. Certain species that California's Central Valley is able to stave off due to night-time low temperatures and frosts will be more easily accessible once global temperatures rise. The growing range for invasive agricultural weeds will likely expand for similar reasons, altering competition patterns with native plants and requiring increased funds to keep them at bay. To exacerbate the issues, the interactions of changing patterns and stresses among the many ecosystems that reside in our state's farms are hard to forecast, meaning we can expect more unforeseen changes as our landscapes transform. For example, as our wine grapes mature earlier in the year, a well-known pest the glassy-winged sharp-shooter, infamous for transmitting Pierce's disease will infiltrate habitats farther up the coast and result in an increase of the bacterial disease among crops (Luers 2006).

6. Adapting California's Water Management to Climate Change

"As understanding of climate change improves, the challenge for California's water community is to develop and implement strategies that improve resiliency, reduce risk, and increase sustainability for water and flood management systems and the ecosystems upon which they depend." – Authors of "*Managing an Uncertain Future: Climate Change Adaptation Strategies for California's Water,"* 2008.

There is no question that, although we have a long way to go, California is one of the world leaders in planning and implementing the principle preliminary changes that will have to happen in the coming decades to plan for climate change. One of the biggest moves thus far, in 2006 former Governor Arnold Schwarzenegger and the California Legislature passed Assembly Bill (AB) 32, the Global Warming Solutions Act. This was the start of an aggressive plan to curb greenhouse gas emissions to 1990 levels by 2020 and by 80% of our current emissions (current in 2006) by 2050. This was to be made possible by: (1) mandating state caps on greenhouse emissions, (2) greatly reducing and sequestering emissions from inevitable producers, and (3) developing a systematic way of recording emissions. Reducing global warming means a smaller impact on water supply (State 2008).

It is universally agreed that both adaptation and mitigation strategies will need to be utilized. Much of the future can be determined by actions now, however even if all emissions were halted starting tomorrow we would still feel the effects of what has already been released into the atmosphere for years to come. This is because many of the green house gases take years and decades to dissipate out of the stratosphere. Therefore, water planners have begun to tweak their plans for the future, realizing that more people will be demanding greater amounts of water, with significantly less to go around. Multiple state agencies, including the State Resources Control Board and the Department of Water Resources have already composed documents with research and data concerning future action, and these suggestions are being taken seriously: the latest California Water Plan included preliminary adaptive movements to account for climate change (California 2009).

The adaptation strategies in consideration fall into four main categories:

(1.) Investment, (2.) Regional, (3.) Statewide, and (4.) Improving Management and Decision-Making Capabilities (State 2008)

One of the most common themes among department suggestions centers around Integrated Regional Water Management (IRWM), an approach format that takes multiple factors into consideration, such as the most cost-efficient technologies, area-specific concerns, and the appropriate mix of water supply and demand management options. In other words, according to the DWR, ***"Integrated Regional Water Management (IRWM) is a collaborative effort to manage all aspects of water resources in a region. IRWM crosses jurisdictional, watershed, and political boundaries; involves multiple agencies, stakeholders, individuals, and groups; and attempts to address the issues and differing perspectives of all the entities involved through mutually beneficial solutions."*** (State 2008).

Measures to increase conservation and efficiency are at the top of the priority list. Efficient Water Management Practices (EWMP's) and Urban Best Management Practices (BMP's) will become widespread and common, as efforts to sustain and increase biodiversity will prove just as important as flood management techniques.

Supplemental suggestions of the top state-funded comprehensive reports to read involving California water policy and climate change adaptation strategies:

1. Department of Water Resources: *An Interagency Work Team's Plan for Assessing Risks of Climate Change on Management of California's Resources*. October 2005. http://baydeltaoffice.water.ca.gov/climatechange/FIHMCPaperDWR-ReclamationClimateChangeOct05.pdf

2. California National Resources Agency: *California Climate Adaptation Strategy 2009*: A Report to the Governor in Response to Executive Order S-13-2008. 2009. http://www.energy.ca.gov/2009publications/CNRA-1000-2009-027/CNRA-1000-2009-027-F.PDF

3. Department of Water Resources: *Managing an Uncertain Future: Climate Change Adaptation Strategies for California's Water*. October 2008. http://www.water.ca.gov/climatechange/docs/ClimateChangeWhitePaper.pdf

7. Best-Fit Solutions From Around the World

Although water use varies hugely from country to country, looking at global water trends can still tell us a lot about what we are doing right, what we are doing wrong, and who we can look to when considering solutions to counter the water crisis in California. There are currently 700 million people in 43 countries facing water stress today. By 2030, 40% of the world's population will be in the same position (World Bank 2010). The time is now to come together on a global scale and share the most efficient water strategies around the world.

7.1 Global Water Use

Agriculture accounts for 70% of the global freshwater use, with some countries using up to 90% of their freshwater for irrigation purposes. Trailing behind are industrial uses (20%) and domestic uses (10%), however again these numbers vary greatly between regions. Belgium, for example, uses 80% of their freshwater supply during industrial endeavors. According to statistics from www.worldometers.org, freshwater use has tripled worldwide over the last fifty years, showing a strong correlation to population growth. Freshwater demand on the global level goes up by 64 billion cubic meters (m^3) a year, or 1,000 liters/person. Nearly 80% of disease in developing countries, or countries of a low-level material well-being, is associated with water use and the problems that arise when water withdrawal is substantial and is strongly associated with contamination levels; this results in roughly 3 million premature deaths per year (Worldometers 2011).

The "water footprint" of a region is defined as the total volume of water needed for the production of all the goods and services consumed by the inhabitants of that region. This is not a complete picture as many nations use resources for goods that will eventually be exported to other countries for consumption or use, however it helps to illustrate which nations use water more wisely.

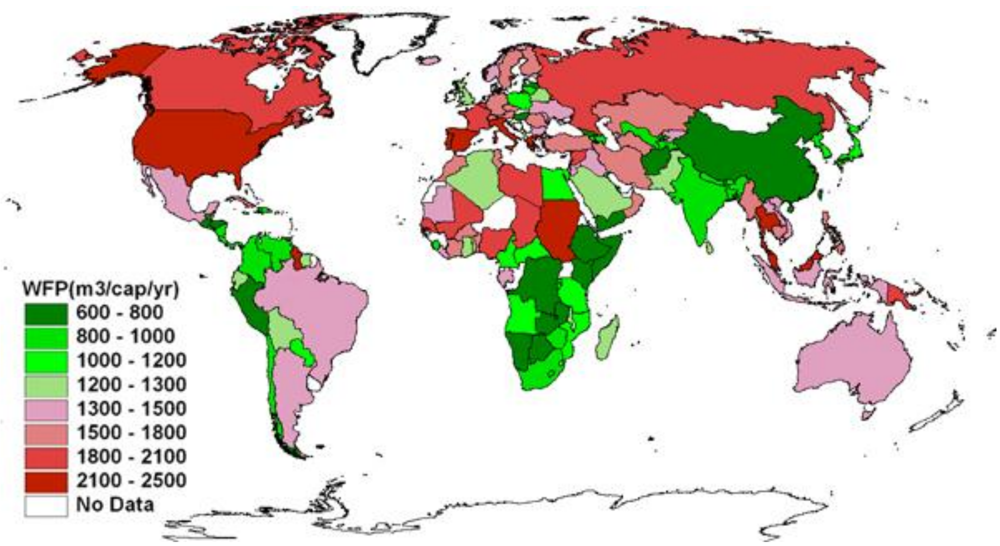


Figure 30. The average national water footprint by country. Data period: 1997-2001. From Water 2011.

7.2 Australia's Water Use

Although Australia uses more water than some of its counterparts, this country has come up with myriad advantageous methods of countering their dwindling supply of freshwater. From economic incentives and water-trading to recycling storm water, they have embodied many of the Efficient Water Management Practices (EWMP) and Integrated Regional Water Management (IRWM) techniques that we will aim for in the future. As the world's driest inhabited continent, Australia's people have had to work around a limited water supply since the nation's conception. Agricultural practices have threatened the health of their native marine species, especially those that inhabit the Great Barrier Reef (warm-water reef systems are extremely important in regards to marine biodiversity as they house roughly 70% of all marine species), as agricultural runoff such as fertilizer and pesticides alters the chemical components in surrounding reef waters, such as pH level. Since most Australians live in coastal urban areas, they have had to tighten up their environmental regulations in order to protect the delicate ecosystems at stake.

7.2.1 The Murray-Darling Basin

At the helm of their current water problems, their Murray-Darling Basin covers a seventh of the continent, meeting 40% of their irrigation needs (54% of Australia's water was used for agriculture in 2008-09 (National 2011)) and provides water to over 3 million residents (Australia's total population is currently at roughly 22 million).

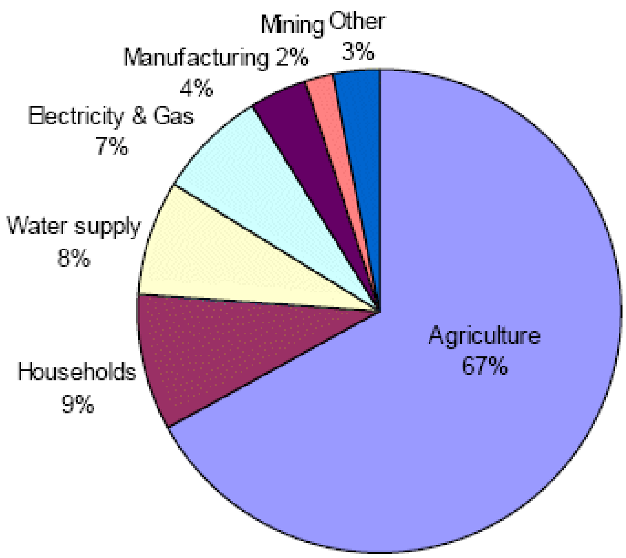


Figure 31. Breakdown of Australia's water use, averaging data from all regions on the continent in 2005. From Australian 2010.

The aridity of this basin is becoming increasingly evident as groundwater supplies are depleted, varied habitats bordering the liquid lifelines have dried up, and its ocean outlet has disappeared due to low water flow (Scientific 2009). Many of the Basin's endemic species are under stress due to water extraction, with native fish species 90% less abundant than pre-European levels (World 2011). In many ways, Australia is more susceptible to global warming then California. This Mediterranean-like landscape is minus a substantial mountain range which plays a large part in climactic weather control. The waters of its Southern Ocean are extremely chilly due to the close proximity to the frozen Antarctic, and its atmosphere is dryer than most others on Earth with very little precipitation held in the sky. All of these factors result in extinguished vegetation making land more vulnerable to bushfires with dried kindling, reducing the landscape's ability to soak up and house water, which perpetuates the cycle (Scientific 2009).

In the face of hardship, two of Australia's cities have shown great fortitude in countering their water woes. Both at the terminus of the Murray-Darling Basin, Adelaide, South Australia's state capital, has shown excellent leadership in implementing "hard technologies" to increase water supply such as desalination- this is the systematic removal of salt and other minerals from water to make it potable. Second, the smaller city Salisbury has put a large focus on increased water-use efficiency techniques, or "soft technologies," utilizing natural filtration systems (i.e. wetland and lagoons) and ingenious methods for capturing and recycling waste and storm water (Scientific 2009). During the drought, between the years 2000-2007 water supply to farmers using the Murray-Darling Basin for irrigation was cut by 70% and yet production remained nearly the same- this was due to large increases in water efficiency and water trading with regions with H_20 surpluses. An $8.9 billion legislation plan ***Water for the Future*** actually increased jobs in the Basin even though 800 workers in the agricultural industry were let go, meaning this money was spent re-employing these workers in jobs largely related to water conservation. Of this money, $3.1 million was committed to buying water, while the remaining $5.8 million went towards improved water efficiency infrastructure. Economic incentives have boosted citizen support as education of the public has aimed to have water purchasers view it as a commodity, one that should be invested in by the private sector so the government does not have to fund every retrofit and new development conservation project. Irrigators that use water wisely have the ability to sell their water at market prices and increase funds to invest in other places or further enhance water-saving technologies. Water cut-backs to ensure flow is brought back to the Basin have been instated despite the difficulty it will bring; according to Water Minister Tony Burke, return of flow to the region is an absolute must and will bring with it healthy rivers, food production and strong regional communities (World 2011). In addition, efforts to curb impacts on the Great Barrier Reef included an allocation of $200 million to farmers by the Australian Government to adopt safer farming techniques. The government in the Queensland region mandated strict requirements for animal grazing and cane growth in areas when pollution poses a high risk (Scientific 2009).

Full coverage of *Water for the Future*'s methods of encouraging smart water use can be found at the following link: http://www.environment.gov.au/water/publications/action/pubs/water-for-the-future.pdf:

Australia's bottom-line: to have sustainable water management practices that can withstand the changes global warming will bring about. With their extremely extensive initiative, *Water for the Future,* the government can raise awareness and set requirements and regulations with a top-down approach, requiring their private sector to be the change. Coupled with government incentives, subsidies, and education, they have a cohesive plan that partners their people with their environment, as one will not succeed without the other. *Water for the Future* will be delivered through a ten year plan of investment strategies in clean, innovative water technologies.

7.2.2 Queensland

Queensland is Australia's fastest growing state with a current population of 2.7 million people, occupying the north-eastern region of the mainland continent. They too have been riddled with water shortages over the last decade, with multiple consecutive drought years ransacking reservoirs. In 2007, they received a measly 4% of their average annual inflow to their major dam. In response, the Queensland Water Commission worked in close conjunction with researchers and water planners to cut water use down drastically; **Queensland now uses 30 gallons per person per day compared to Southern California's 200-300 gallons per person per day.** Today, the rains have returned to Queensland. Water use can be much less restricted for the time-being. However, they aim to keep their water consumption down, claiming they will continue to push their residents to use only what they need. So how do they do it?

On the management side, Queensland reduced its number of utilities from 23 down to 7 (Carpenter 2010) [a utility is an agency/organization designed to maintain the infrastructure for a public service, most often having to do with water or energy. Agency ownership can range from local community-based groups to state-wide government monopolies (Wikipedia 2010)]. Along with other Australian states, Queensland built a desalination plant to supply more freshwater from the salty sea and built a large indirect potable re-use system. Many of their local dams were connected to cut down on transmission costs and losses. On the consumption side, they used aggressive education via television and outdoor advertising to cut down residential water use as it is Queensland's largest consumer. The watering of landscapes and washing of cars and windows was banned to the private sector. Families were asked to cut down water use to 35-40 gallons per person per day, and were provided with tips to make the goals more easily attainable, such as cutting 7 minute showers down to 4 (free shower timers were doled out). Households that did not meet the new water goal were sent letters asking them to explain their water use and examine what it was they did that water-thrifty neighbors did not; 34% eventually made the necessary changes, of which 9% discovered they simply had a leak. Queensland was aided with a $261 million government rebate program which was responsible for the purchase of 508,000 retrofit water-saving devices like rainwater toilet tanks, water-efficient showerheads and low-flush toilets.

The cumulative result? This thirsty state not only met their water goals, but exceeded them (Carpenter 2010).

7.3 Austria's Drip Irrigation Techniques

As previously noted, much of the water we use today goes towards the growing of food crops (approximately 70% global average). Africa, a notoriously parched country, allocates as much as 90% of their available freshwater towards irrigation in certain regions. Farmers in Vienna, Austria, have started utilizing a cost-effective watering technique called "drip irrigation," or "trickle irrigation", to bring moisture to their plants which can conserve as much as 50% of the water otherwise needed for the same result, while improving soils and lessoning manpower. Typical water delivery rates are extremely low, at around 2-20 liters/hour. Scientists and researches from the Joint Division of the United Nation's Food and Agricultural Organization and the International Energy Agency (conveniently located in Vienna), part of the International Atomic Energy Agency (IAEA), are coming together to help aide farmers do their part in what has become a global water and farming crisis.

Drip irrigation works by targeting the water delivery, dropping it right where the plant needs it the most, in the root zone. Drop by drop, water is distributed to crops via crawling vines of plastic tubing fitted with emitter outlets or drippers that run right along growth beds. Because so much of our surface water is lost through evaporation and leaky pipes, this helps conserve H_20 by minimizing the amount of moisture left on the surface of soils, slowing water flow down in transport tubes, and avoiding over-watering. In addition, unnecessary deep percolation into the ground soil is terminated. This in turn produces higher quality crops. When plants are over watered the natural nutrients found in soil and any of the synthetic fertilizers added into the mixture will get diluted and large percentages will be lost in runoff. So less water means less runoff, and less agrochemicals contaminating downstream habitats

(UnitedNations 2010). Drip irrigation systems water plants at more frequent intervals than standard sprinkling systems, wetting fields every 1-3 days. This keeps the moisture content in soils higher than average but with an overall net decrease in fed H_20. These systems work best with row crops, such as vegetables and soft fruit trees (FAO 2011).

Scientists from the IAEA are currently working with the United Nations Food and Agriculture Organization to promote the distribution of this knowledge to areas in the world that need help revolutionizing their farming techniques. This includes 19 countries in Africa, of which 60% still use the “bucket method” to water their crops (filling buckets at a river or well and dumping them over the thirsty plant). The drip system has been adopted in many places worldwide, including Israel, which has reduced their cubic meter/hectare water requirement from 8,700 cum/ha in 1975 to their current rate of 5,500 cum/ha. Drip irrigation could largely aide cultivators in many setting, undeveloped to developed countries, reducing irrigation water and fertilizer usage by 50% (UnitedNations 2010).

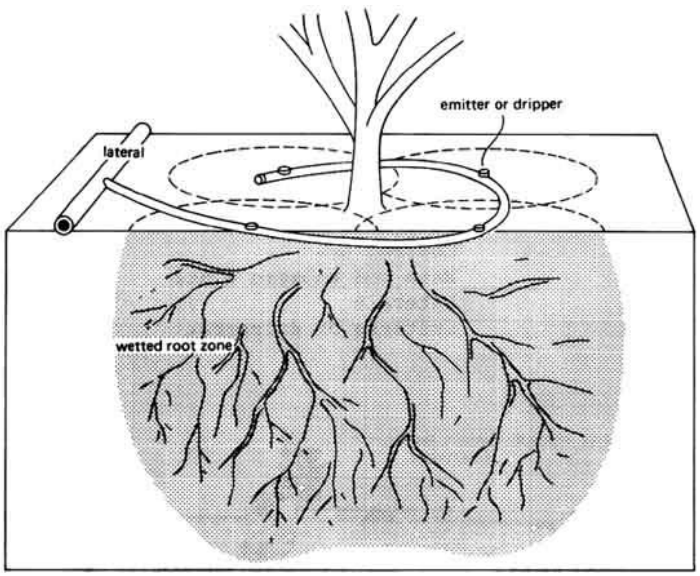


Figure 32. Schematic of how a drip irrigation system works, a method that transports the minimum amount of water needed to fully quench a plant system by tubing that emits water droplets directly onto the root system. Requires 50% less water and fertilizer for the same yield, while saving both money and man power. From FAO 2011

7.4 Israel’s Innovative Water Efficiency Strategies

Israel is one country that has been overcoming water scarcity for over half a century. Notorious for being one of the most arid plots of land in the world, Israel faces their fair share of water withdrawal which has forced them to treat water efficiency as a national priority (Invest 2010). The revelation that changes were going to be essential became evident when three of their major water sources, the Sea of Galilee and two sizeable aquifers became over-pumped due to increasing populations. Crops began to go un-watered, prompting waste-water recycling efforts to take off. Before the end of the last millennium, they had already begun watering their crops with recycled waste-water from the drains of Tel Aviv, the second most populous city in Israel, putting themselves on the map for having the most intensive water recycling program of any nation. They have not only come up with solutions to the problems of their own country, but have provided new technologies to the global water market, aiding other countries in overcoming their own water deficits by sharing their girth of knowledge on the subject and turning the opportunity into a multi-billion dollar operation (Reuters 2010).

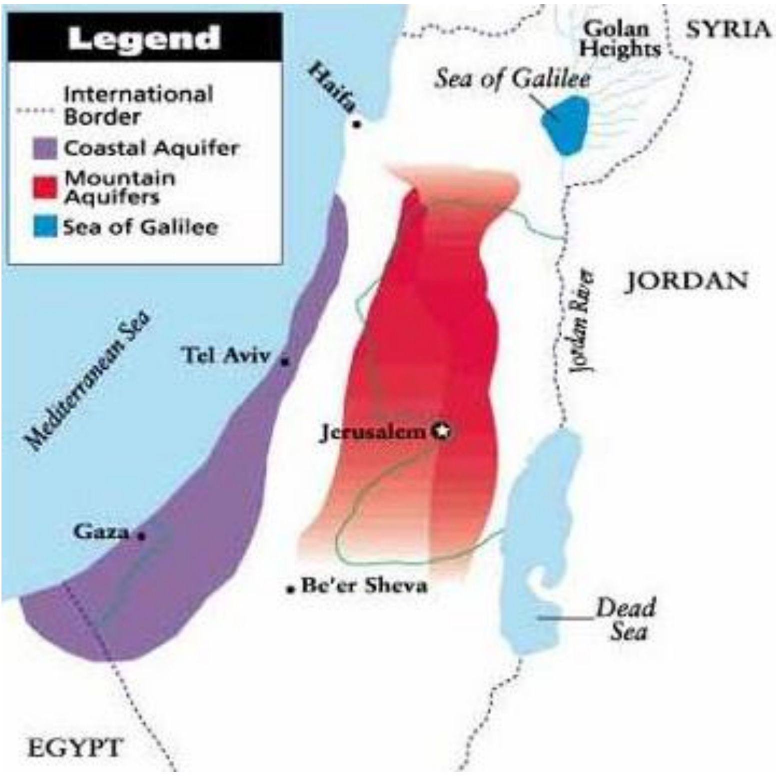


Figure 33. Map of Israel, showing their three main freshwater sources, the Sea of Galilee, mountain aquifers, and coastal aquifers. From Earth 2008

Currently, their water saving technologies are saving them $1.5 billion per year on retained water. Legislators are drafting a bill that will force all new development, business or private, to recycle "grey water,"- water generated from domestic activities. Homes are to recycle all water, save that from toilets, utilizing treatment technologies that will be on each individual property. In addition they will strive to incorporate a method many other nations have already employed, the creation of wetlands that will act as a type of kidney system, filtering pollutants from water naturally in a more aesthetically pleasing way (Reuters 2010).

Examples of their water technology that have been implemented in other countries are many. Romania has looked to Israel for help with water management, hiring a group of Israeli water and infrastructure companies to integrate 500 water schemes in 1,000 villages. Schemes ranged from construction of treatment plants to recycling programs. The Moscow Water Company of Russia, laden with transportation leakage issues, has saved the municipality tens of millions of dollars in potential damage by using the "pressure control valve" system of another Israeli company. **Israel's water loss is 9.7% less than half the European average.** Another drip irrigation success story, this time using the Israeli's specific approach, South Africa is using Israel's crop-watering materials to maximize sugar cane yields, allowing certain regions to transition to bio-fuel as a source of power as a result of water saving techniques. **Israel holds 50% of the global drip irrigation market.** In 2008, the Olympic Games were held in China's Beijing. A country already fraught with water shortages, they also looked to the middle-eastern country to help maintain the new developments necessary to make the games a success. Israel provided a green alternative to China's outdated methods, giving them the information to use ultra-filtration (UF) membrane technologies to purify wastewater generated from over 2,000 m^3 of sewage a day to irrigate the gardens both inside and out of the Olympic Village. **Israel recycles 75% of its wastewater- a world record.** The fisheries in Turkey strategized with Israel to build hydro-optic purifying solutions on its fish farms, increasing productivity and almost dissolving the need for antibiotic treatments, cutting the usage of them by 90%. The island nation of Cypress, facing increasing demand for water as their people multiplied, contracted an Israeli company to build a massive desalinization plant, capable of delivering 54,000 m^3 of potable water per day and greatly absolving their water supply issues. **At $0.52 per m^3, the most cost-efficient desalinization plant on the planet is in Israel** (Invest 2010)**.**

8. Conclusion

California will soon have too many people and too little water. We will have to change the way we use our limited ration, and drastically. Even without the impacts of climate change on our water supply, we will be facing shortages. Tack on rising sea levels, lessoned rainfall and ecological devastation and you have the recipe for disaster. However, there is light at the end of the tunnel should we choose to see it soon enough. From both the supply and demand sides, there are copious climate, energy and water options that can help us mitigate much of our dangerous interfering actions and adapt to the changes that will inevitably come. California business, consumers and water managers will require the drive, resources and technology to employ the most innovative techniques to use *less* water and do *more* with what we have.

By looking to our global neighbors, we can gain the ancillary support to learn what works and what doesn't. Societies with less water and less money are coming up with solutions that work. In areas where there simply isn't enough liquid to satisfy the needs of the people and their surroundings, additional water supply can be produced using technologies such as desalination plants and more water wells. From drip irrigation and indirect potable reuse operations to rainwater harvesting, California can come to the necessary compromises with our rains, oceans and landscapes. We can better our interactions with the natural world.

The realization that climate change will be a force to reckon with is becoming more widely accepted. Efforts to not only cap dangerous greenhouse gas emissions but also sequester that which we have already produced must become widespread, and quickly, or we will feel the heat of our decisions before we can adequately prepare. The more we do now, the less our water supply will be affected in the future.

9. Literature Cited

1. **Alternative** Energy Hydro Power: *News and Information about Hydro Electric Power Technologies*. 2011. http://www.alternative-energy-news.info/technology/hydro/

2. **Animal** Science. University of California, Davis. *California Hydroelectric Power Projects.* August 2008. http://animalscience.ucdavis.edu/PulsedFlow/hydro.htm

3. **Arachnoid**. Natural History: *Lake Mead Water Levels- Historical and Current.* 2011. http://vps.arachnoid.com/NaturalResources/index.html

4. **Australian** Government. *Water for the Future.* October 2010. http://www.environment.gov.au/water/publications/action/pubs/water-for-the-future.pdf

5. **Big Sky** Carbon Sequestration Partnership. *Frequently Asked Questions.* Montana State University. 2010. http://www.bigskyco2.org/whatisit/frequently_asked_questions/answers

6. **Butler**. *Map of the Amazon.* 2010. http://rainforests.mongabay.com/amazon/amazon_map.html

7. **California Climate** Adaptation Strategy 2009: *A Report to the Governor in Response to Executive Order S-13-2008*. California National Resources Agency. 2009. http://www.energy.ca.gov/2009publications/CNRA-1000-2009-027/CNRA-1000-2009-027-F.PDF

8. **California's Water** Crisis: A Public Education Project. 2009. www.californiawatercrisis.org

9. **Carpenter**, Susan. The Los Angeles Times: Environment. *Australia's Water Crisis Offers Clues for California.* January 2010. http://latimesblogs.latimes.com/greenspace/2010/01/australian-water-crisis-provides-clues-for-california-at-gday-usa.html

10. **Celsius**. *Climate Change: Dire Consequences for California's Agriculture.* 2011. http://www.celsias.com/article/climate-change-dire-consequences-californias-agric/

11. **Climate Central**: *The Keeling Curve*. August 2010. http://www.climatecentral.org/gallery/graphics/keeling_curve/

12. **Climate Institute**. *Oceans and Sea Level Rise: Consequences of Sea Level Rise on the Oceans.* 2010. http://www.climate.org/topics/sea-level/index.html

13. **Colorado** River Commission of Nevada. *Annual Financial Reports.* June 2009. http://crc.nv.gov/index.asp

14. **Cubed**, M. and the Aspen Environmental Group. *2005 Integrated Energy Policy Report: Potential Changes in Hydropower Production from Global Climate Change in California and the Western United States.* June 2005. http://www.energy.ca.gov/2005publications/CEC-700-2005-010/CEC-700-2005-010.PDF

15. **Department of Finance**: *Demographic Research.* 2011. http://www.dof.ca.gov/research/demographic/

16. **Department of Water Resources**: *An Interagency Work Team's Plan for Assessing Risks of Climate Change on Management of California's Resources*. October 2005. http://baydeltaoffice.water.ca.gov/climatechange/FIHMCPaperDWR-ReclamationClimateChangeOct05.pdf

17. **Department_______**: *Climate Change in California*. June 2007. http://www.water.ca.gov/climatechange/docs/062807factsheet.pdf

18. **Department_______**: *California State Water Project Supply History*. 2011. http://www.water.ca.gov/swp/watersupply.cfm

19. **Department_______**: *Managing an Uncertain Future: Climate Change Adaptation Strategies for California's Water.* October 2008. http://www.water.ca.gov/climatechange/docs/ClimateChangeWhitePaper.pdf

20. **Department_______**: *Progress on Incorporating Climate Change in Management of California's Water Resources.* July 2006. http://baydeltaoffice.water.ca.gov/climatechange/DWRClimateChangeJuly06_update8-2-07.pdf#pagemode=bookmarks&page=1

21. **Duke** University: Bio 217: Ecology and Global Change. *Fish Species Example,* Spring 2010. http://www.duke.edu/web/nicholas/bio217/lsm11/fish.htm

22. **Earth** News. *Water Shortages Looms in Israel, but Supply to Jordan Continuing.* 2008. http://www.earthportal.org/news/?p=958

23. **Earth** Observatory. NASA: Goddard Institute for Space Studies. *Earth's Temperature Tracker.* November 2007. http://earthobservatory.nasa.gov/Features/GISSTemperature/giss_temperature.php

24. **FAO** Corporate Document Repository. National Resources Management and Environment Department. *Irrigation Water Management: Irrigation Methods.* 2011. http://www.fao.org/docrep/s8684e/s8684e07.htm#TopOfPage

25. **Geerts**, Bart. Water Encyclopedia: Science and Issues. *Global Warming and the Hydrological Cycle.* 2011. http://www.waterencyclopedia.com/Ge-Hy/Global-Warming-and-the-Hydrologic-Cycle.html

26. **Intergovernmental** Panel on Climate Change. *Publications and Data: IPCC Reports.* 2011. http://www.ipcc.ch/publications_and_data/publications_and_data.shtml

27. **Invest** in Israel. *Israel's Novel Efficient Water Technologies.* 2010. http://www.investinisrael.gov.il/NR/exeres/31B1D285-4DCB-49FE-A76A-8408A3811675.htm

28. **Kiparsky**, Michael and Peter H. Gleick. *Climate Change and California Water Resources*: A Survey and Summary of the Literature. Pacific Institute for Studies in Development, Environment, and Security, June 2003. http://www.pacinst.org/reports/climate_change_and_california_water_resources.pdf

29. **Latham** & Watkins LLP: *Delta Water Supplies to Two-Thirds of All Californians May Be Restricted By Endangered Species Act Injunction*. 2008. http://www.lw.com/Resources.aspx?page=FirmPublicationDetail&publication=2075

30. **Legislative** Analyst's Office. *Colorado River Water: Challenges for California*. October 1997. http://www.lao.ca.gov/1997/101697_colorado_river/101697_colorado_river.html

31. **Luers**, Amy Lynd, et. al. *Our Changing Climate: Assessing the Risks to California: A Summary Report from the California Climate Change Center.* 2006. http://meteora.ucsd.edu/cap/pdffiles/CA_climate_Scenarios.pdf

32. **Lund**, J. Ray, Ellen Hanak, William Fleenor, Richard Howitt, Jeffrey Mount and Peter Moyle. *Envisioning Futures for the Sacramento-San Joaquin Delta*. Public Policy Institute of California. 2007. http://books.google.com/books?hl=en&lr=&id=HR9A--fs2qoC&oi=fnd&pg=PR3&dq=sacramento-san+joaquin+delta+vulnerability&ots=toInFT58Vo&sig=BlcR7qzCPc8cS0RU5yrZhasem4A#v=onepage&q=sacramento-san%20joaquin%20delta%20vulnerability&f=false

33. **Mandia**, Scott. *Global Warming: Man or Myth?* Climate Change Impacts on Mediterranean Ecosystems. October 2010. http://profmandia.wordpress.com/2010/10/24/climate-change-impacts-on-mediterranean-ecosystems/

34. **McKeown,** Alice and Gary Gardner. State of the World 2009: *Climate Change Reference Guide and Glossary.*

35. **Metropolitan** Water District of Southern California. *California's Colorado River Allocation*. March 2009. http://www.mwdh2o.com/mwdh2o/pages/yourwater/supply/colorado/colorado04.html

36. **NASA** Science: Earth. *Climate Variability.* May 2010. http://science.nasa.gov/earth-science/oceanography/ocean-earth-system/climate-variability/

37. **National** Geographic: *Five Global Warming "Tipping Points."* October 2010. http://news.nationalgeographic.com/news/2009/03/photogalleries/tipping-points-climate-change/photo5.html

38. **Pachauri**, R. K. State of the World 2009: *Foreword*.

39. **Reuters**. *Arid Israel Recycles Waste Water on Grand Scale.* November 2010. http://www.reuters.com/article/2010/11/14/us-climate-israel-idUSTRE6AD1CG20101114?pageNumber=1

40. **Rice** Space Institute. Rice University and the Houston Museum of Natural Science. *Earth's Distribution of Water.* 2010. http://earth.rice.edu/mtpe/hydro/hydrosphere/hot/freshwater/0water_chart.html

41. **Romick**, Kevin. *Our Precarious Levee System*. February 2009. http://romickinoakley.wordpress.com/2009/02/14/our-precarious-levee-system/

42. **Sacramento** Bee. *California's Water Shortages.* February 2009. http://www.sacbee.com/378/story/1641720.html

43. **Salt** River Project: *The Water Around Us*. 2011. http://www.srpnet.com/education/water101.aspx

44. **San Diego** Natural History Museum. Exhibits: *Water: A California Story*. 2011. http://www.sdnhm.org/exhibits/water/castory.html

45. **Scientific** American. *Baked Australia: Water Management Lessons for the World from Down Under*. November 2009. http://www.scientificamerican.com/article.cfm?id=australia-water-management

46. **Schmidt**, Gavin and Joshua Wolfe. Climate Change: Picturing the Science. W.W. Norton & Company, 2008.

47. **Sir Alister** Hardy Foundation for Ocean Sciences. *Marine Climate Change Impacts*. 2006. http://www.sahfos.ac.uk/climate%20encyclopaedia/sealevelchanges.html

48. **Solcomhouse**: *The Hydrological Cycle*. 2011. http://www.solcomhouse.com/hydrologiccycle.htm

49. **Trager** Water Report. *Central Valley: Reclamation Boosts Efforts to Meet Water Delivery Needs.* June 2010. http://tragerwaterreport.wordpress.com/category/central-valley-project/

50. **Union** of Concerned Scientists. California Climate Choices: *Global Warming and California's Water Supply*. 2010. http://www.ucsusa.org/assets/documents/global_warming/ucs-ca-water.pdf

51. **UnitedNations** Radio. *Drip Irrigation Makes Efficient Use of Scarce Water Resources.* March 2010. http://www.unmultimedia.org/radio/english/detail/92662.html

52. **United** States Environmental Protection Agency: *Green House Effect*. October 2006. http://www.epa.gov/climatechange/kids/greenhouse.html

53. **United** States Geological Survey: *Grinnel Glacier from Mt. Gould.* 2009. http://www.nrmsc.usgs.gov/repeatphoto/gg_mt-gould.htm

54. **United_______**: *How Much Water is There In, On, and Above the Earth?* November 2010. http://ga.water.usgs.gov/edu/earthhowmuch.html

55. **University** of California: California Agriculture. *California Wine Industry Evolving to Compete in the 21st Century*. 2008. http://www.google.com/imgres?imgurl=http://ucce.ucdavis.edu/files/repository/calag/img6201p12.jpg&imgrefurl=http://californiaagriculture.ucanr.org/landingpage.cfm

56. **University_______**: *Structural Adjustment, Resources, Global Economy to Challenge California Agriculture.* 2000. http://www.google.com/imgres?imgurl=http://ucce.ucdavis.edu/files/repository/calag/tab5404p17thumb.jpg&imgrefurl=http://californiaagriculture.ucanr.org/landingpage.cfm

57. **Water** Footprint Network. *Global Water Footprint: Footprint of Nations.* 2011. http://www.waterfootprint.org/?page=files/WaterFootprintsNations

58. **Wikipedia**. *Public Utility*. December 2010. http://en.wikipedia.org/wiki/Public_utility

59. **Wilkinson**, Robert C., 2002. *The Potential Consequences of Climate Variability and Change for California, The California Regional Assessment,* Report of the California Regional Assessment Group

for the U.S. Global Change Research Program, National Center for Geographic Information Analysis, and the National Center for Ecological Analysis and Synthesis, University of California, Santa Barbara.

60. **World** Bank Group. *World Bank Projects in Watershed and Management.* 2010. http://web.worldbank.org/WBSITE/EXTERNAL/EXTOED/EXTWATER/0,,contentMDK:22558482~pagePK:64829573~piPK:64829550~theSitePK:6817404,00.html

61. **World** Wildlife Federation. *Cuts to Water Allocations in the Murray-Darling Basin are Inevitable.* 2011. http://www.wwf.org.au/ourwork/water/

62. **Worldometers**. *Water Consumption: Uses and Methods.* 2011. http://www.worldometers.info/water/