Global Warming Effects on Water In the Great Basin

An Interactive Qualifying Project Report

Submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

By

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May 21 2009

Approved: ______________________________

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Abstract

The struggle to supply fresh water to the overwhelming demand in the American Southwest faces many challenges. The region's economy is growing at a fast pace and the water supply is very limited. Global warming could give rise to a number of problems for the Great Basin's water supply. This study explores the geology, climate, and economic development of the Great Basin. This inquiry provides insight into the kinds of problems the Great Basin can be expected to face in the relatively near future. A case study with the Humboldt River suggests possible ways to protect the water supply by examining ways to better retain the limited supply available.

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1 Introduction

The Great Basin is located in the American Southwest and consists of most of Nevada, the western half of Utah, and small parts of California, Idaho, Oregon, and Wyoming. The Great Basin is thought to have formed due to tectonic plate shifting, especially the Pacific Plate moving north relative to the North American Plate. This effect caused the crust of the Earth to be stretched apart and is still the underlying reason for frequent earthquakes in California. The Sierra Nevada and mountains to the West of the Basin thus formed from the uplifted side of overlapping plates known as ranges, and low valleys formed from the crust thrown downward known as basins. The Great Basin is composed of a series of basins surrounded on all four sides by mountain ranges: the Sierra Nevada to the west, the Rocky Mountains to the east, the Colorado Plateau to the south, and the Columbia plateau to the north. It acts as a highway for fresh water to be delivered from snow and precipitation in the mountains to terminal lakes, never reaching salt water.

Figure 1.1: The Great Basin

<http://www.fs.fed.us/rm/boise/research/gis/maps.shtml>

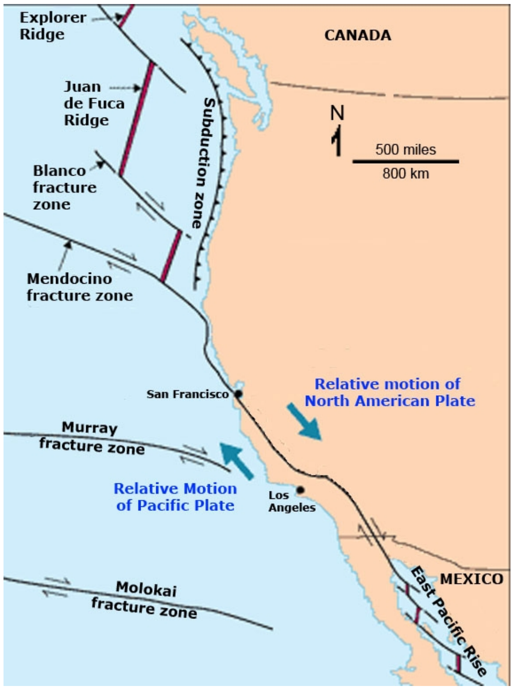

Figure 1.2: The North American and Pacific Tectonic Plates

<http://pubs.usgs.gov/gip/dynamic/understanding.html>

The Great Basin is known for its barren terrain and arid climate. One reason for its barrenness is the rain shadow effect caused by orographic precipitation. As moist air travels up the Sierra Nevada, the highest range in the United States, it begins to cool as it reaches the mountain tops. At this point the moist air condenses into rain or snow and then falls down onto the mountain in the direction of the wind. The remaining water is mostly absorbed by the warm wind, leaving the valley on the other side relatively dry.[1] This helps to explain why on the western side of the Sierra Nevada the annual precipitation is approximately 30 inches, whereas on the eastern side it is only 10 inches over the course of five miles.[2] This effect causes the dew point to rise on the side of the mountain over which the warm air travels, causing the region to become more arid. The arid climate resulting from this rain shadow effect gives rise to the importance of the fresh water within the Great Basin.

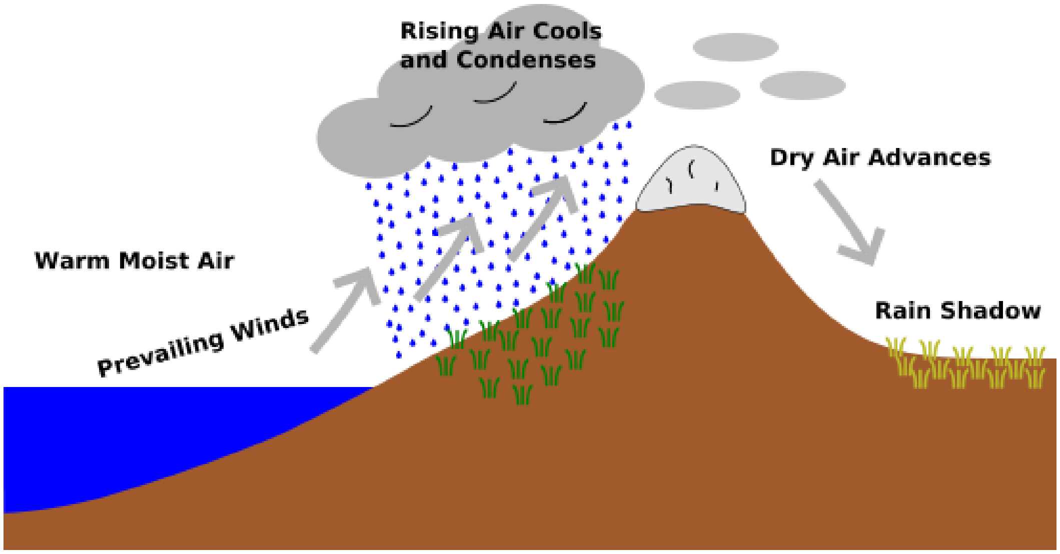

Figure 1.3: The Rain Shadow Effect
<http://commons.wikimedia.org/wiki/File:Rain_shadow.svg>

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[1] *Whiteman, C. David (2000). Mountain Meteorology: Fundamentals and Applications. Oxford University Press.* ISBN 0-19-513271-8.

[2] Christensen, Jon. "What is the Great Basin?" Great Basin Web. 24 May 2009 <http://www.greatbasinweb.com/whatisgreatbasin.html>.

1.1 Description of the Area

The weather in the Great Basin varies with the season and locality. The harshest part of the Great Basin is Death Valley, a 3000 square mile area of desert wasteland where the summer temperatures reach over 115 degrees Fahrenheit but the winter temperatures fall below freezing.[3] At its lowest point the Basin is 282 feet below sea level, the lowest elevation in the United States, where approximately 2.1 inches of rain falls each year. On the other end of the spectrum are its 15 mountain ranges with summits over 11,000 feet. The California White Mountains are the highest, reaching 14,246 feet. The higher elevations receive precipitation from the moisture traveling eastward during autumn, winter, and spring. The lower arid regions don't receive much precipitation until late summer.

The climate of California is a great example which demonstrates the two ends of the spectrum in the Great Basin. The arid southeastern areas of California in Death Valley and the cold northeastern territories such as Boca are in the Great Basin. Temperatures records in these areas span from -45° F to 134° F. "The lowest temperature recorded in the State was at Boca, 5,532 feet in Nevada County, when a reading of minus -45° F. was observed on January 20, 1937. Here at Boca where sub-freezing temperatures have been recorded in every month of the year, the long-term average minimum for January is only 8° F. Greenland Ranch, on the other hand, at an elevation of 168 feet below sea level, has reported a maximum temperature of 134° F. This temperature record, the highest observed anywhere in the United States, occurred on July 10, 1913. Temperatures there

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[3] Death Valley's incredible weather. 24 June 2000. US Geological Survey Western Earth Surface Processes Team and the National Park Service. 3 Dec. 2009 <http://www.nature.nps.gov/geology/usgsnps/deva/weather.html>.

are persistently high throughout the summer and comfortably cool in winter. In the summer of 1917 there were 43 consecutive days with maximum readings exceeding 120° F at Greenland Ranch.[4]

Weather in the Great Basin thus varies as greatly as the elevation. Overall the summer is hot, humid, and known for its intense thunderstorms; in the higher elevated regions, however, it can snow at any point during the year. Besides this precipitation, the Great Basin is a predominantly arid area for the reasons discussed in the Introduction. There are no outlets for water, so any water that is brought in by rain leaves by evaporation. If precipitation patterns are to face changes, the amount of snowpack, available fresh water, and flow rate of river will all change. Ultimately the water sources of the Great Basin will feel the consequences of global warming.

4Climate of California. Western Regional Climate Center. 15 Apr. 2009 <http://www.wrcc.dri.edu/narratives/CALIFORNIA.htm>.

2 Changes in Atmospheric Greenhouse Gases

According to the Energy Information Administration of the United States, greenhouse gases (carbon dioxide, methane, and nitrous oxide) in the atmosphere capture sunlight that reflects off the Earth as infrared radiation heading to space. The greenhouse gases trap some of this escaping heat within the atmosphere. When this process is stable, the amount of energy captured from the Sun should equal the amount of energy that radiates into space. This behavior, known as the greenhouse effect, helps the Earth's surface remain near a constant temperature.[5]

When greenhouse gas levels increase due to human activity, the planet's atmosphere captures even more infrared radiation. As Science magazine states, "The greenhouse gases trap outgoing radiation from the Earth to space, creating a warming of the planet."[6] In a sense, the stability of the Earth's surface temperature is like an equation. Global warming is an imbalance in the equation, because although there should be a stability between the energy the Earth receives as sunlight and the amount of energy it reflects back towards space, increased levels of the greenhouse gases capture more infrared radiation in the atmosphere than history has seen. This additional captured heat causes global temperatures to increase.

The major source of these greenhouse gas emissions is undeniably human energy use. Carbon dioxide emissions began increasing significantly during the Industrial Revolution in the mid-1850s and increased exponentially over the next 150 years. Three-fourths of industrial nations are directly to blame for the changes in these gas levels. Due to carbon dioxide emissions and

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[5] Greenhouse Gases, Climate Change, and Energy. May 2008. Energy Information Administration and the US Government. 4 Apr. 2009 <http://www.eia.doe.gov/bookshelf/brochures/greenhouse/Chapter1.htm>.

[6] Science 302 (2003): 1719-723. Modern Global Climate Change. 29 Oct. 2003. 13 Apr. 2009 <http://www.sciencemag.org/cgi/content/full/302/5651/1719>.

deforestation, the atmosphere's carbon dioxide levels have increased by nearly thirty percent in the past 100 years. Figure 2.1 demonstrates the correlation between average global temperature and atmospheric carbon dioxide concentration as both increased between 1860 and 2000. An extreme increase in both can be seen from 1960 until 2000.

Methane, another major greenhouse gas, is released into the atmosphere by a variety of human activities. Significant sources include our abundant landfills which hide "disposed" waste, pipeline leakage, rice agriculture, and even livestock. Overall, atmospheric methane levels have increased by about 145% in the past century. Nitrous oxide levels have also increased by 15%, primarily as a result of fossil fuel combustion and chemical fertilizer use.[7]

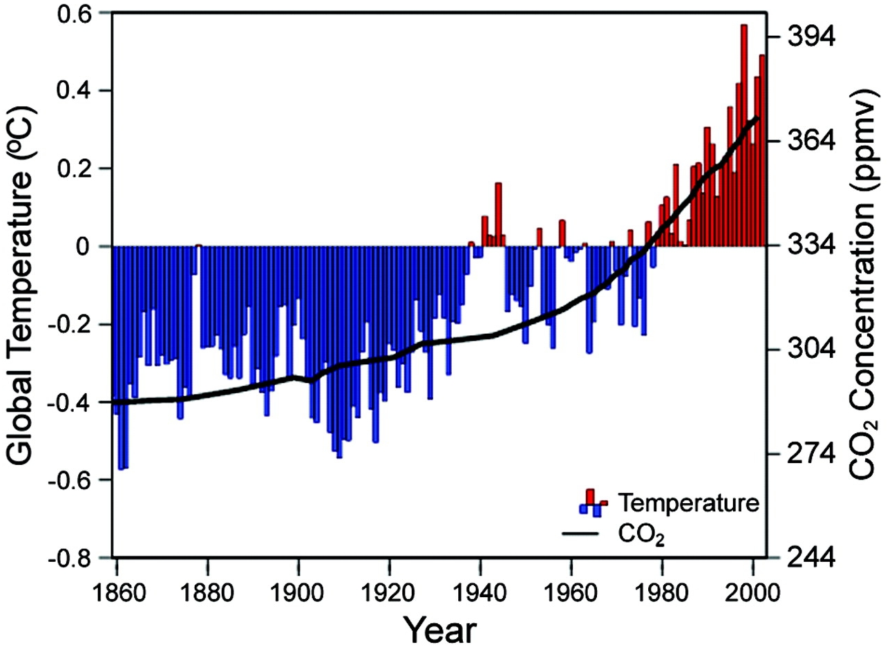

Figure 2.1: Global Temperature vs. Carbon Dioxide Concentration
<http://www.sciencemag.org/cgi/content/full/302/5651/1719/FIG1>

The United States alone accounts for approximately 25% of the world's total carbon dioxide emissions due to its rapid economy. Figure 2.2 illustrates the major sources of United States

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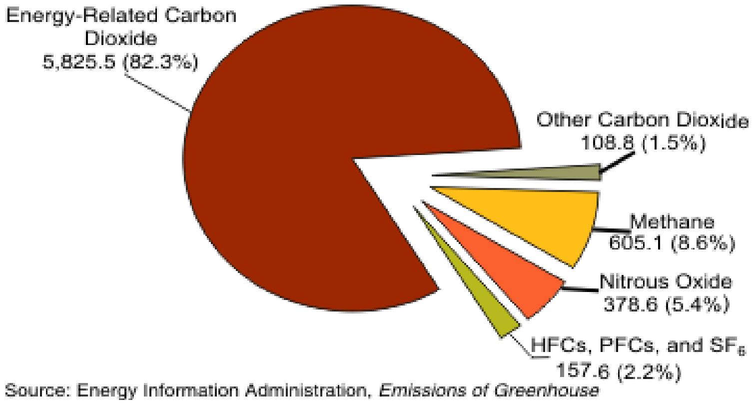
[7] Global Warming <http://www.sierraclub.org/population/reports/globalwarming.asp>

greenhouse gas emissions. Notably, fossil fuel combustion effectively accounts for 82% of total emissions.



Source: Energy Information Administration, *Emissions of Greenhouse Gases in the United States 2006* (Washington, DC, November 2007)

Figure 2.2: Sources of U.S. Gas Emissions, 2006 (Million Metric Tons of Carbon Dioxide Equivalent)
<http://www.eia.doe.gov/oiaf/1605/ggccebro/chapter1.html>

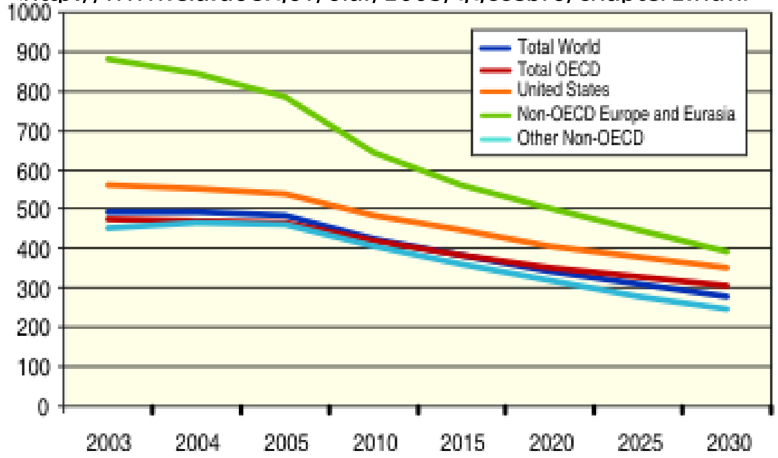


Figure 2.3: Projected Carbon Intensity by Region, 2003-2030 (Metric Tons of Carbon Dioxide per Million 2000 Dollars)
<http://www.eia.doe.gov/oiaf/1605/ggccebro/chapter1.html>

According to the U.S. Department of Energy, "the U.S. is projected to lower its carbon intensity by 25 percent from 2001 to 2025, and remain below the world average."[8] This projection is illustrated in Figure 2.3. Developing countries that have not gone through such an intense industrial revolution as the United States are expected to release nearly double the greenhouse gas emissions

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[8] Greenhouse Gases, Climate Change, and Energy. May 2008. Energy Information Administration and the US Government. 4 Apr. 2009 <http://www.eia.doe.gov/bookshelf/brochures/greenhouse/Chapter1.htm>.

due to their proportionally greater economic and population growth. The United States will still release more emissions than industrialized countries.

Atmospheric greenhouse gas levels are increasing every day and human energy use is conclusively the primary cause. With greenhouse gas emission reduction programs there may be hope for a cleaner atmosphere in the future. If they follow their current trends, however, global warming may pose the devastating effects that have been foretold. Its effects on snowpack and fresh water levels will be major concerns for the Great Basin.

3 Population Growth and Its Effects on the Great Basin

In recent times the population of the Great Basin has grown significantly. Figure 3.1 and Table 3.1 depict the region's population growth over the past twenty years.

State	1990	2000	2007	Growth
Nevada	1,201,833	1,998,257	2,565,382	1,363,549
Utah	1,722,850	2,233,169	2,645,330	922,480
Oregon	2,842,321	3,421,399	3,747,455	905,134
Idaho	1,006,749	1,293,953	1,499,402	492,653
California	29,760,021	33,871,648	36,553,215	6,793,194

Table 3.1: Population Growth in Great Basin States, 1990-2007 <www.census.gov>

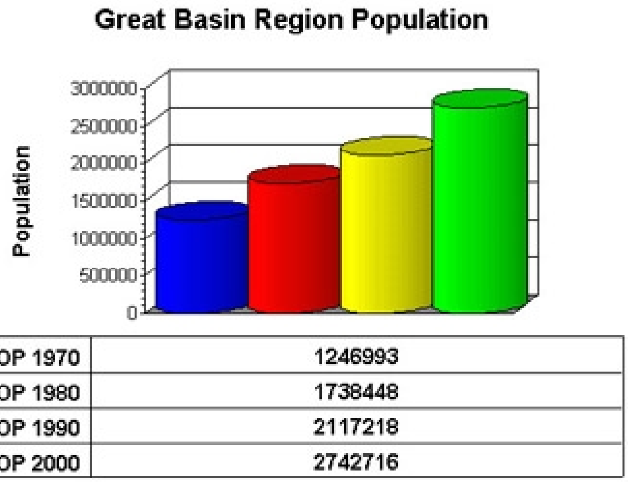

Figure 3.1: Great Basin Region Population, 1970-2000 <http://wtol.envirocast.net/?pagename=ow_regionalWatersheds_16>

It is important to note the contribution of each Great Basin state to the overall population. From Figure 1.1 it can be seen that the Basin includes almost all of Nevada, the western half of Utah, and only a fraction of the other states. Nevada's population has more than doubled in 17 years, and given the population size, it showed the greatest increase of all the states. "Between 1990 and 2006 Las Vegas grew substantially as far as population size is concerned. According to the Center for Business and Economic Research, between 2006 and 2035, Las Vegas is estimated to grow by 86%, which will in turn cause a 74% increased demand for water."[9] Although Las Vegas is technically not part of the Great Basin, it is exemplary of the kinds of problems the Basin faces.

The Great Basin contained 5 out of the fastest growing 10 U.S. states between 1995 and 2008. "The growth is also increasing demands on scarce water resources which are allocated under jurisdiction of state laws based on the Doctrine of Prior Appropriation: water is allocated according to historical issuance of rights, with junior applicants receiving water only after senior holders' needs have been satisfied. In dry, water-short periods, junior holders may not receive any allocations."[10] The senior holders are the longest businesses running on the thinnest profits, with newer businesses receiving junior status. These old laws prevent any new businesses from receiving necessary water in times of drought. As global temperatures heat up, so will arguments over water jurisdiction.

Population growth can also be correlated with the effects of global warming. The Industrial Revolution is solely responsible for creating the means by which so many countries support today's population levels. The massive amounts of deforestation and greenhouse gas emission which came alongside it were brought by it out of necessity. As the world became more industrialized, it created the conditions for global warming which are now apparent.

The increase in population size certainly caused a higher demand for life's necessities, the most important being water and energy in the context of the Great Basin. The nation has a higher standard of living in society today, which leads to wasteful use of energy and resources. Creating

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9<u>Hidden Oasis: Water Conservation and Efficiency in Las Vegas</u>. Rep. Nov. 2007. Pacific Institute and Western Resources Advocate. 25 Apr. 2009 <http://www.pacinst.org/reports/las_vegas/hidden_oasis.pdf>.

10Wagner, Frederic H. PREPARING FOR A CHANGING CLIMATE: The Potential Consequences of Climate Variability and Change. 2003. A Report of the Rocky Mountain/Great Basin Regional Assessment Team for the U.S. Global Change Research Program. 10 Feb. 2009 <http://gaia.econ.utah.edu/planning/seminar/regclimchange.pdf>. Pg 37 more energy has not been a problem in the past; the states simply built more power plants. Creating more water is quite more intricate with an unknown solution. One report concluded, "What this work shows is that, even with a conservative climate model, current demands on water resources in many parts of the West will not be met under plausible future climate conditions, much less the demands of a larger population and a larger economy."[11] This means that even if the Great Basin doesn't face serious drought as seen to happen every 5-7 years, the effects of the Great Basin population doubling in the past twenty years will place extreme restrictions upon water usage.

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[11] Barnett, Tim, and Robert Malone. THE EFFECTS OF CLIMATE CHANGE ONWATER RESOURCES IN THEWEST: INTRODUCTION AND OVERVIEW. Rep. 2000. 2 Nov. 2008 <http://wwa.colorado.edu/western_water_law/docs/West_CCEffectsonWest.pdf>.
pg 6

4 Climatologists' Convention of 1998

On September 10th of 1998, a seminar of twelve climatologists specializing in western U.S. climates met for three days at the National Center for Ecological Analysis and Synthesis in Santa Barbara, CA to discuss possible outcomes. Using computer simulations that take into account atmosphere, earth, and ocean, the climatologists analyzed climate change possibilities. They further went on to use climate records from the 20th century. One major dilemma they faced was that the Great Basin and Rocky Mountain regions have three unique climates that differ greatly. Additionally, records of climate changes only go back approximately 100 years, which limits the simulations' ability to take into account historical trends.

Thomas J. Stohlgren concluded on the assessment approach that, "Accurate forecasts of future regional climate due to a doubling of CO2 are not possible now because of limited global climate predictability from nonlinear effects and the neglect of important direct and feedback effects on climate."[12] However, John Fyfe stated that "the summer would become warmer and drier and the winters warmer and wetter."[13] Fyfe went on to examine the 20-year return values for daily temperature and precipitation, which simply show a known temperature range for twenty years (1955-1975) and then predicts the temperature range of future twenty year periods based on greenhouse gas increases.

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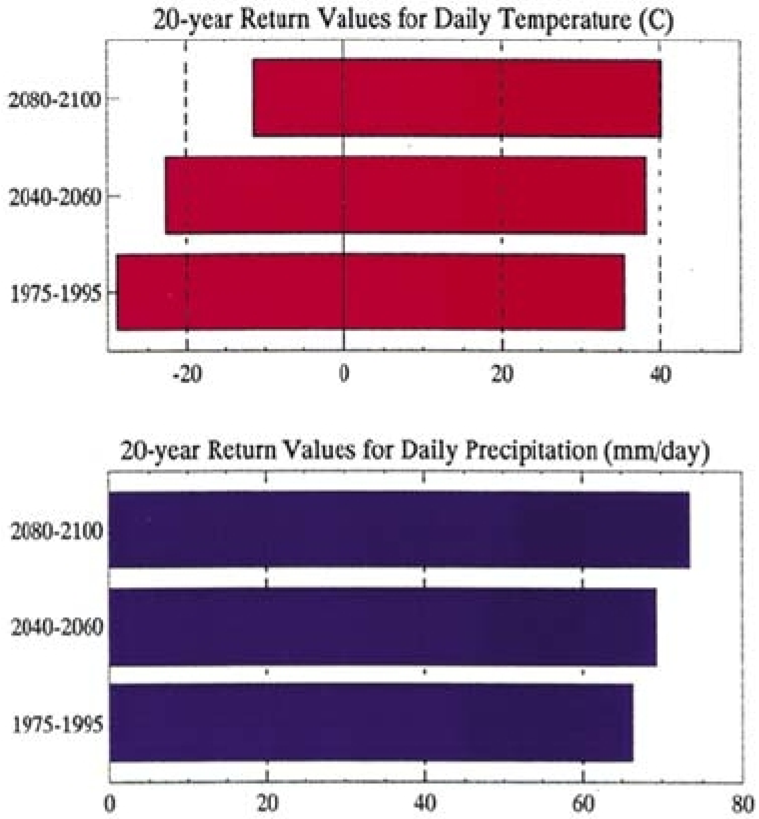
[12] Wagner, Frederic H. PREPARING FOR A CHANGING CLIMATE: The Potential Consequences of Climate Variability and Change. 2003. A Report of the Rocky Mountain/Great Basin Regional Assessment Team for the U.S. Global Change Research Program. 10 Feb. 2009 <http://gaia.econ.utah.edu/planning/seminar/regclimchange.pdf>. Pg. 43

[13] Ibid Pg. 46


20-year Return Values for Daily Temperature (C)

20-year Return Values for Daily Precipitation (mm/day)

Figure 4.1: Projected Temperature and Precipitation Ranges in the Great Basin for Current (1975-1995), Doubled (2040-2060), and Tripled (2080-2100) Levels of Atmospheric Carbon Dioxide
<http://gaia.econ.utah.edu/planning/seminar/regclimchange.pdf>

The graphs in Figure 4.1 display ranges of temperature and precipitation in the present day climate (1975-1995) and projected ranges for a climate with double the carbon dioxide content (2040-2060) and a climate of triple the carbon dioxide content (2080-2100). According to these projections, the minimum daily temperature will rise more quickly than the maximum temperature. Precipitation will increase on average—warmer water will evaporate more quickly, leading to larger or more frequent rainstorms. More precipitation does not necessarily mean more water everywhere nor at all times, but combined with higher average temperatures it can be expected that rainfall will increase more than snowfall. This causes an increased streamflow earlier in the season due to less snowpack and higher temperatures, leaving less streamflow for the later and higher temperature months that also receive much less precipitation. This is one of the most crucial problems arising from the expected impact of global warming on the Great Basin.

In his discussion Stohlgren announces that "global-scale climate models may be inappropriate for developing regional and subregional scenarios due to: (1) poor topographic and spatial resolution (Fig. 3.10); (2) systematic biases (Doherty and Mearns 1999)[14]; (3) lack of biophysical feedbacks and land-use change effects which are known to affect, although to unknown degrees, local, regional, and global climate; (4) inability to assess the spatial accuracy and actual probabilities of modeled outputs; and (5) limited ability to assess multiple ecosystem stresses (i.e., deforestation, exotic species, air pollution,etc.)."[15] Due to the limitations in their models' analysis of these variables, the climatologists knew they could not find a guaranteed answer. However they showed that global warming was affecting higher elevations more quickly. They conclude that climate monitoring is vital, especially in higher elevated areas, and that a network of sensors would generate the necessary data for further analysis.

4.1 The Problem: Water Shortage

Water is the most vital resource on the planet. Due to global warming and economic growth there may not be enough water for everyone in the Southwest before the next century. The average global temperature increased by approximately 1.5 degrees Fahrenheit during the 20th century. The temperature in the western U.S. may increase by "3.6 to 12.6 degrees Fahrenheit by the end of the

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[14] Doherty, R and L.O. Mearns. 1999. A comparison of simulations of current climate from two coupled atmosphere-ocean GCMs against observations and evaluation of their future climates. Report to the NIGEC National Office. Nat. Cent. Atmos. Res., Boulder, CO.

[15] Ibid

[21st] century."[16] If a 7.2 degrees Fahrenheit rise took place, precipitation would increase by 15-20%. Higher stream flows from greater rain precipitation in the mountains surrounding the Great Basin would cause the primary water sources, mountain snowpack, in its northern and western portions to melt faster, effectively reducing the year's water supply.

Snowpack is crucial in the Basin, since the water from melting snow gathers in streams, rivers, and eventually lakes and reservoirs. Almost all of the the Great Basin's fresh water supply comes from snowpack on the mountain tops due to the rain shadow effect. "Less snowpack and earlier runoff will mean reduced ability to meet summer irrigation needs, higher water temperatures, and increased conflict between agricultural users."[17] Dettinger and Cayan (1995) comment, "winter temperature trends appear to be involved in a decades-long change in the fraction of runoff occurring in late spring and summer runoff found in the Sierra Nevada and many other snowmelt-driven streams over the western United States [...]. Its dependence on temperature makes snow a key diagnostic in climate change scenarios."[18] With less snowpack forming in the coldest months, the runoff from streams will deplete sooner. The projections made at the climatologists' convention showed increased winter flow with reduced and earlier spring peaks. The climatologists projected that seasonal precipitation increases would exceed present-day levels on a scale of approximately 50-100% higher than current levels. Accordingly, I performed an examination of the Great Basin's snowpack and precipitation levels.

16Chambers, Jeanne C. How the West Will Warm. Rep. Feb. 2008. Rocky Mountain Research Station. 05 May 2009 <http://www.fs.fed.us/rm/pubs/rmrs_gtr204.pdf>.

17Barnett, Tim, and Robert Malone. THE EFFECTS OF CLIMATE CHANGE ONWATER RESOURCES IN THEWEST: INTRODUCTION AND OVERVIEW. Rep. 2000. 2 Nov. 2008 <http://wwa.colorado.edu/western_water_law/docs/West_CCEffectsonWest.pdf>.

18Wagner, Frederic H. PREPARING FOR A CHANGING CLIMATE: The Potential Consequences of Climate Variability and Change. 2003. A Report of the Rocky Mountain/Great Basin Regional Assessment Team for the U.S. Global Change Research Program. 10 Feb. 2009 <http://gaia.econ.utah.edu/planning/seminar/regclimchange.pdf>. Pg 90.

5 Precipitation Levels

Precipitation is defined as any product of the condensation of atmospheric water vapor that is deposited on the earth's surface.[19] When the atmosphere becomes saturated with water vapor due to added water vapor or cooling air, the precipitate forms as rain, snow, or hail. Precipitation plays a crucial role in re-depositing fresh water and acts as the most important variable in both the water cycle and the rain-shadow effect.

Precipitation rates are not always consistent with the previous years. When there is a lack of precipitation, surrounding areas may face droughts. In the past, severe droughts have occurred in the Great Basin during the major water months. This causes a lack of water for society and agriculture. Figures 5.1-5.5 show historical precipitation levels in California, Nevada, Utah, Oregon, and Idaho.

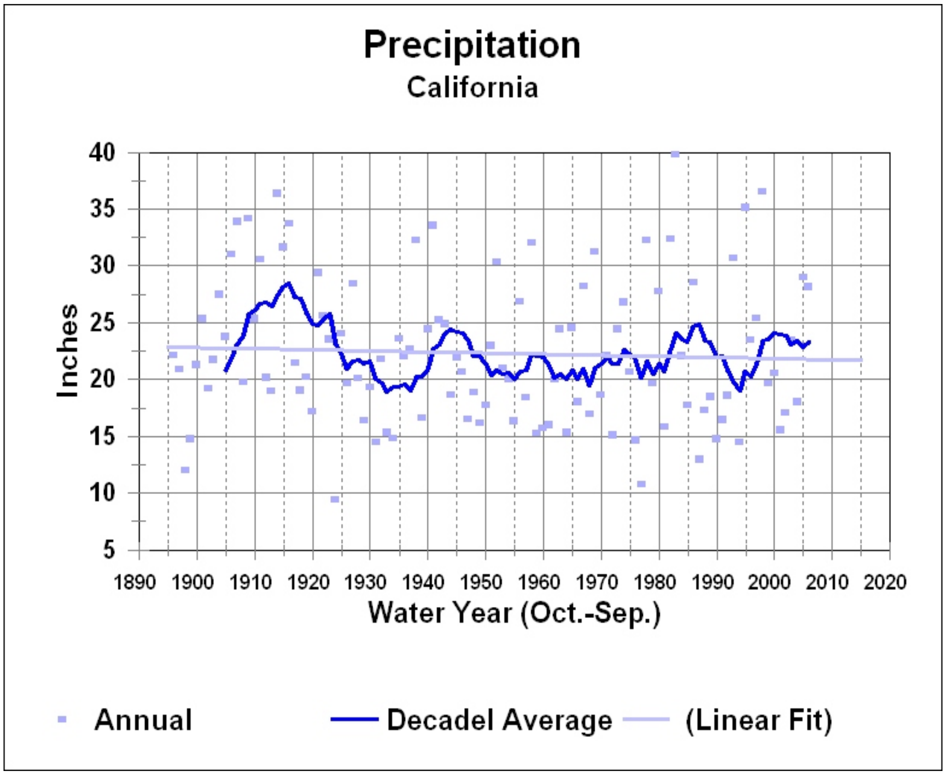

Figure 5.1: Annual and Decadal Average Precipitation in California (Inches)

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[19] *AMS Glossary entry for Precipitation* American Meteorological Society

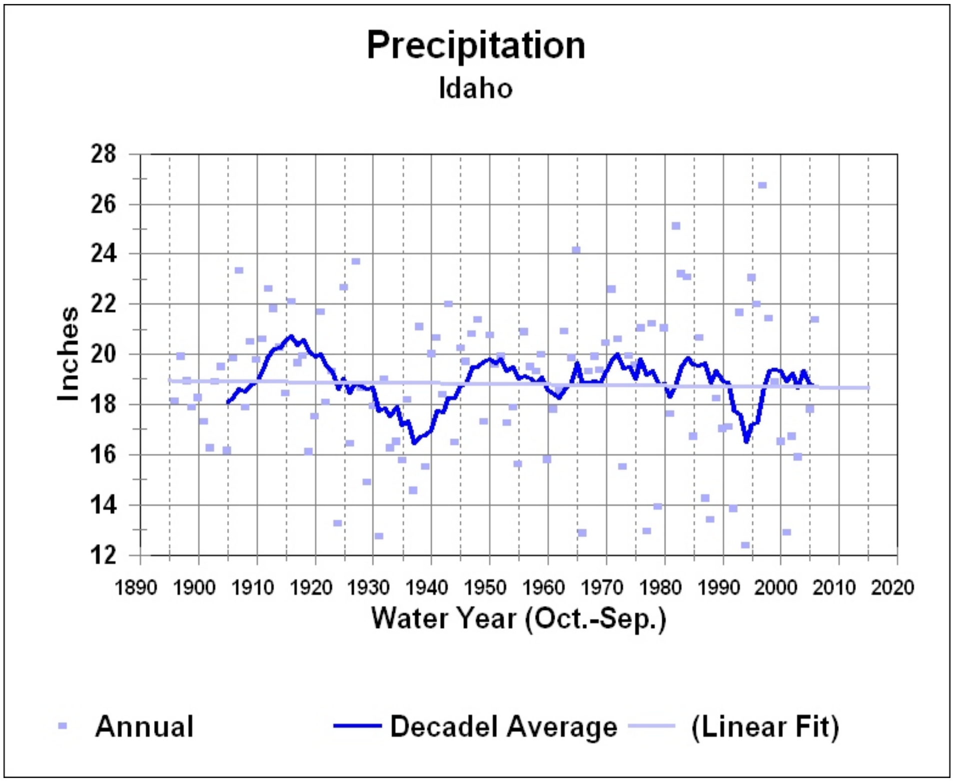


Figure 5.2: Annual and Decadal Average Precipitation in Idaho (Inches)

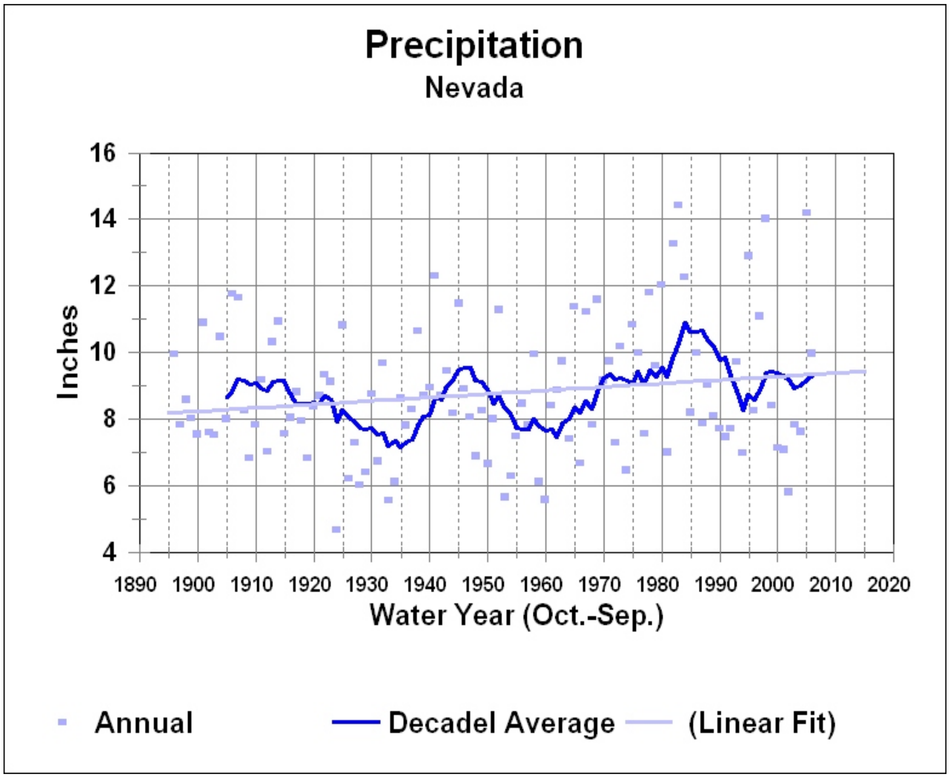


Figure 5.3: Annual and Decadal Average Precipitation in Nevada (Inches)

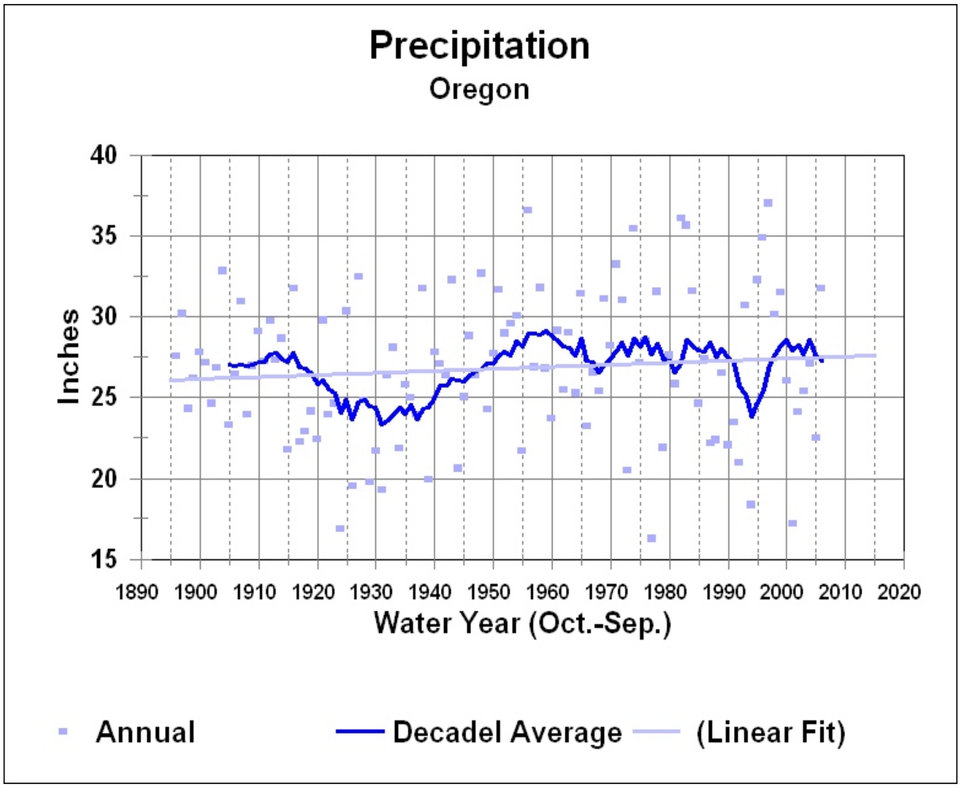


Figure 5.4: Annual and Decadal Average Precipitation in Oregon (Inches)

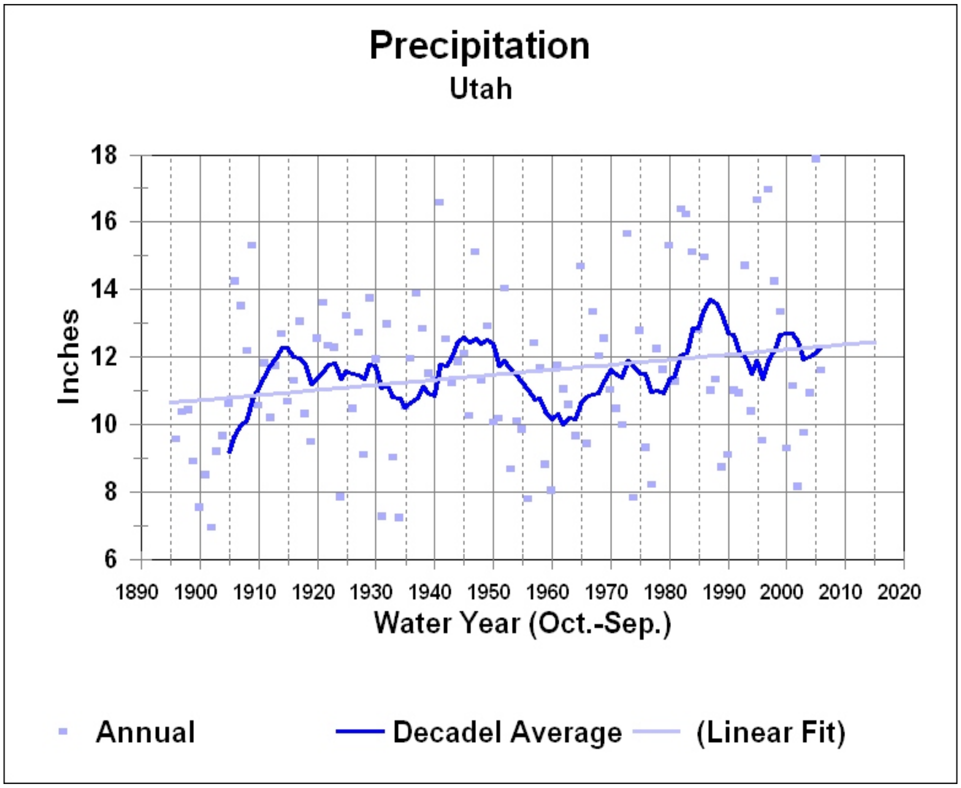


Figure 5.5: Annual and Decadal Average Precipitation in Utah (Inches)

One can immediately see how inconsistent the precipitation patterns are. It appears that every 7-10 years, the precipitation swings heavily from very wet to droughts and severe droughts. However, it is unknown how much of the swing is caused by global warming and how much happens by random occurrence.

	California	**Idaho**	**Nevada**	**Oregon**	**Utah**
Jan	4.15	2.12	0.96	3.79	1.05
Feb	3.95	1.72	0.92	3.16	0.99
Mar	3.55	1.73	1.09	2.93	1.21
Apr	1.4	1.56	0.76	2.18	1.07
May	0.83	1.97	1.01	1.88	1.2
Jun	0.32	1.5	0.63	1.27	0.64
Jul	0.19	0.92	0.51	0.62	0.88
Aug	0.3	0.84	0.63	0.73	1.02
Sep	0.58	1.08	0.71	1.07	1.07
Oct	1.2	1.3	0.75	1.9	1.3
Nov	2.62	2.05	0.81	3.89	0.97
Dec	3.1	2.12	0.72	3.97	0.8
Annual Total	22.19	18.91	9.5	27.39	12.2

Table 5.1: Average Monthly Precipitation, 1971-2000 (Weighted by Land Area)
Data found at <http://www.wrcc.dri.edu/htmlfiles/avgstate.ppt.html>

The average monthly rainfall in each state is shown in tabular form above. This table further illustrates the huge dip which the precipitation rates undergo during the course of an average year. The annual totals of precipitation vary greatly. Nevada constitutes the majority of the Great Basin and receives the least precipitation of the five states. The two states with the least precipitation, Nevada and Utah, also contain the lowest elevations. All five states receive the most precipitation from November until March, at which point it diminishes over the next two months. The summer and autumn months are uniformly the driest.

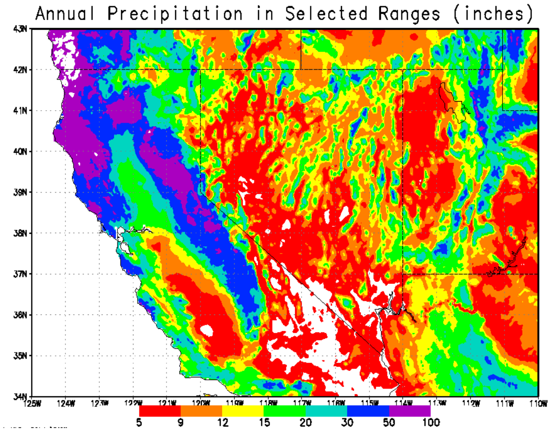


Figure 5.6: Map of Average Annual Precipitation in Great Basin States, 1961-1990 (Inches)
<http://www.wrcc.dri.edu/precip.html>

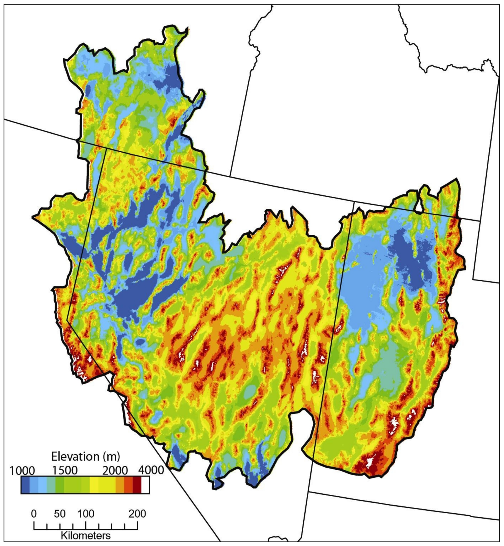
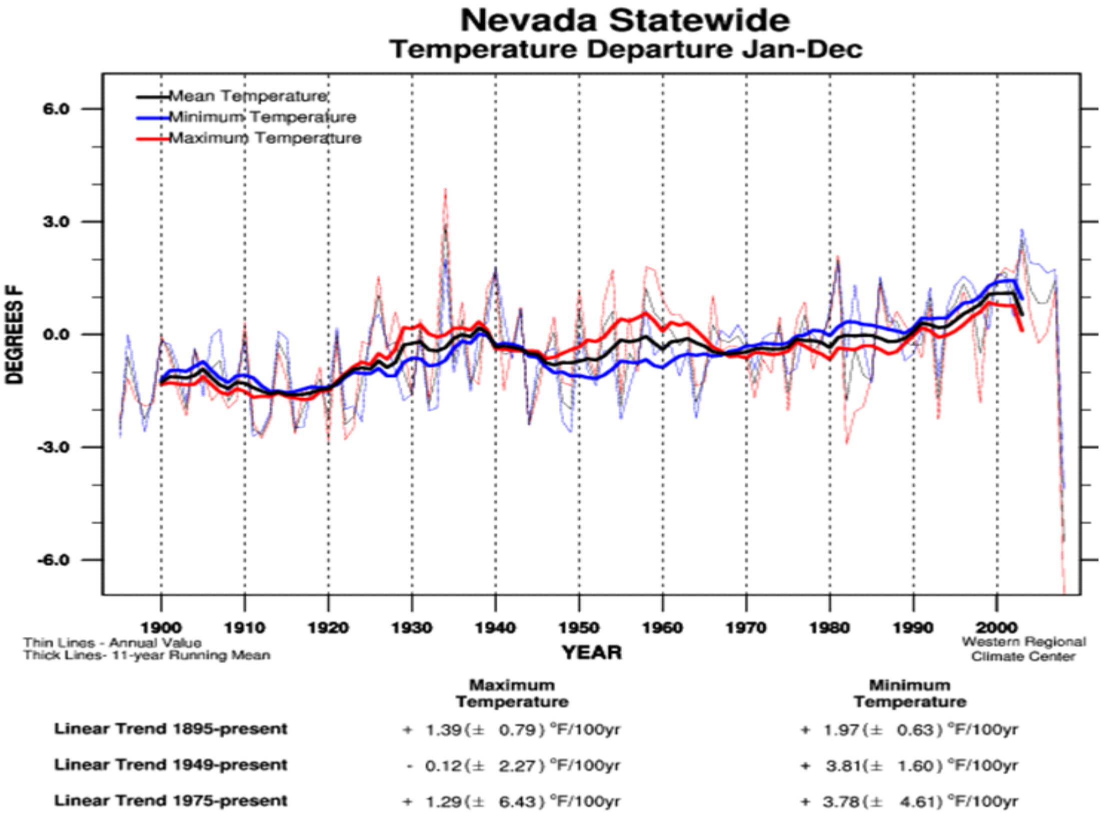


Figure 5.7: Great Basin Topographic Map (Meters)
<http://lcluc.umd.edu/products/pdfs/SigResults2004/SigRes_MustardJ_Jan2004.ppt>

Figure 5.8 contains a color-coded map of the average annual precipitation in the Great Basin. It is clear from this image that a majority of the area receives less than 10 inches of precipitation annually. Comparing the precipitation map with the topographic map in Figure 5.7, it is evident that precipitation is directly proportional to elevation. In particular, the relatively high parts of Nevada in the east and those along the Californian border in the far west receive the most precipitation. The the rest of the state, which is close to sea level, receives the least.



	Maximum Temperature	Minimum Temperature
Linear Trend 1895-present	+ 1.39 (± 0.79) °F/100yr	+ 1.97 (± 0.63) °F/100yr
Linear Trend 1949-present	- 0.12 (± 2.27) °F/100yr	+ 3.81 (± 1.60) °F/100yr
Linear Trend 1975-present	+ 1.29 (± 6.43) °F/100yr	+ 3.78 (± 4.61) °F/100yr

Figure 5.8: Nevada Annual Temperature Summary (1900-2005)
<http://www.wrcc.dri.edu/monitor/nev-mon/index.html>

Precipitation has been seen to be inconsistent year to year based on the data above even though Figure 5.6 shows that temperature levels in the Great Basin (specifically Nevada), have gradually increased approximately 3 degrees Fahrenheit in the past century. This fact helps prove how essential any precipitation that the Great Basin encounters is. With consistent rising temperatures and inconsistent precipitation returns, the ideal system to save as much fresh water is needed. The precipitation form of most importance, is that of snowpack in the Great Basin. "In addition, lower-elevation snowmelt dominated basins might change to rain dominated if cold season temperatures increases are sufficiently large."[20]

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[20] Stewart, Iris T. CHANGES IN SNOWMELT RUNOFF TIMING IN WESTERN NORTH AMERICA UNDER A 'BUSINESS AS USUAL' CLIMATE CHANGE SCENARIO. Rep. 2004. 1Scripps Institution of Oceanography and US Geological Survey. 10 May 2009 <http://meteora.ucsd.edu/cap/pdffiles/stewart_clch.pdf>. Pg. 2

6 Mountain Snowpack Levels

As snowpack melts throughout the year, it moves to waterways. Snowpack normally melts throughout the year, providing much needed fresh water flows to prevent drought in the hot summer months. During warm winters, however, snowpack melts earlier, causing waterways to eventually run dry and drought to set in. "Snowpack, which acts as temporary water storage, provides up to 75 percent of the region's annual water supply. Additional increases in global temperatures will decrease snowpack in the West by as much as 40 percent by 2060."[21] That means in 2060, 30% of the annual water supply relied upon in the Spring will be gone. It has been found that even "a temperature rise of 1.5 degrees Celsius by 2050 resulted in a [calculated] loss of nearly 60% of the 1 April snowpack in the Oregon and Washington Cascades."[22]

Jeanne C. Chamber's stated, "Trends in April 1 snow pack have been negative at most monitoring sites in the Great Basin. Elevation and mean winter temperature have a strong effect on snowpack with the warmest sites exhibiting the largest relative losses."[23] The amount of snowpack formed from January until May clearly deserves careful investigation. The following images were produced by the NRCS (Natural Resources Conservation Service).

21Chambers, Jeanne C. How the West Will Warm. Rep. Feb. 2008. Rocky Mountain Research Station. 05 May 2009 <http://www.fs.fed.us/rm/pubs/rmrs_gtr204.pdf>.

22Ibid

23Chambers, Jeanne C. Climate Change and the Great Basin. Rep. Feb. 2008. Rocky Mountain Research Station. 05 May 2009 <http://www.fs.fed.us/rm/pubs/rmrs_gtr204.pdf>.

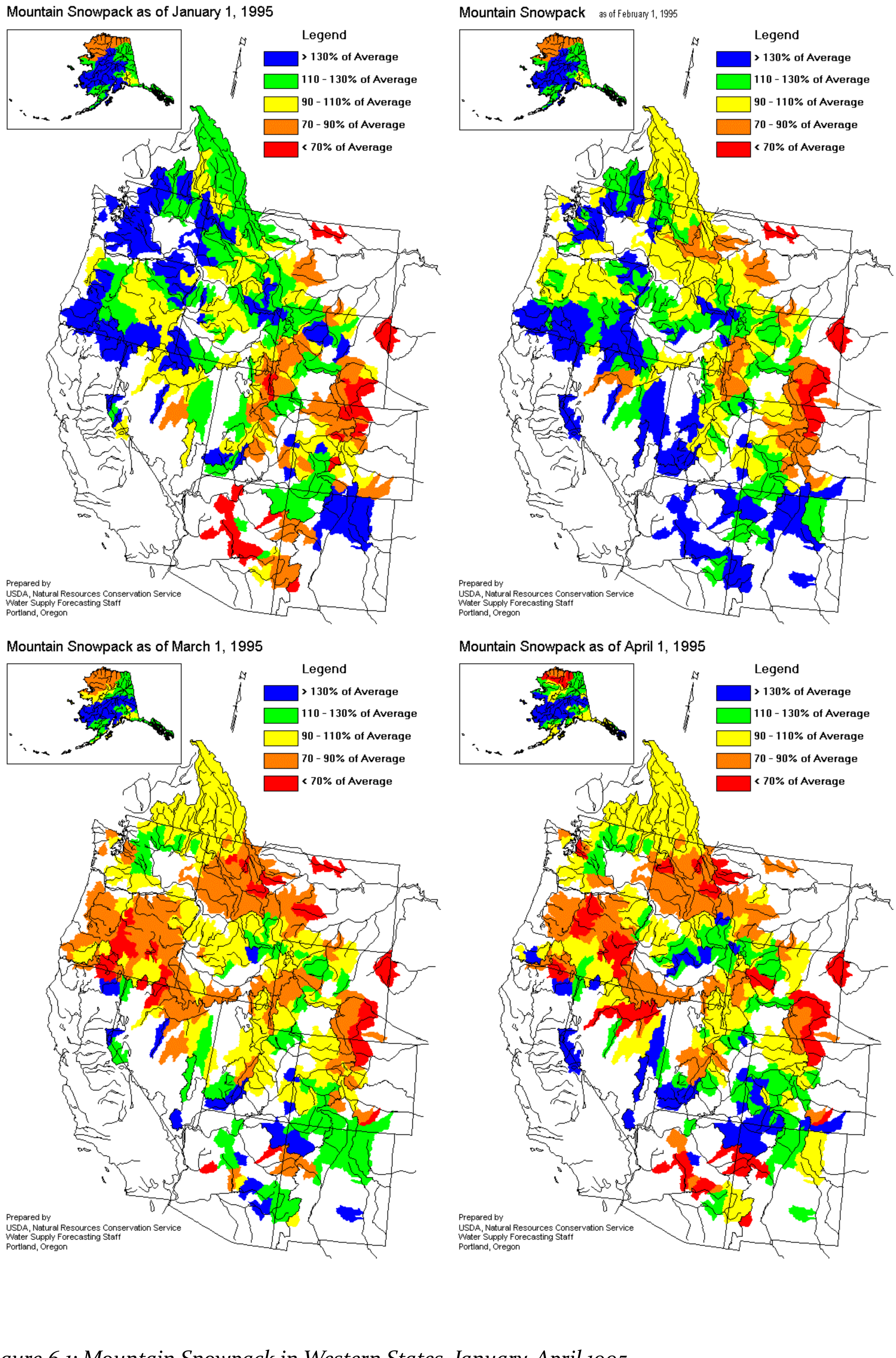
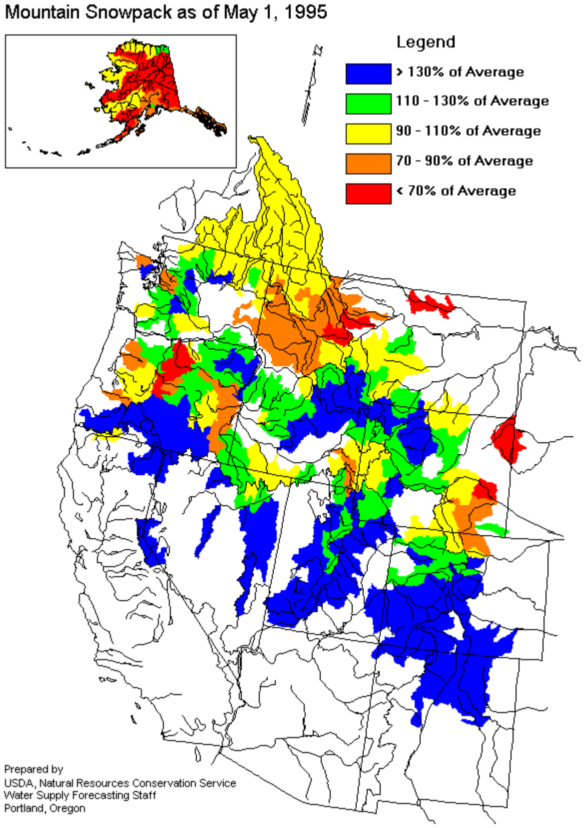


Figure 6.1: Mountain Snowpack in Western States, January-April 1995



Prepared by
USDA, Natural Resources Conservation Service
Water Supply Forecasting Staff
Portland, Oregon

Figure 6.2: Mountain Snowpack in Western States, May 1995

When examining the figures for snowpack formed in 1995, and then 2000, the difference is as noticeable as can be. In 1995, February and May had the most snowpack formed averaging well over 130%. The other months had quite a variety in levels of snowpack but almost all of the Great Basin was above 70% of the average.

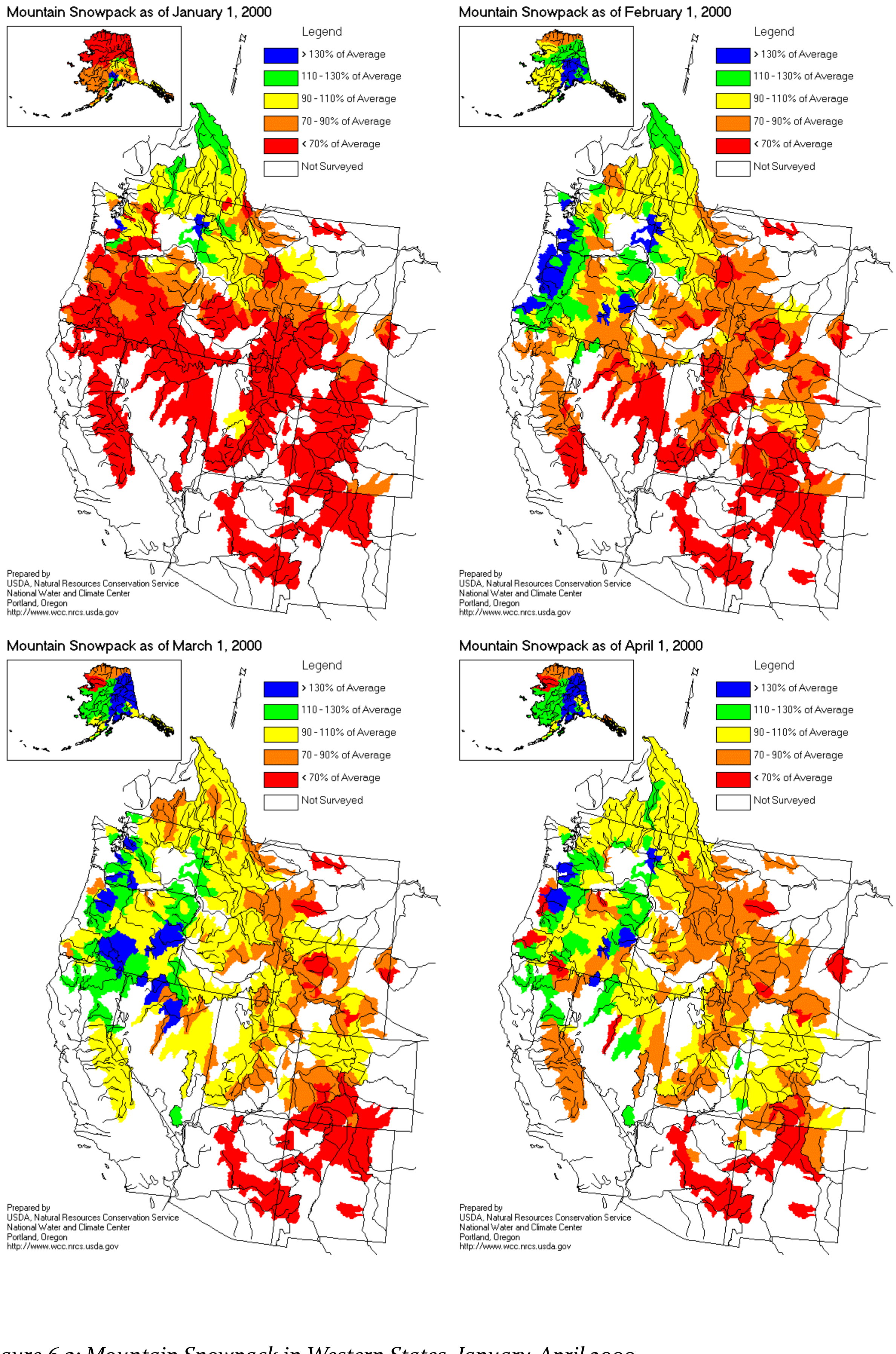


Figure 6.3: Mountain Snowpack in Western States, January-April 2000

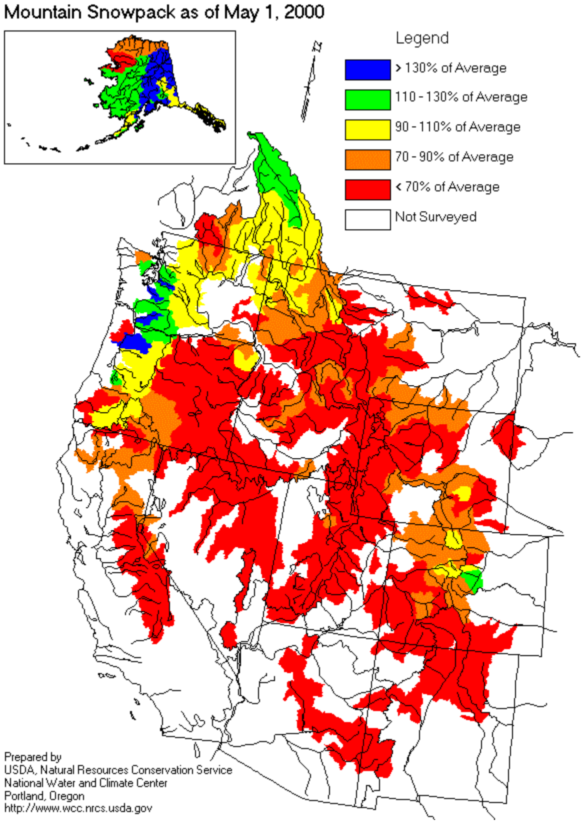
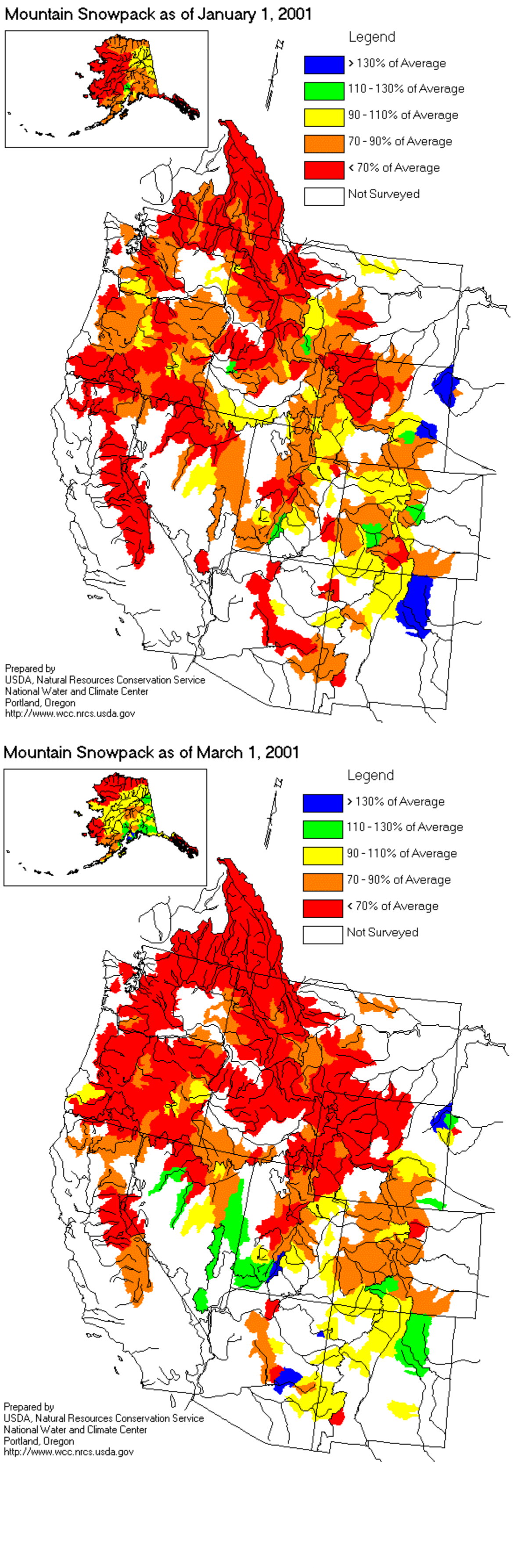


Figure 6.4: Mountain Snowpack in Western States, May 2000

However in 2000, the amount of snowpack formed was drastically different. January and February of 2000 were very dry, with the majority of the Great Basin having less than 70% average snowpack formed. March and April had the highest percentages, with some areas of the Great Basin being as high as 110%, but mostly averaged around 70-90%. In May of 2000, the entire Great Basin had less than 70% of the average amount of snowpack formed.



Mountain Snowpack as of January 1, 2001

Prepared by
USDA, Natural Resources Conservation Service
National Water and Climate Center
Portland, Oregon
http://www.wcc.nrcs.usda.gov

Mountain Snowpack as of February 1, 2001

Prepared by
USDA, Natural Resources Conservation Service
National Water and Climate Center
Portland, Oregon
http://www.wcc.nrcs.usda.gov

Mountain Snowpack as of March 1, 2001

Prepared by
USDA, Natural Resources Conservation Service
National Water and Climate Center
Portland, Oregon
http://www.wcc.nrcs.usda.gov

Mountain Snowpack as of April 1, 2001

Prepared by
USDA, Natural Resources Conservation Service
National Water and Climate Center
Portland, Oregon
http://www.wcc.nrcs.usda.gov

Figure 6.5: Mountain Snowpack in Western States, January-April 2001

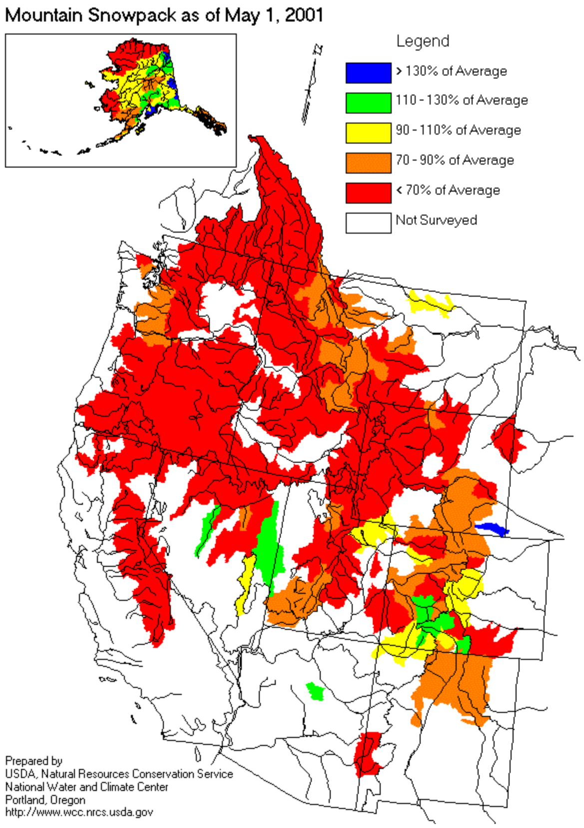


Figure 6.6: Mountain Snowpack in Western States, May 2001

2001 only got drier, with less than 70% of the average snowpack being formed for all five months shown in the majority of the Great Basin. The fact that the eastern border of California received such low snowpack, had very detrimental effects on precipitation passing over into the Great Basin.

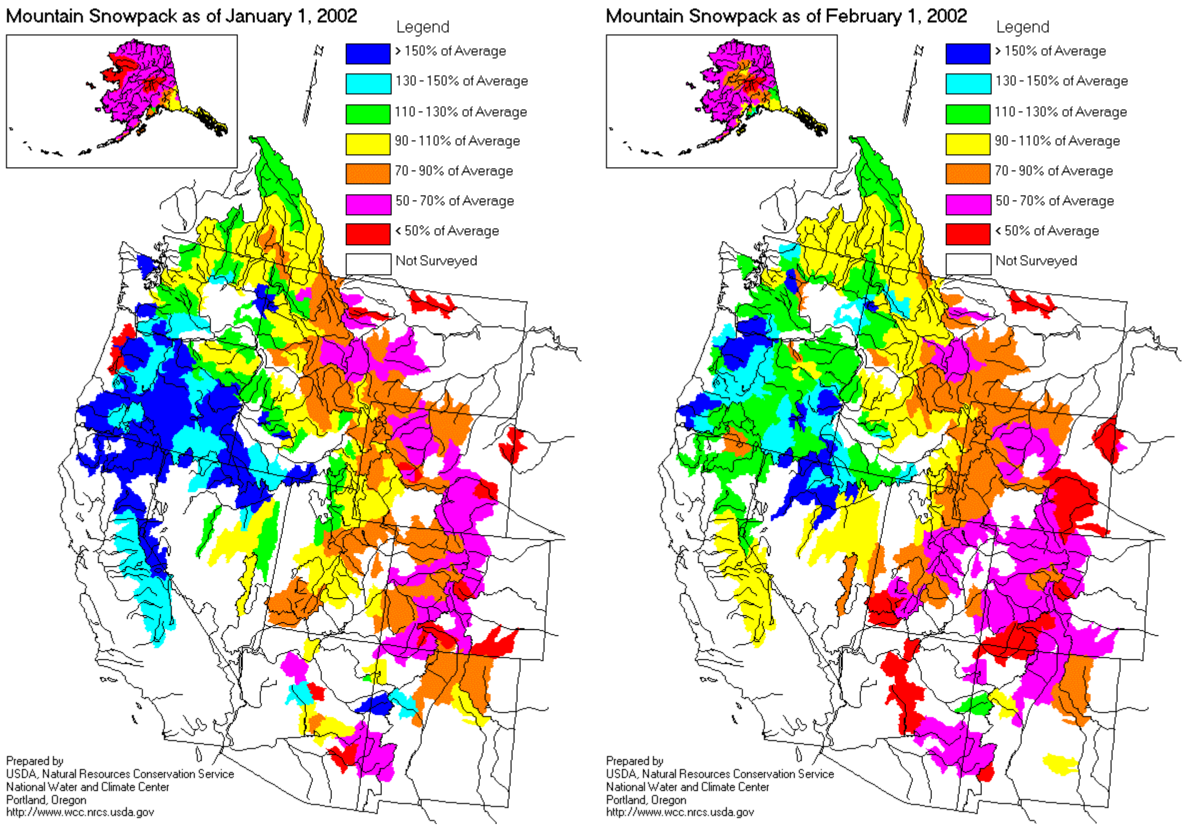
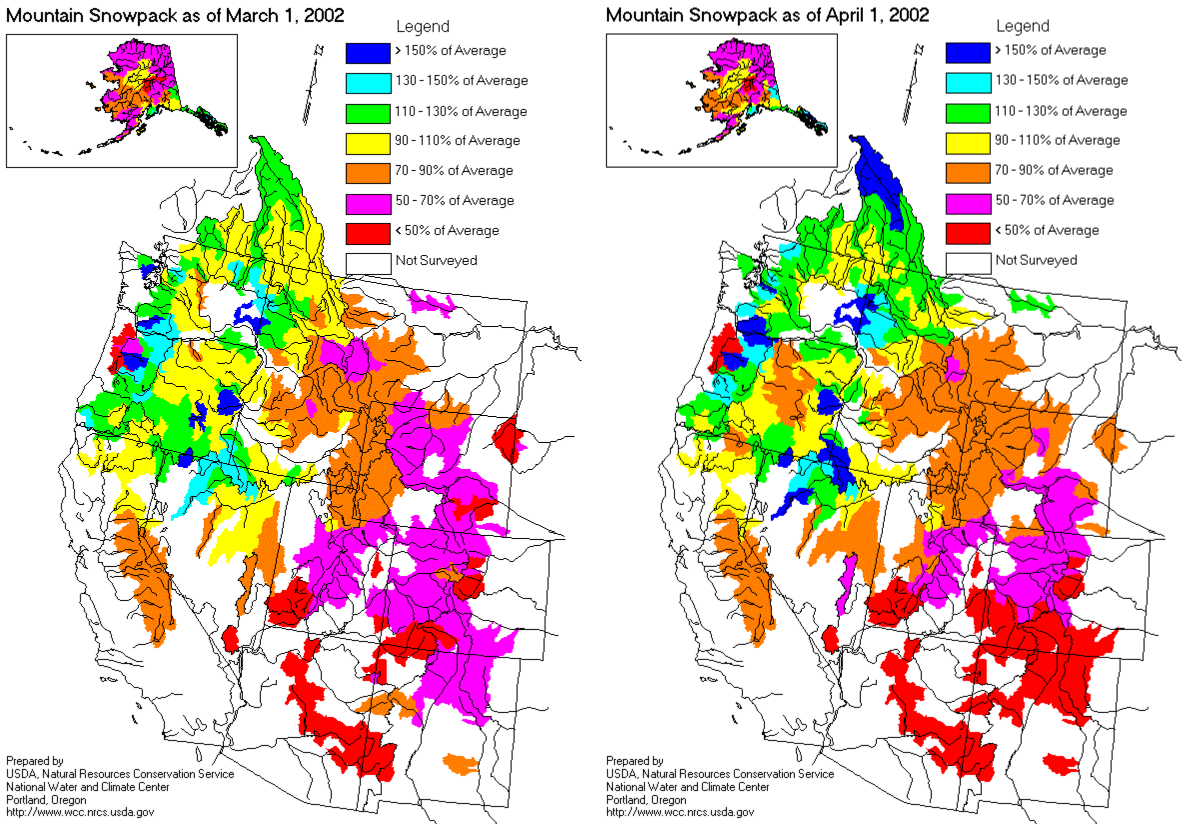
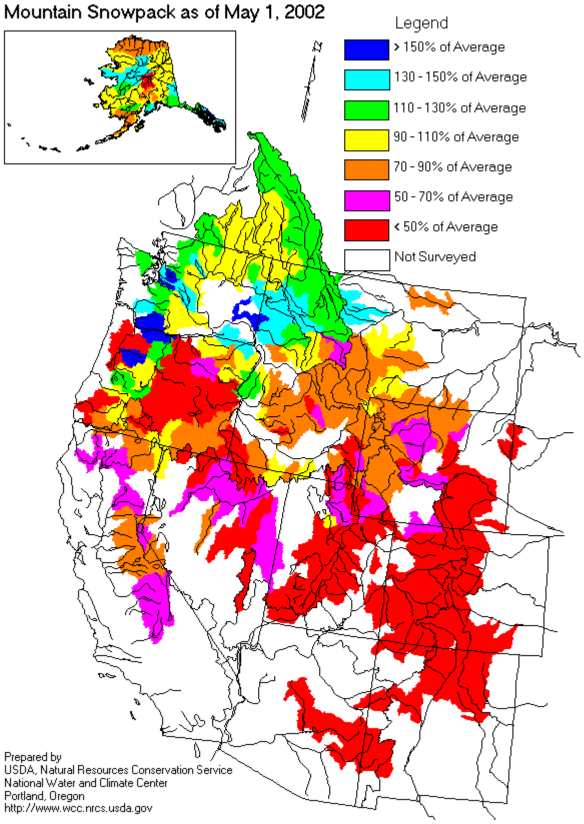



Figure 6.7: Mountain Snowpack in Western States, January-April 2002



Mountain Snowpack as of May 1, 2002

Prepared by
USDA, Natural Resources Conservation Service
National Water and Climate Center
Portland, Oregon
http://www.wcc.nrcs.usda.gov

Figure 6.8: Mountain Snowpack in Western States, May 2002

In 2002 the majority of the Great Basin experienced similar conditions, with small northwestern regions receiving 90-110% the average snowpack in January and February. It shows a common trend that January and February have high snow pack around the Great Basin, with March bringing 130%, April 110%, and May reaching lows of less than 50% average snowpack.

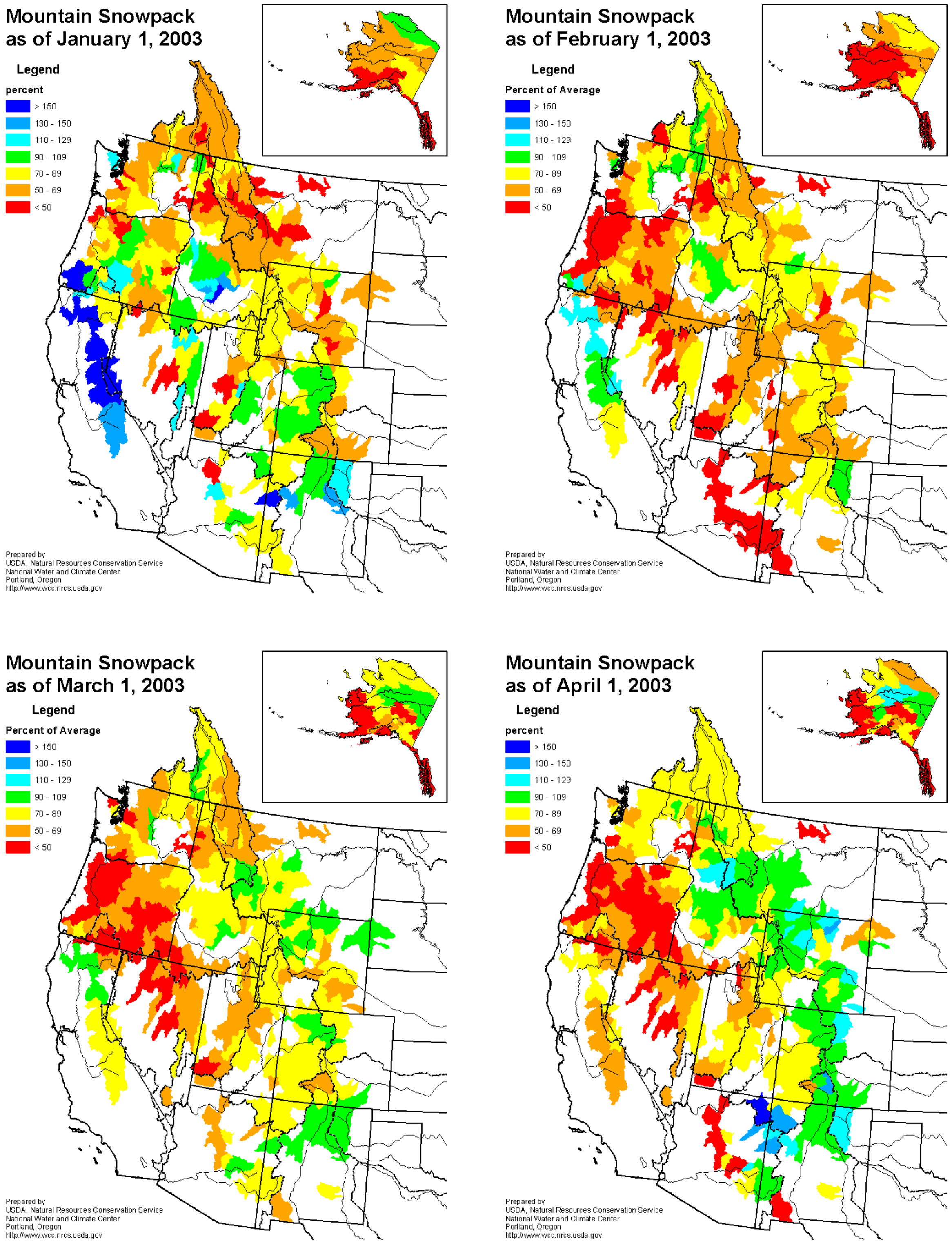


Figure 6.9: Mountain Snowpack in Western States, January-April 2003

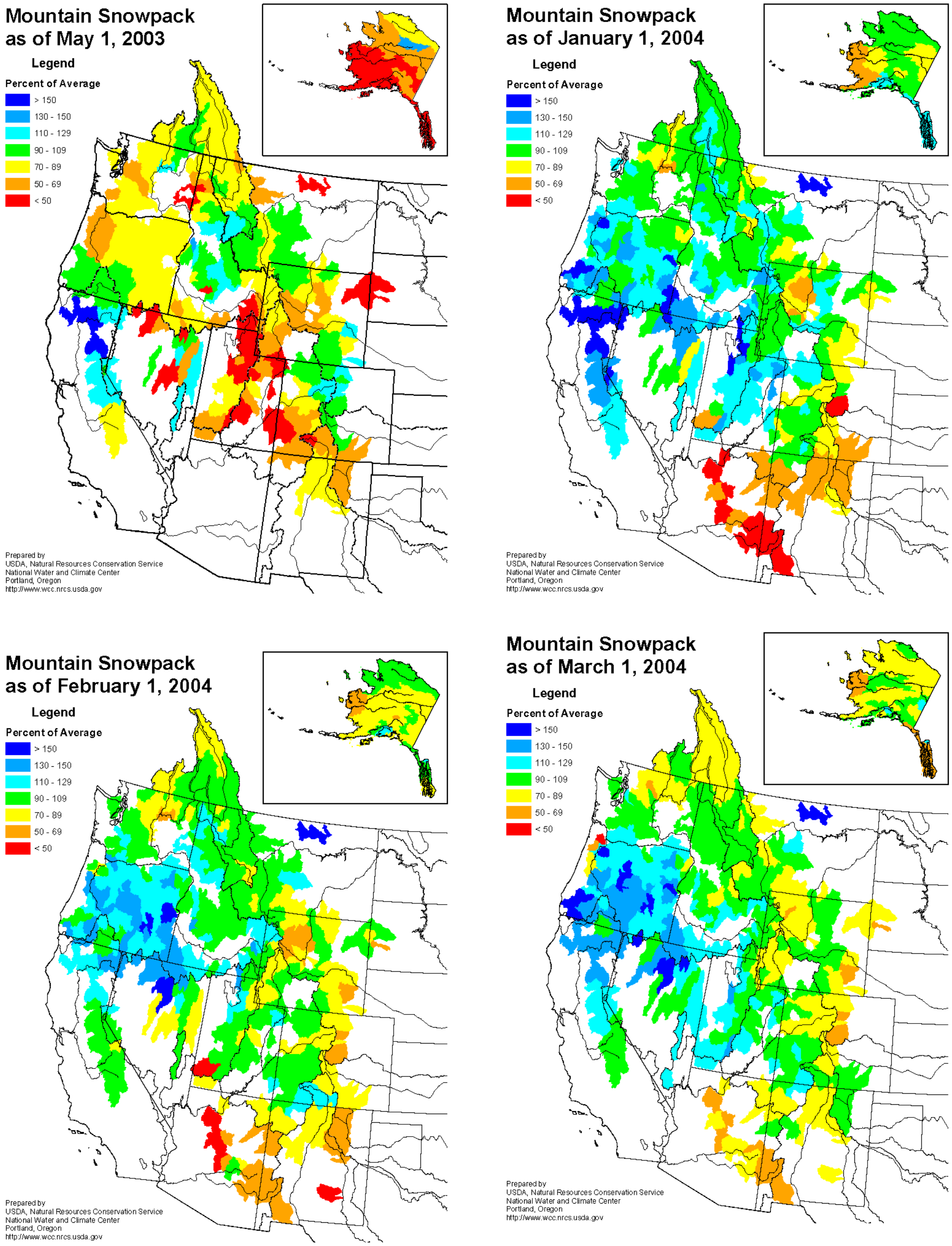


Figure 6.10: Mountain Snowpack in Western States, May 2003, January-March 2004

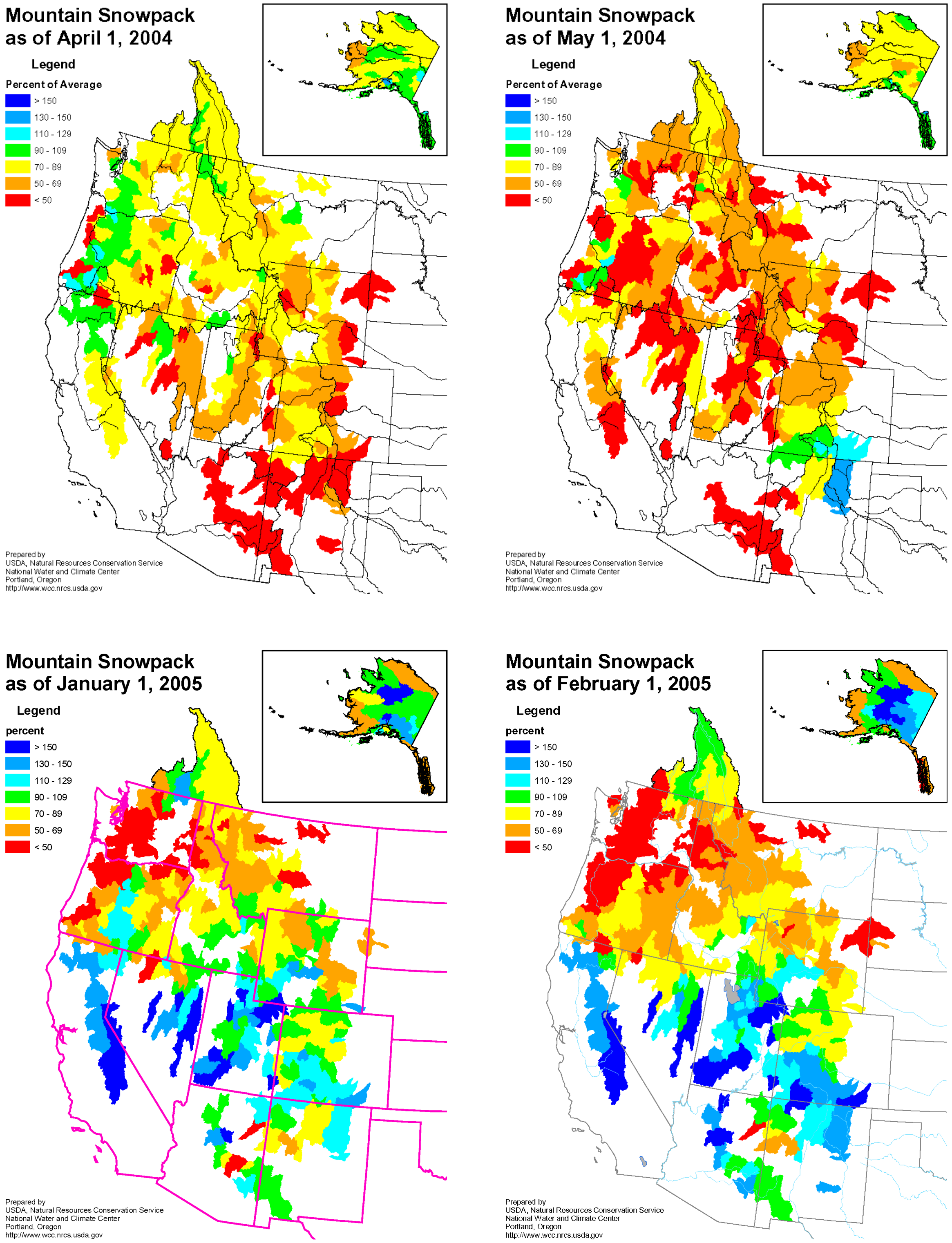
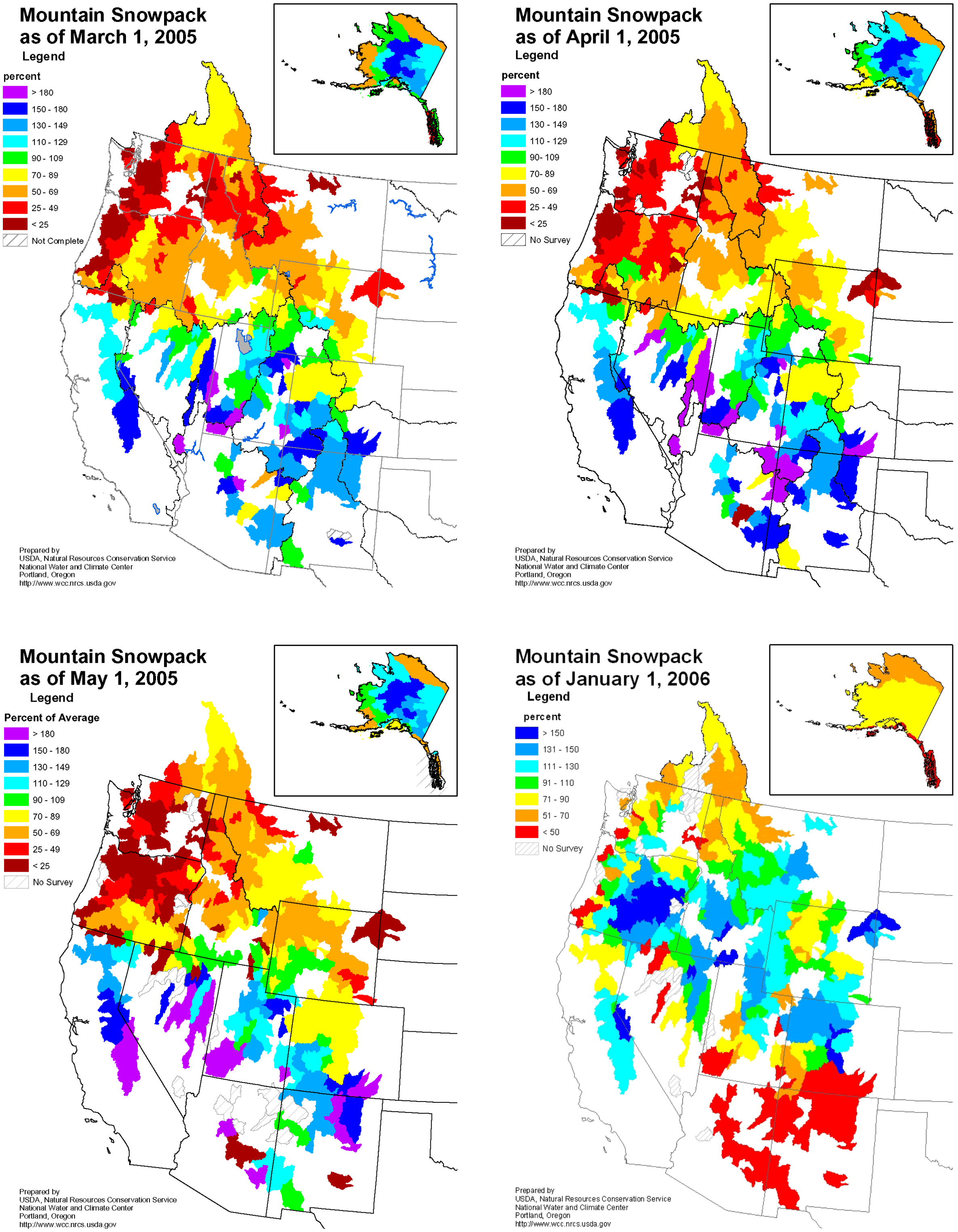


Figure 6.11: Mountain Snowpack in Western States, April-May 2004, January-February 2005


Mountain Snowpack as of March 1, 2005

Mountain Snowpack as of April 1, 2005

Mountain Snowpack as of May 1, 2005

Mountain Snowpack as of January 1, 2006

Figure 6.12: Mountain Snowpack in Western States, March-May 2005, January 2006

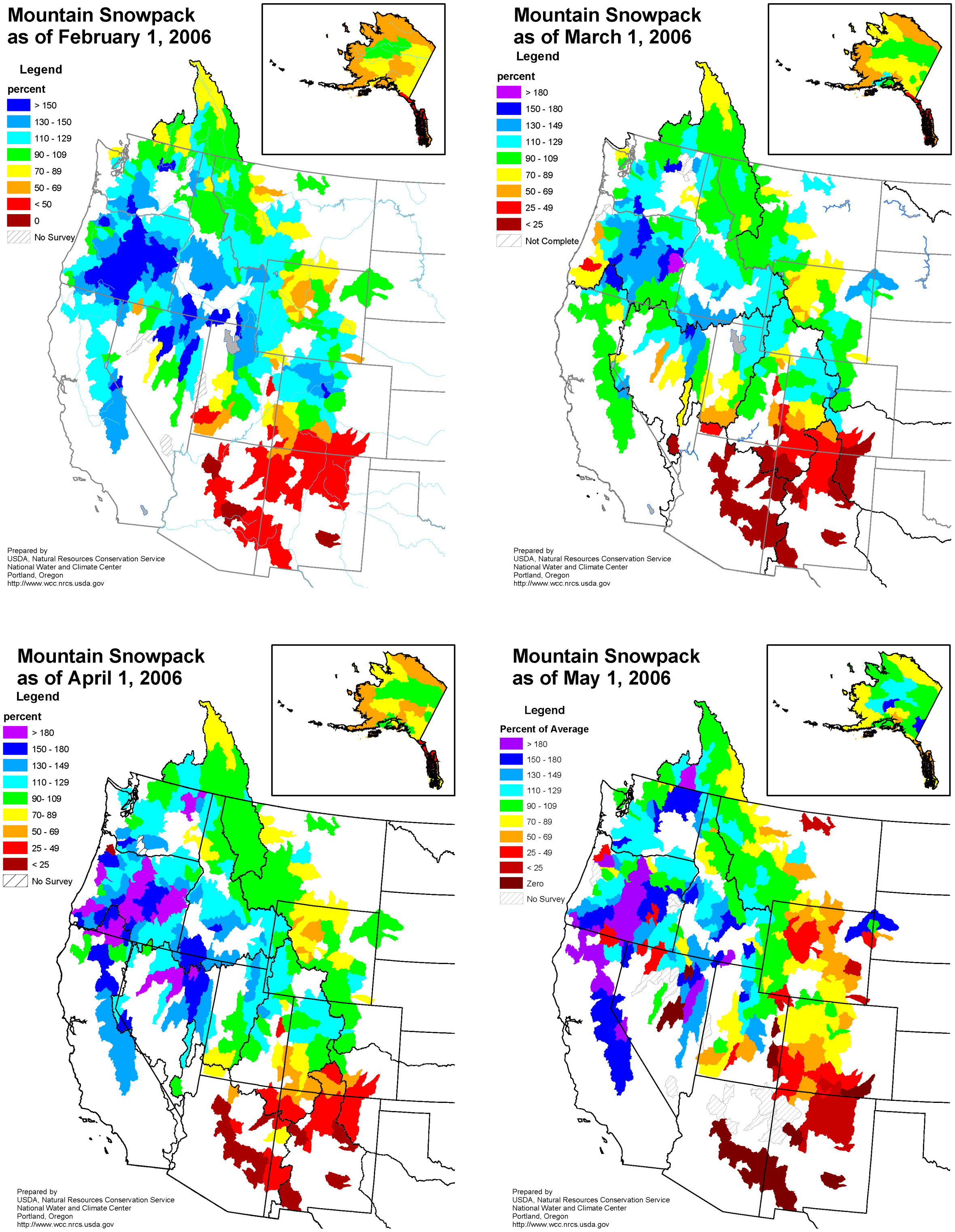


Figure 6.13: Mountain Snowpack in Western States, February-May 2006

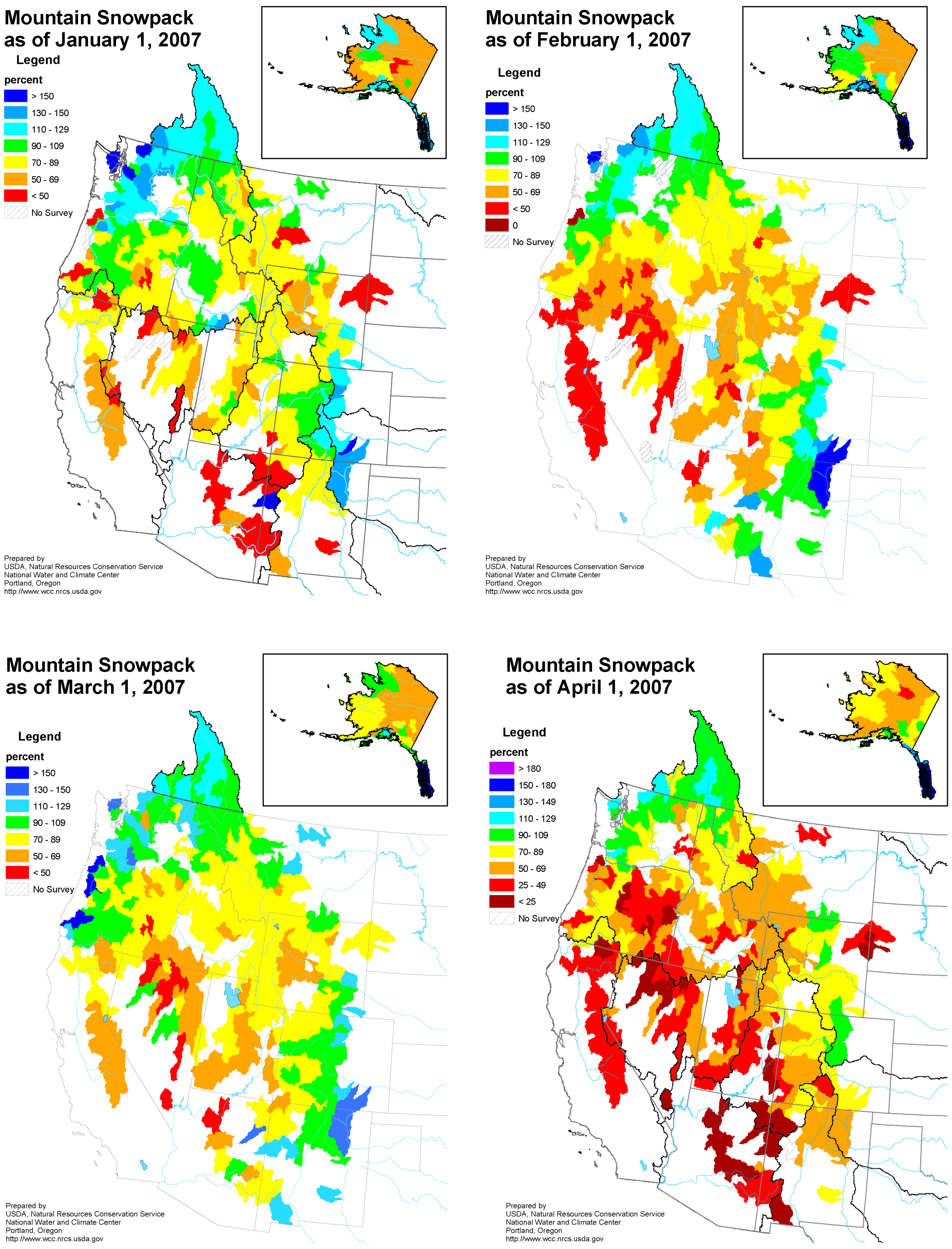
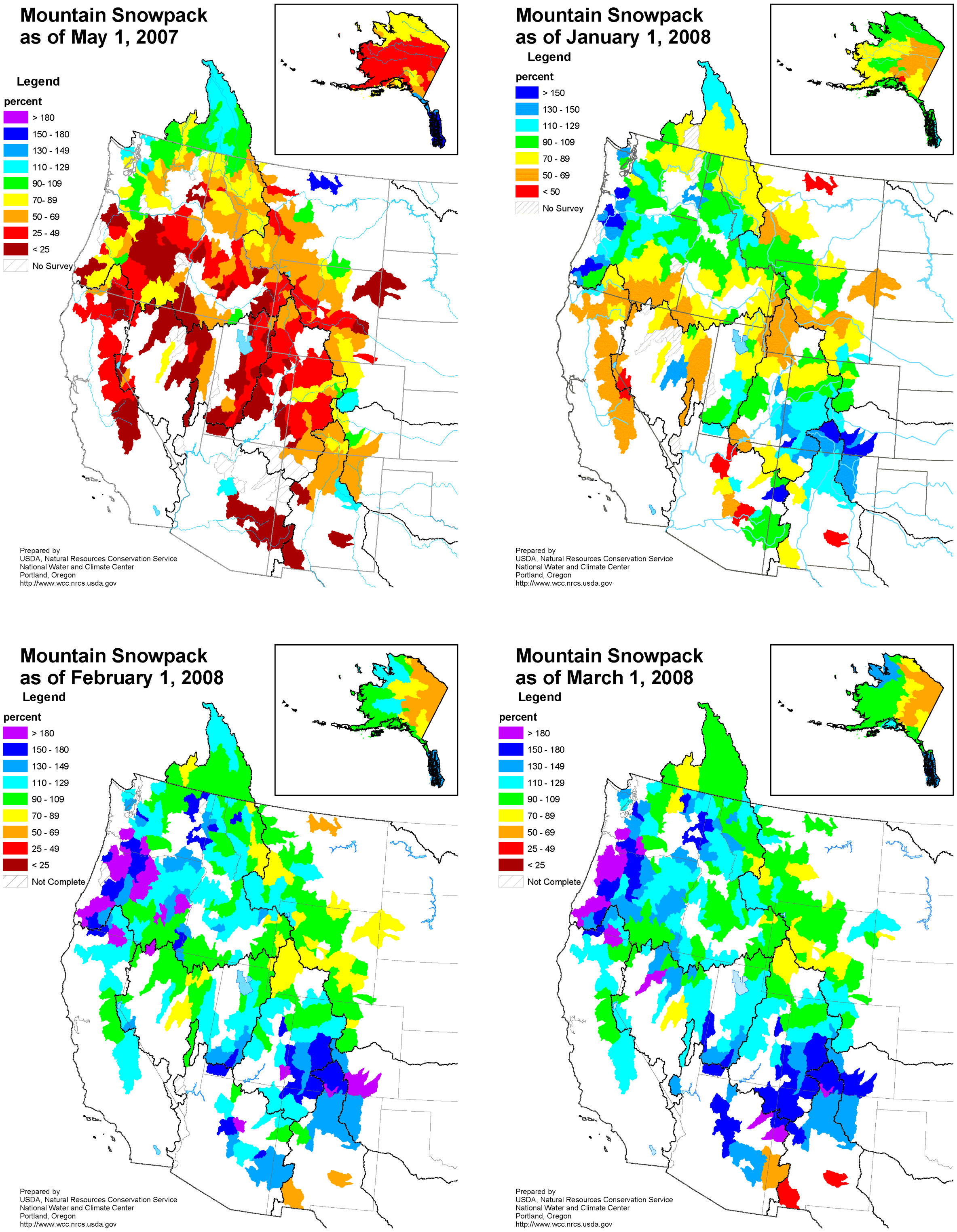


Figure 6.14: Mountain Snowpack in Western States, January-April 2007



Mountain Snowpack as of May 1, 2007

Prepared by
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National Water and Climate Center
Portland, Oregon
http://www.wcc.nrcs.usda.gov

Mountain Snowpack as of January 1, 2008

Prepared by
USDA, Natural Resources Conservation Service
National Water and Climate Center
Portland, Oregon
http://www.wcc.nrcs.usda.gov

Mountain Snowpack as of February 1, 2008

Prepared by
USDA, Natural Resources Conservation Service
National Water and Climate Center
Portland, Oregon
http://www.wcc.nrcs.usda.gov

Mountain Snowpack as of March 1, 2008

Prepared by
USDA, Natural Resources Conservation Service
National Water and Climate Center
Portland, Oregon
http://www.wcc.nrcs.usda.gov

Figure 6.15: Mountain Snowpack in Western States, May 2007, January-March 2008

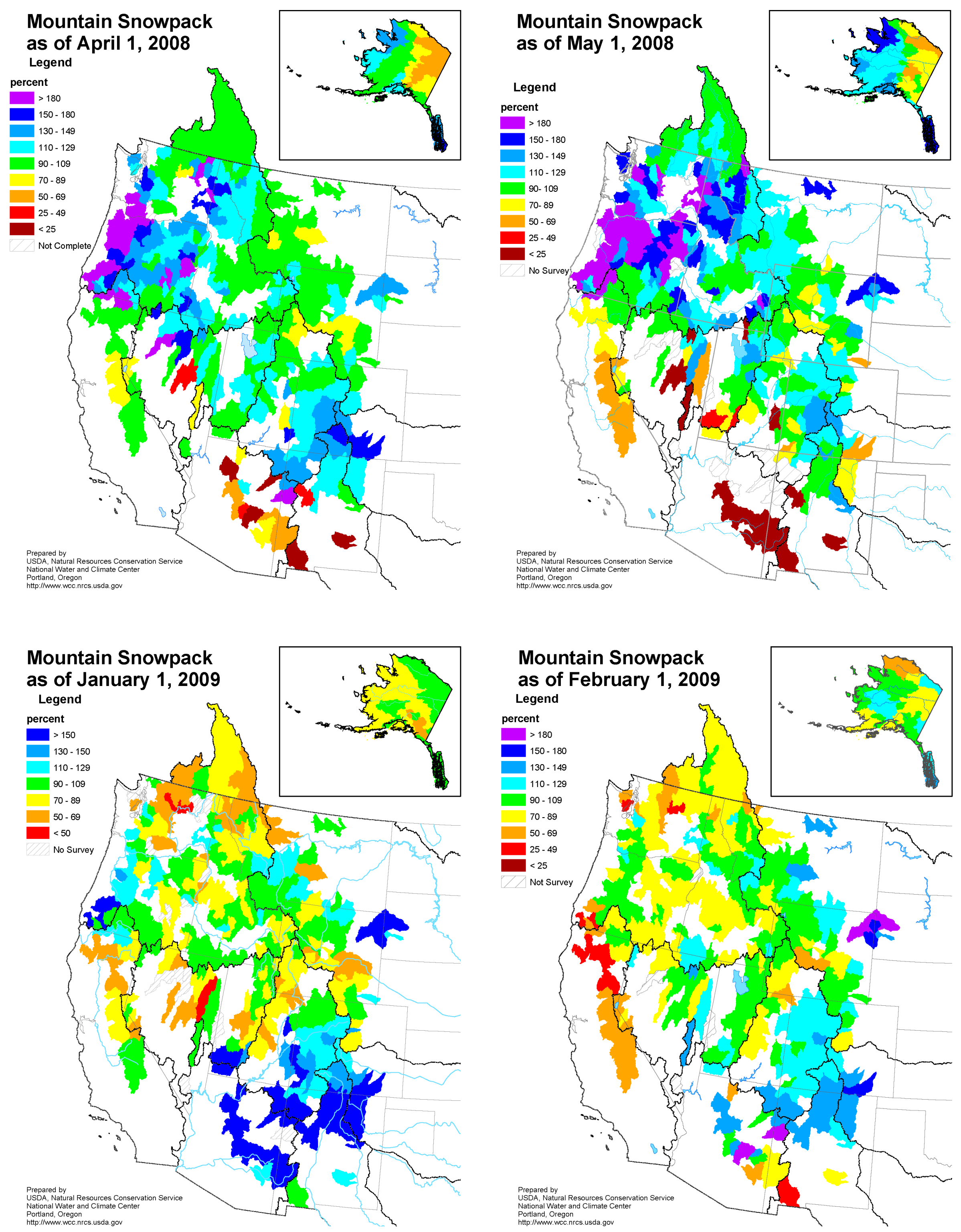

Figure 6.16: Mountain Snowpack in Western States, April-May 2008, January-February 2009

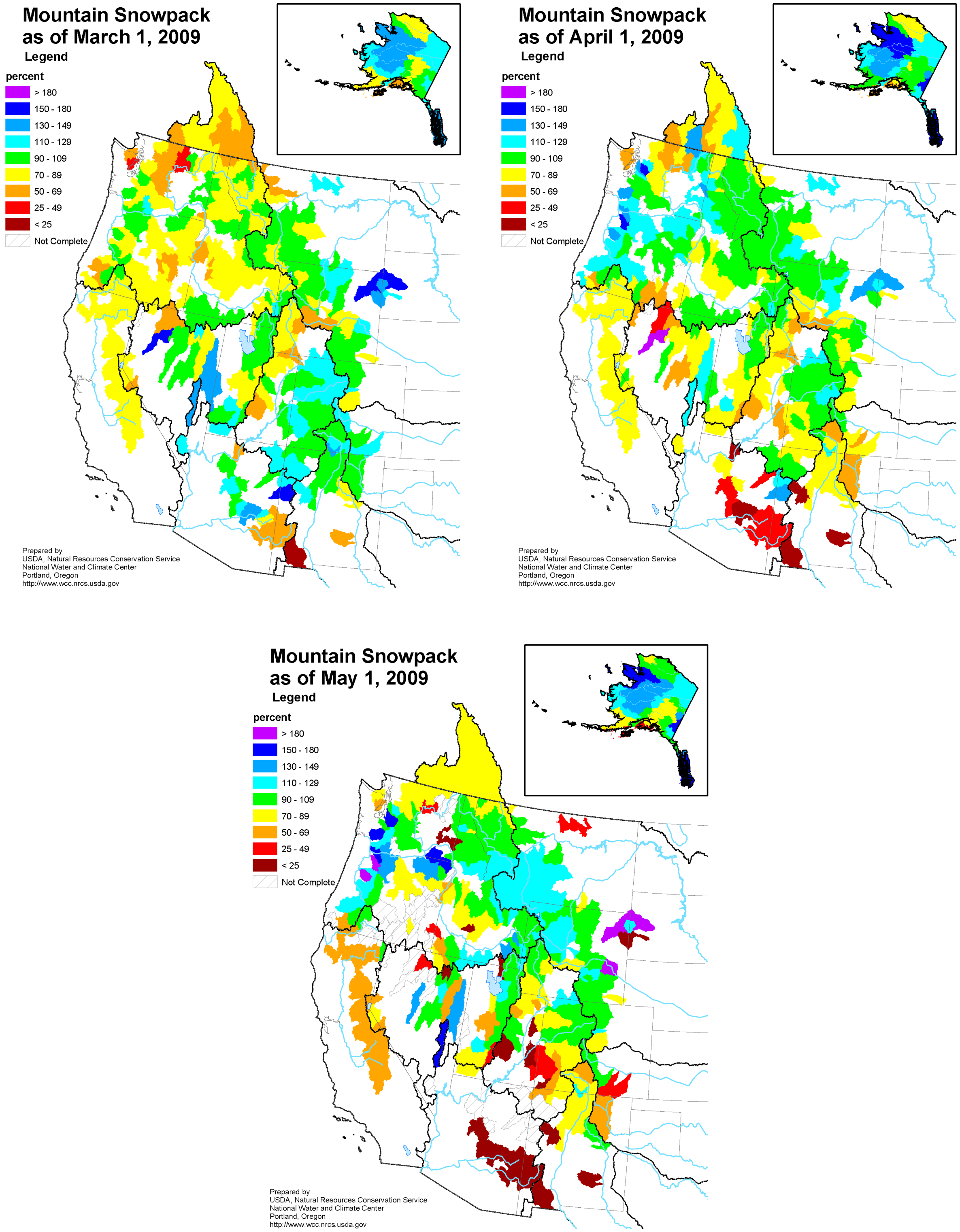

Figure 6.17: Mountain Snowpack in Western States, March-May 2009

From 2003 through 2006 the Great Basin experienced a change in snowpack formation. The majority of the region received well above 110% of the average level, sometimes reaching as high as 150-200%. 2006 was the wettest year in this series. A huge drop in snowpack followed it the next year. April and May of 2007 recorded the least snowpack of all, with the majority of the region having less than 50% and some areas less than 20%.

2008 was a remarkably great year for snowpack formation, with the majority of the region having well over 100%. February and March were the wettest months of 2008. In 2009 the snowpack in the Great Basin was highest in January at approximately 100% in most regions, with less snowpack retained in April and May. This data correlates well to the fact that Nevada receives little precipitation in April and May.

Overall, 2000 and 2007 show similar trends of how the Great Basin can receive 100% average snowpack one year, and then rising temperatures can cause less than half the average snowpack to form the next year or two. The United States Environmental Protection Agency examined the Colorado River basin and found “that if climate becomes hotter and drier, runoff could decline in the basin by 15-20%, with a 10% reduction in deliveries to water users. Such a reduction would cost water users in the Colorado Basin about $200-300 million per year.”[24] Since the Great Basin is a considerably more arid region than the Colorado Basin, its figures may well be higher. Additionally Chamber's found that within the Great Basin “the timing of spring snowmelt-driven streamflow is now about 10 to 15 days earlier than in the mid-1900s”[25] Yet, projections by Stewart showed that snowmelt-driven streamflow could cause runoff 20 to 40 days earlier, leaving

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[24] Water Supply and Demand. 07 Jan. 2000. U.S. Environmental Protection Agency. 15 Dec. 2008 <http://yosemite.epa.gov/oar/globalwarming.nsf/content/ImpactsWaterResourcesWaterSupplyandDemand.html>

[25] Chambers, Jeanne C. How the West Will Warm. Rep. Feb. 2008. Rocky Mountain Research Station. 05 May 2009 <http://www.fs.fed.us/rm/pubs/rmrs_gtr204.pdf>.

the summer months to be very dry.[26] Thus an examination of the Great Basin's largest river, the Humboldt River, and its flow rates over the past ten years is imperative.

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[26] Stewart, Iris T. CHANGES IN SNOWMELT RUNOFF TIMING IN WESTERN NORTH AMERICA UNDER A 'BUSINESS AS USUAL' CLIMATE CHANGE SCENARIO. Rep. 2004. 1Scripps Institution of Oceanography and US Geological Survey. 10 May 2009 <http://meteora.ucsd.edu/cap/pdffiles/stewart_clch.pdf>. Pg. 2

7 Groundwater Facts

Fresh water is tremendously valuable to human life, yet it only makes up less than one percent of the Earth's surface. Agriculture, which uses 70% of all fresh water consumed by humans, supplies 40% of the world's food crops. Energy produced by hydroelectric power totals 20% of the world's electricity. An estimated 12% of all animal species live in fresh water, and numerous other species depend either on fresh water or a fresh water ecosystem for survival.[27]

One might make the mistake of thinking that ground water and surface water have little correlation with each other. If this were true, many countries could rely on ground water during times of drought and hardship indefinitely. Actually, ground water actually provides much of the water in rivers and streams. Any water that is not evaporated, used by plants, or emptied into another body of water eventually percolates into the soil. It is then absorbed by the aquifer, which acts as storage for ground water in between soil until it makes its way to the water table. Here water can be withdrawn into a well and the aquifer will then recharge depending on how much water is available, how much is absorbed by plants, and how much water is available in nearby streams/rivers.[28] This process is known as the hydrologic cycle.

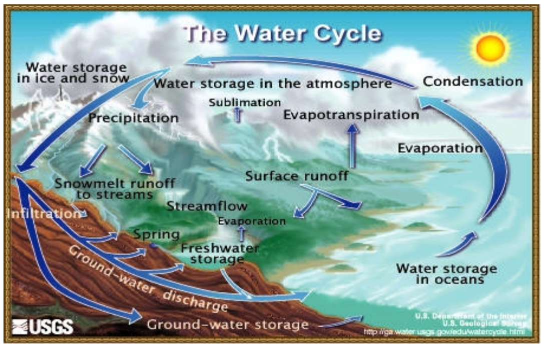

Figure 7.1: The Hydrologic e
<ga.water.usgs.gov/edu/watercycle.html>

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27 Johnson, Revenga, Echeverria. 2001. Managing Water for People and Nature. Science, vol 292, p.107-108

28 Gone to the Well Once too Often. Rep. Apr. 2007. Trout's Unlimited Western Water Project. 05 May 2009 <http://www.greatbasinwater.net/pubs/TU_Groundwater_West.pdf>.

As water sits on the water table, a stream that feeds off it will either gain or lose reach over time depending on whether the stream is above or below the water table at that point. When gaining reach, ground water enters the stream and “gains reach” towards the waterway. When losing reach, the stream water enters the aquifers and water table and therefore “loses reach” from the waterway. Thus if more ground water is pumped out into a well than the aquifers can recharge, these gaining reaches will now become losing reaches. Eventually the aquifers won’t be able to recharge as quickly and ground water use should slow down to match how fast it can recharge. As Trout Unlimited puts it, “Geologists estimate that if the aquifer that underlies the High Plains of New Mexico were drained completely, it would take thousands of years to replenish.”[29]

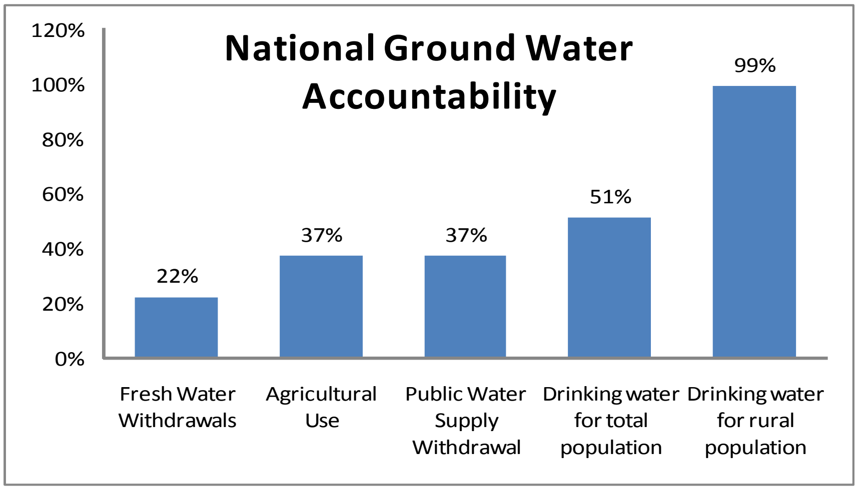

Figure 7.2: Accountability of Groundwater in the United States
Data found at:
http://www.greatbasinwater.net/pubs/TU_Groundwater_West.pdf

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[29] Gone to the Well Once too Often. Rep. Apr. 2007. Trout's Unlimited Western Water Project. 05 May 2009 <http://www.greatbasinwater.net/pubs/TU_Groundwater_West.pdf>.

Figure 7.2 shows that ground water is used for 99% of the drinking water in rural populations and 51% of the drinking water in the total population. Also it is used for 37% of the agriculture within the nation. Figure 7.3 demonstrates the distribution of demand for drinking water and provides insight into how ground water is divided among different areas of the communities found in the western United States. The least reliant state is Nevada at 37%, with every other state being over 40% reliant and some even as great as 96% reliant (Idaho). Nevada's 37% is still a high percentage of reliability on ground water for domestic care, especially since the region has been demonstrated to be undeniably dry.

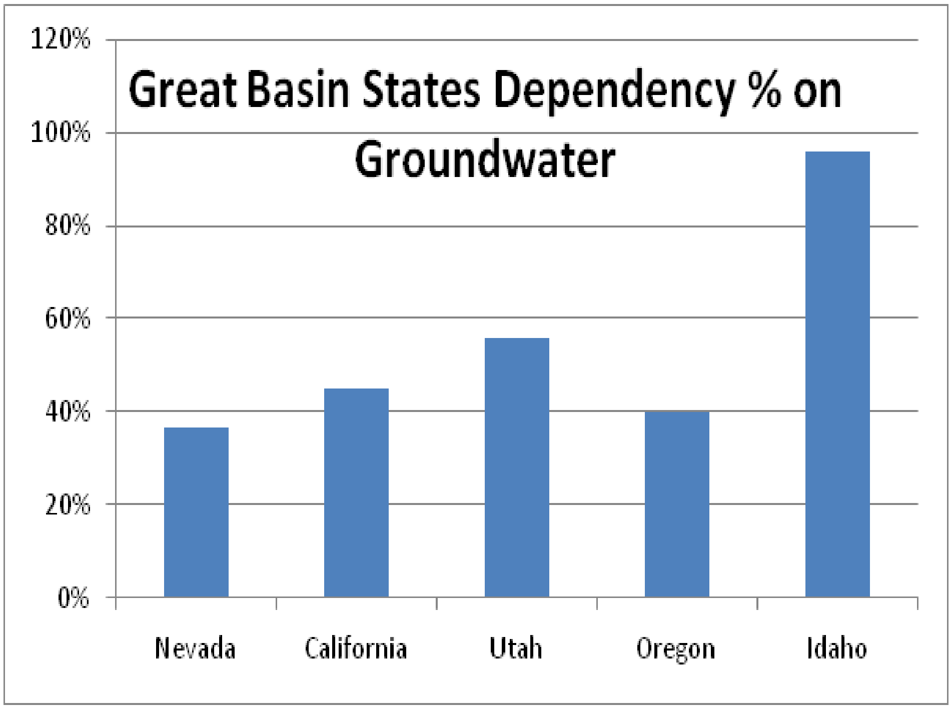

Figure 7.3: Population Dependence on Groundwater in Western States
Data from <http://www.greatbasinwater.net/pubs/TU_Groundwater_West.pdf>

To say that ground water is a necessity would be quite an understatement. Groundwater is so important that it must be protected and managed first and foremost before it is too late. It is clear that ground water does not have a different source than surface water and that the balance of the two greatly impact each other. The world must heed caution before the aquifers are drained too far, especially arid regions such as the Great Basin which must carefully partition their ground water sources.

8 The Humboldt River

The Humboldt River is the largest river in the Great Basin and the largest river that doesn't empty into the ocean within the United States. The Humboldt River runs 310 miles southwest from Humboldt Wells and terminates at Rye Patch Dam and reservoir. In wet years, the river can flow all the way to the Humboldt Lakes and ultimately end up at the Humboldt Sink where evaporation consumes any water left. It has an annual average flow of 296,000 acre feet. This river is very significant to the Great Basin: it is the largest river, it is the only natural transportation route, and it has great variability depending on the amount of precipitation each year. Although the river flow is

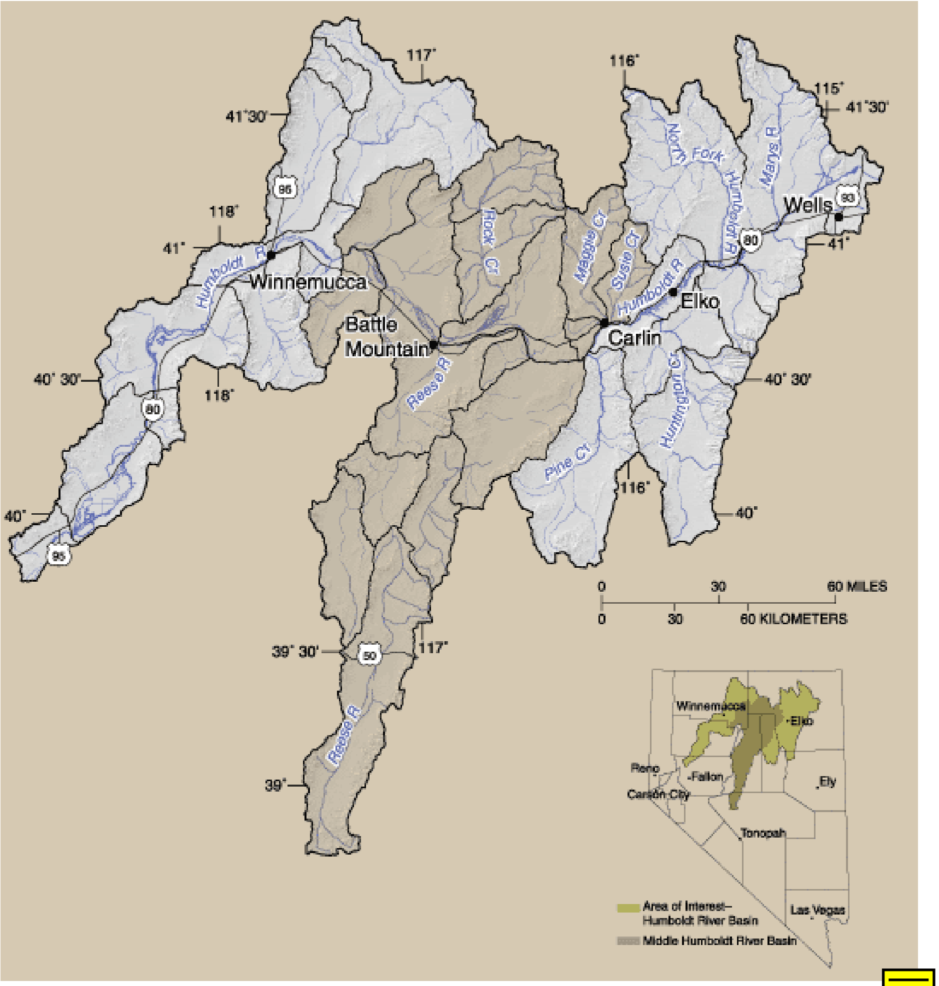

Figure 8.1: The Humboldt River Basin <http://nevada.usgs.gov/humb/>

generally strong, the actual flow varies greatly more due to removal of water for irrigation in its western portions.[30]

The primary source of the Humboldt River is snowpack runoff from the higher elevated areas in the Upper Humboldt River Basin. The Ruby Mountains, Jarbidge Mountains, and Independence Mountains are most responsible for contribution to the Humboldt River. The abundance of mountains found in the Lower Basin tends to not prevent much precipitation from reaching the Humboldt River. Unfortunately, due to the high salt concentration and the vast amount of gold mines, the water that reaches the Humboldt Lakes and Sink is often highly contaminated.[31]

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30 *Humboldt River Chronology. Rep. 1999. Nevada Division of Water Resources Department of Conservation and Natural Resources. 05 May 2009* <http://water.nv.gov/WaterPlanning/humboldt/PDFs/hrc-pt1.pdf>.

31Ibid

9 Dangers Faced by the Humboldt River

The increasing temperatures from global warming will only complicate the dangers of fresh water within the Great Basin further, but especially for its largest fresh water source. Additionally, population growth within the Humboldt River Basin has followed a near exponential growth. As seen in Figure 9.1, the population in the Humboldt River Basin has grown by approximately 20,000 people per year, with an overall growth of almost four times its population back in 1970. Such a quick and unexpected growth will undeniably add stress to fresh water resources.

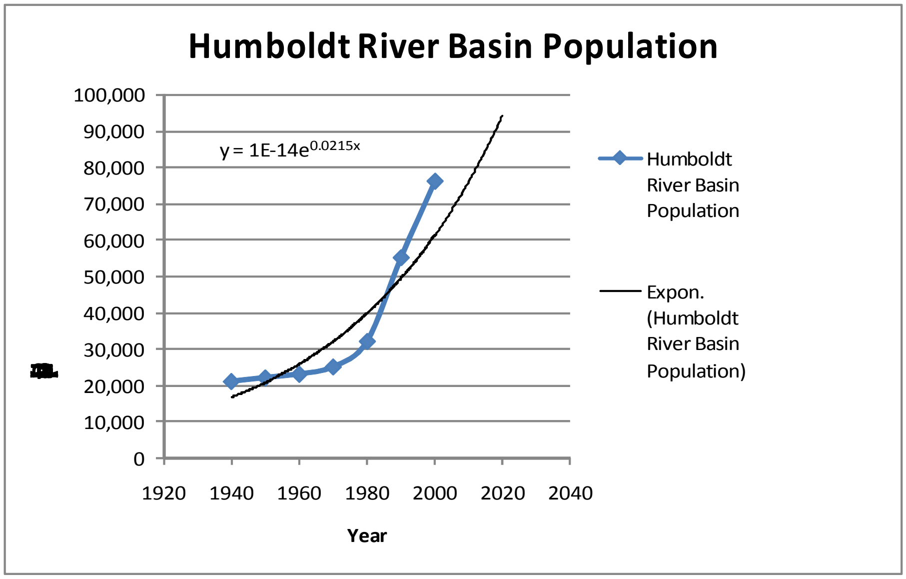

Figure 9.1: The Humboldt River Basin Population Growth
Data based on : http://nevada.usgs.gov/humb/

With a decrease in precipitation, there will be a decrease in the amount of snowpack formed. If this snowpack is formed in the earlier months of January and February, then the amount of water that enters the Humboldt will be higher earlier in the year, leaving the late summer months to face drought.

The Trout Unlimited's Western Water Project report concluded, "Scientists estimate that the Humboldt River hydrology may require two centuries to recover, drying some streams and springs for decades."[32] Even the largest fresh water resource in the Great Basin is at danger. If precautions to store the Humboldt River's water are not performed, the arid state of Nevada that receives less than 8 inches of precipitation per average year will face extreme dangers. It is proposed that the fresh water of the Humboldt River could be protected in a few ways, with much importance relying on Rye Patch Dam and Reservoir.

9.1 Rye Patch Dam

Positive change needs to occur in order to protect the Great Basin's primary fresh water source. An examination of one of the dams and reservoirs downstream of the Humboldt River is necessary for this inquiry. Rye Patch Dam and Reservoir were originally built in 1936, then enlarged in 1975 to a storage capacity of 213,000 acre feet.[33] This reservoir is located at an elevation 4,135 feet high with a surface area of 11,000 acres.[34]

Figure 9.2: Rye Patch Dam and Reservoir
<http://www.usbr.gov/mp/lbao/water_projects.html>

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[32] Gone to the Well Once too Often. Rep. Apr. 2007. Trout's Unlimited Western Water Project. 05 May 2009 <http://www.greatbasinwater.net/pubs/TU_Groundwater_West.pdf>.

[33] U.S. Department of Interior, Beureau of Reclamation: Managing Water in the West. The Humboldt Project <http://www.usbr.gov/dataweb/html/humboldt.html>

[34] Rye Patch Reservoir and Dam. Nevada Division of State Parks. Department of Conservation and Natural Resources. <http://parks.nv.gov/rp.htm>

Rye Patch Dam and Reservoir is also gated, meaning that has a device to control the flow into and out of the waterway. It also has a set of outlet works, which is a series of pipes to control releases out of the reservoir for many purposes such as regulation of stream flow to irrigation.[35] Therefore the water that is stored within Rye Patch Dam can be held until it serves an agricultural purpose and released on demand.

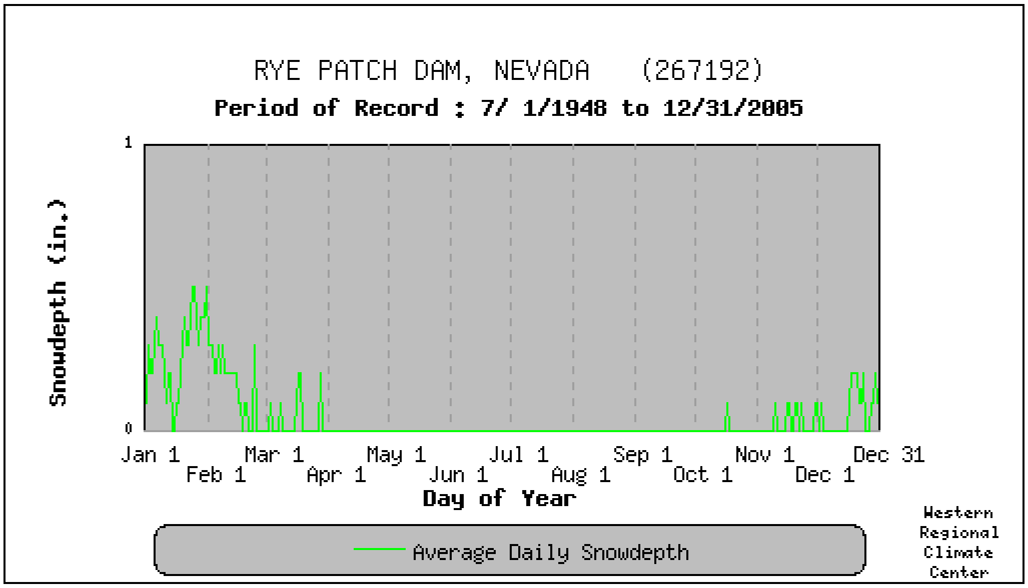

Figure 9.3: Average Snow Depth at Rye Patch Dam, NV, 1948-2005

Figure 9.3 shows the daily snow depth found at Rye Patch Dam averaged over the years 1948-2005. Less than an inch of snowpack is received during any month of the year in that area. This reservoir relies solely upon the snowpack the Humboldt River receives further upstream to maintain its capacity, and more specifically the discharge from the dam located in Imlay, NV.

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[35] U.S. Department of Interior, Beureau of Reclamation: Managing Water in the West. <http://www.usbr.gov/library/glossary>

10 Calculated Evaporation

Most reservoirs like the Rye Patch were built to appear as lakes, so they typically have a very large surface area. For each square foot of surface area, approximately four to nine feet of water is evaporated per year. "In some desert areas, potential annual evaporation can be greater than 7 ft (2.1 m), meaning that over the course of one year, if no water flowed into or out of the system, the reservoir would drop in elevation by 7 ft (2.1 m). At Lake Mead on the Colorado River in Arizona and Nevada, evaporation losses in one year can be as great as 350 billion gal (1.3 trillion l)."[36] This is an immense loss of fresh water, and with certain precautions a high amount of it can be saved. However, with a surface area of 11,000 acres, the Rye Patch Reservoir could be losing anywhere from 3,000 to 7,000 acre-feet of water (one acre of area containing one foot of water on top). The Nevada Division of Water Resources released a report in 1972 and stated that the Rye Patch Dam was the most efficient along the Humboldt River and estimated its annual evaporation two ways. Their reasoning for its efficiency was that the storage volume to annual evaporation ratio was highest, being 2.4. Considering that Rye Patch Reservoir has a capacity of 213,000 acre-feet, the annual evaporation from this reservoir would be nearly 88,000 acre-feet of water. The second way they calculated annual evaporation loss, was by multiplying the surface area (11,000 sq feet) by the average net evaporation rate of 3.6 feet per year. Other sources have stated that evaporation loss can be anywhere from three to seven feet per square foot of water surface area. However, the USGS found in 1965 that the average annual loss at Rye Patch Reservoir between 1936-1961 was 32,000 acre-feet.

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[36] Dams – Impact of Dams. Science Encyclopedia Vol. 2. January 2008 <http://science.jrank.org/pages/1942/Dams-Impact-dams.html>

The amount of water loss due to evaporation that the Rye Patch Dam and Reservoir has encountered was examined with greater detail. An evaporation control project for assessment of dam evaporation was conducted and they found the equation to water loss due to evaporation within dams is given by: $\Delta v = Q_{in} - Q_{out} - E - S$ [37]

Where, Δ v = measured change in water volume

Q_{in} - Total water input including direct precipitation (avg precipitation per month)

Q_{out} - Total water output . ie. water used

E - Evaporation Rate

S - Dam floor / Wall seepage

The first step taken was to find the evaporation rate at Rye Patch Reservoir was to find the pan evaporation data for that location. Pan evaporation statistics are determined by the amount of water level change in a pan at that specific site. However, the metal sides of the pan get hot causing an increase in the amount of evaporation. Therefore, the evaporation from a natural waterway is typically lower and the pan evaporation should be multiplied by 0.70, which is the approximate k pan coefficient for a class A pan.

Thus: E = Epan * Kpan [38] Where, E = Potential Evaporation

E pan = Pan Evaporation Variable K pan = Pan coefficient (0.70 for a class A pan)

Using this formula and the pan evaporation data for Rye Patch Dam, the following bar graph was created. [39]

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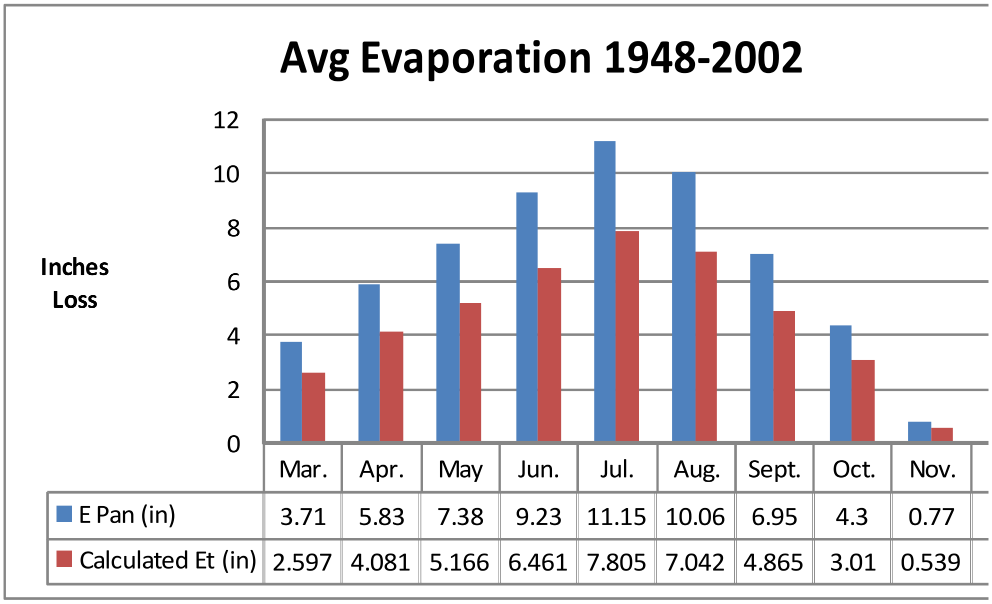
[37] Craig, I. Methods for Assessing Dam Evaporation – An Introductory Paper. Rep. 11 May 2004. National Centre for Engineering in Agriculture and University of Southern Queensland Toowoomba. 06 May 2009 <http://eprints.usq.edu.au/280/1/Craig_and_Hancock_IAA_paper_04.pdf> Pg 5

[38] Irrigation Water Management: Irrigation Water Needs. National Resources Management and Environment. 08 May 2009 <http://www.fao.org/docrep/S2022E/s2022e07.htm>

[39] Data collected from: http://www.ocs.orst.edu/page_links/comparative_climate/evap.html

Average annual pan evaporation between 1948 and 2002 at Rye Patch Dam and Reservoir was found to be 59.38 inches (1.5 meters), meaning an estimated annual evaporation of 41.57 inches(1.05 meters).



	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.
🟦 E Pan (in)	3.71	5.83	7.38	9.23	11.15	10.06	6.95	4.3	0.77
🟥 Calculated Et (in)	2.597	4.081	5.166	6.461	7.805	7.042	4.865	3.01	0.539

Figure 10.1: Average Evaporation at Rye Patch Dam, NV, 1948-2002

The next step was to determine values for Q_{in} *and* Q_{out}. Q_{in} is the total amount of stream inflow as well as the amount of precipitation received. Although exact amounts of Rye Patch Reservoir inflow is not available, the USGS (U.S. Geological Survey) has all the data for reservoir and dam discharges. Considering that the discharges from the Imlay, NV dam are known on a monthly basis and this location is very close upstream, these values must be an approximate of how much water inflow was received at Rye Patch. Figure 10.2 is an overhead terrain map of the region, and the distance from Imlay to Rye Patch Dam is only 17.5 miles.

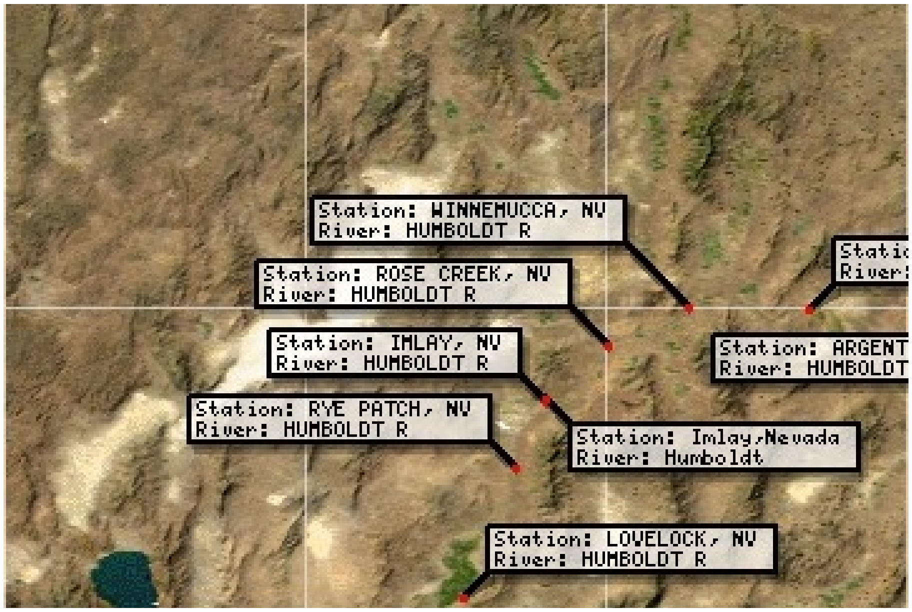
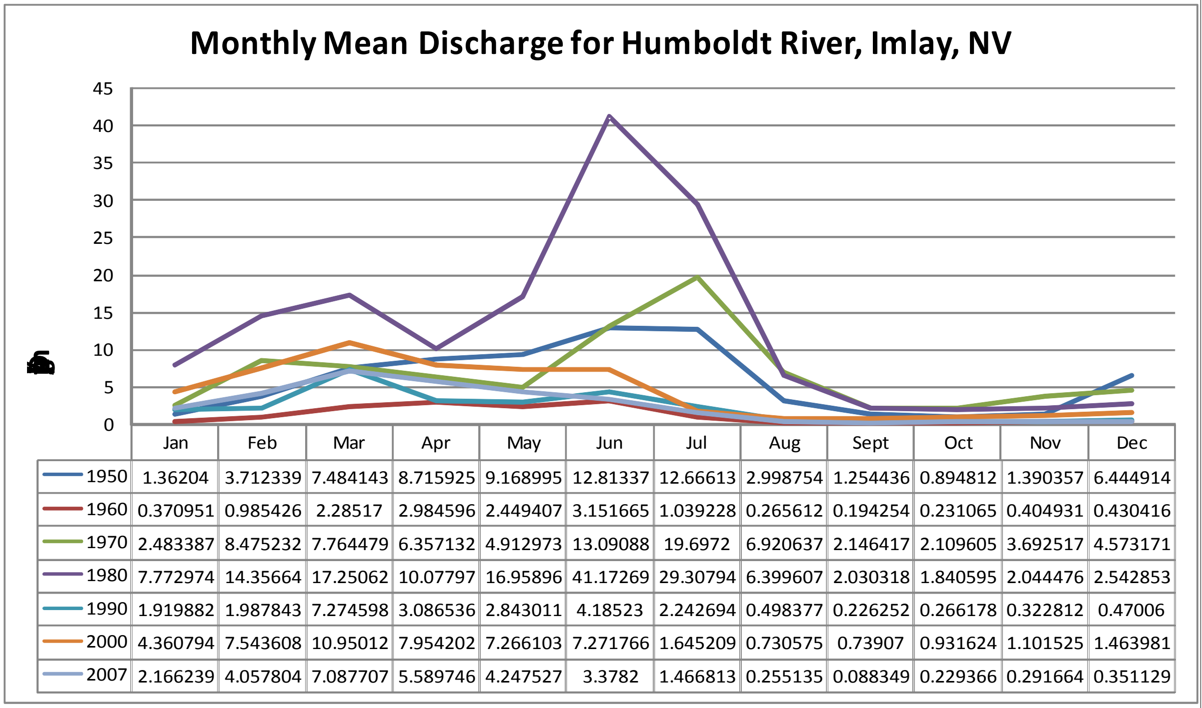


Figure 10.2: Depiction of how close Imlay,NV is to Rye Patch, NV.

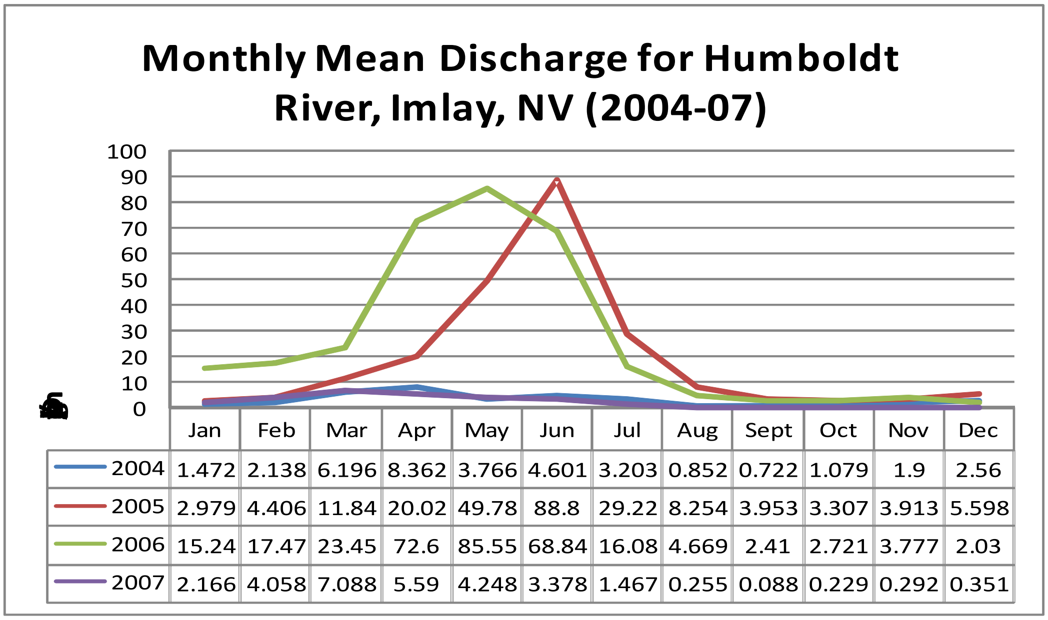
<http://www.sage.wisc.edu/riverdata/scripts/world_map_large.php?oldx=1112&oldy=887&qual=256&newxy=?1,1>

Q_{in} is approximated for Rye Patch Reservoir by the addition of the Imlay discharge value to the average precipitation received at Rye Patch Reservoir for a specific month. The following three figures all help explain the monthly mean discharge values for Imlay, NV and are in cubic feet/sec.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1950	1.36204	3.712339	7.484143	8.715925	9.168995	12.81337	12.66613	2.998754	1.254436	0.894812	1.390357	6.444914
1960	0.370951	0.985426	2.28517	2.984596	2.449407	3.151665	1.039228	0.265612	0.194254	0.231065	0.404931	0.430416
1970	2.483387	8.475232	7.764479	6.357132	4.912973	13.09088	19.6972	6.920637	2.146417	2.109605	3.692517	4.573171
1980	7.772974	14.35664	17.25062	10.07797	16.95896	41.17269	29.30794	6.399607	2.030318	1.840595	2.044476	2.542853
1990	1.919882	1.987843	7.274598	3.086536	2.843011	4.18523	2.242694	0.498377	0.226252	0.266178	0.322812	0.47006
2000	4.360794	7.543608	10.95012	7.954202	7.266103	7.271766	1.645209	0.730575	0.73907	0.931624	1.101525	1.463981
2007	2.166239	4.057804	7.087707	5.589746	4.247527	3.3782	1.466813	0.255135	0.088349	0.229366	0.291664	0.351129

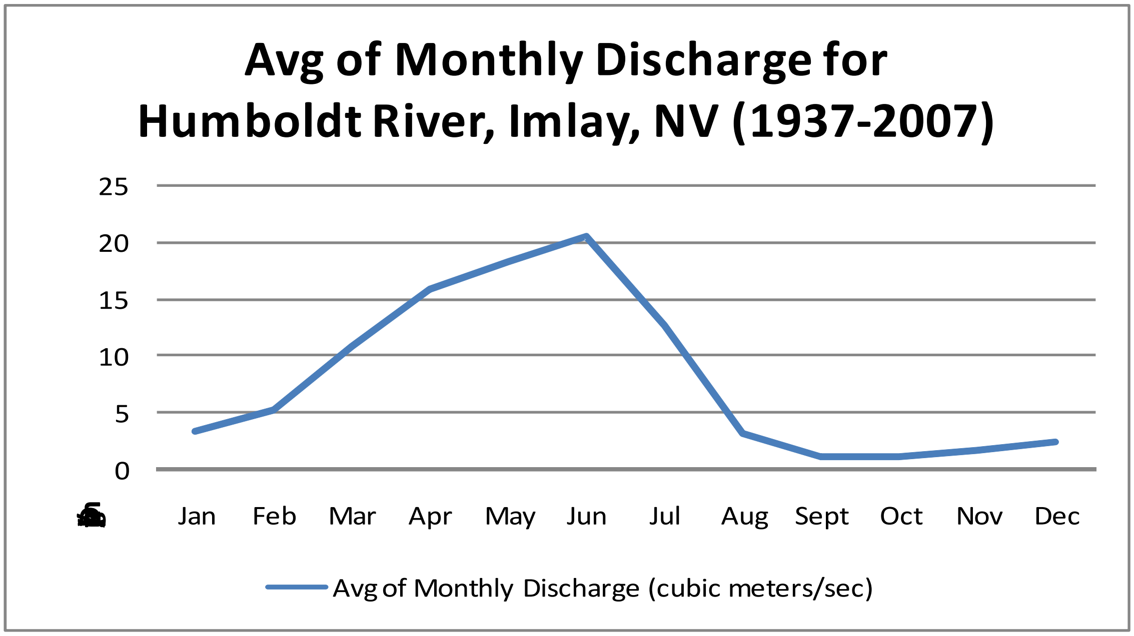
Figure 10.3: Monthly Mean Discharge for Humboldt River, Imlay,NV



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2004	1.472	2.138	6.196	8.362	3.766	4.601	3.203	0.852	0.722	1.079	1.9	2.56
2005	2.979	4.406	11.84	20.02	49.78	88.8	29.22	8.254	3.953	3.307	3.913	5.598
2006	15.24	17.47	23.45	72.6	85.55	68.84	16.08	4.669	2.41	2.721	3.777	2.03
2007	2.166	4.058	7.088	5.59	4.248	3.378	1.467	0.255	0.088	0.229	0.292	0.351

Figure 10.4: Monthly Mean Discharge for Humboldt River, Imlay,NV(2004-2007)

Figure 10.5: Average Monthly Discharge for Humboldt River, Imlay, NV (1937-2007)



Figures 10.3 and 10.4 demonstrate how inconsistent the discharge levels from Imlay into Rye Patch Reservoir are. Figure 10.4 specifically analyzes a four year period of 2004 to 2007. In 2004 there was severe drought. In 2005 the highest point of discharge was in June topping at 88.8 cubic meters per second. In 2006, a very similar trend appeared as 2005, except the highest discharge level was 85.55 in May. Finally in 2007, severe drought struck again. In a period of four years, the Imlay location showed the extreme fluctuations it can face. Additionally, Figure 10.5 shows that the average discharge builds up gradually until June (the usual high point), and then it consistently drops throughout the rest of the summer as the mountain snowpack disappears.

As mentioned previously, Q_{in} requires not only the inflow levels, but also precipitation levels. Since mean monthly precipitation levels of Rye Patch Dam were not available past 2000, an examination of the amount of water loss to evaporation at Rye Patch Dam in the year 2000 was to be done. The data comprising Figures 10.6 and 10.7 is needed for the variable Q_{in} for 2000.

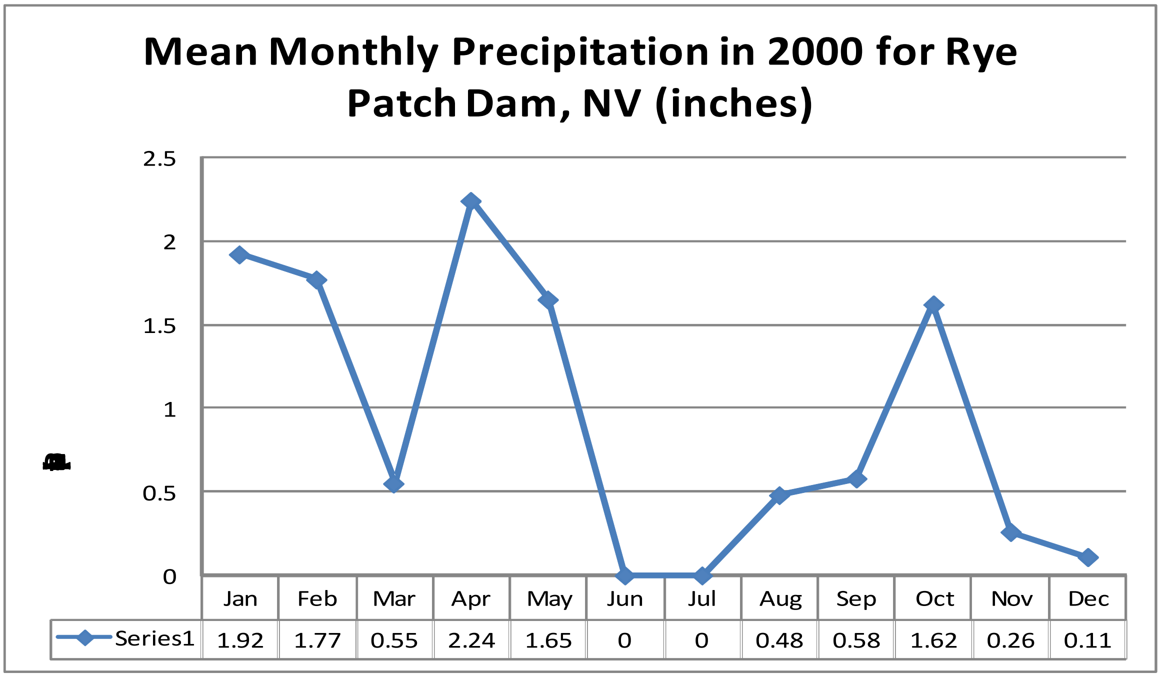


Figure 10.6: Average Monthly Precipitation at Rye Patch Dam, NV in 2000.

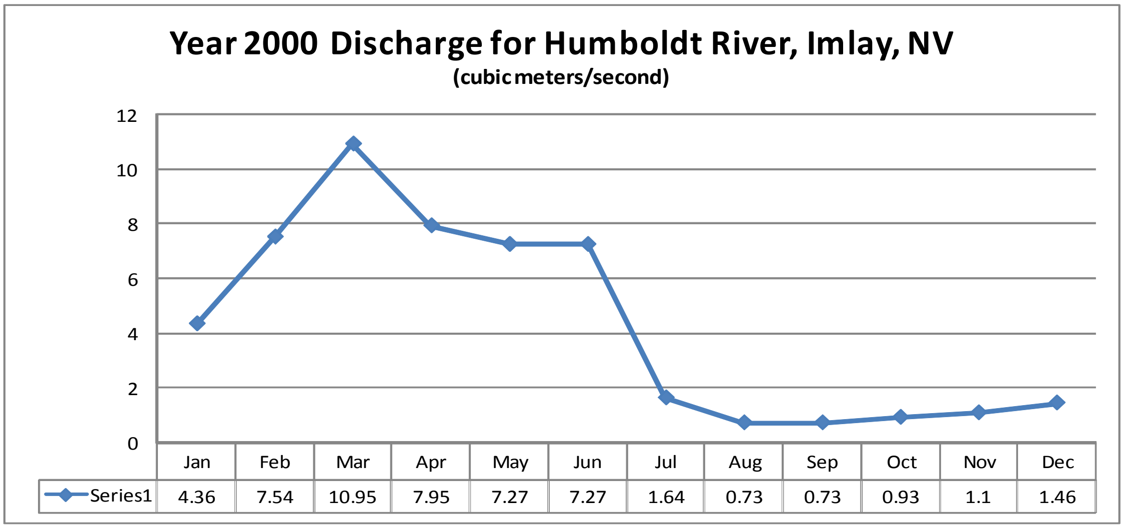
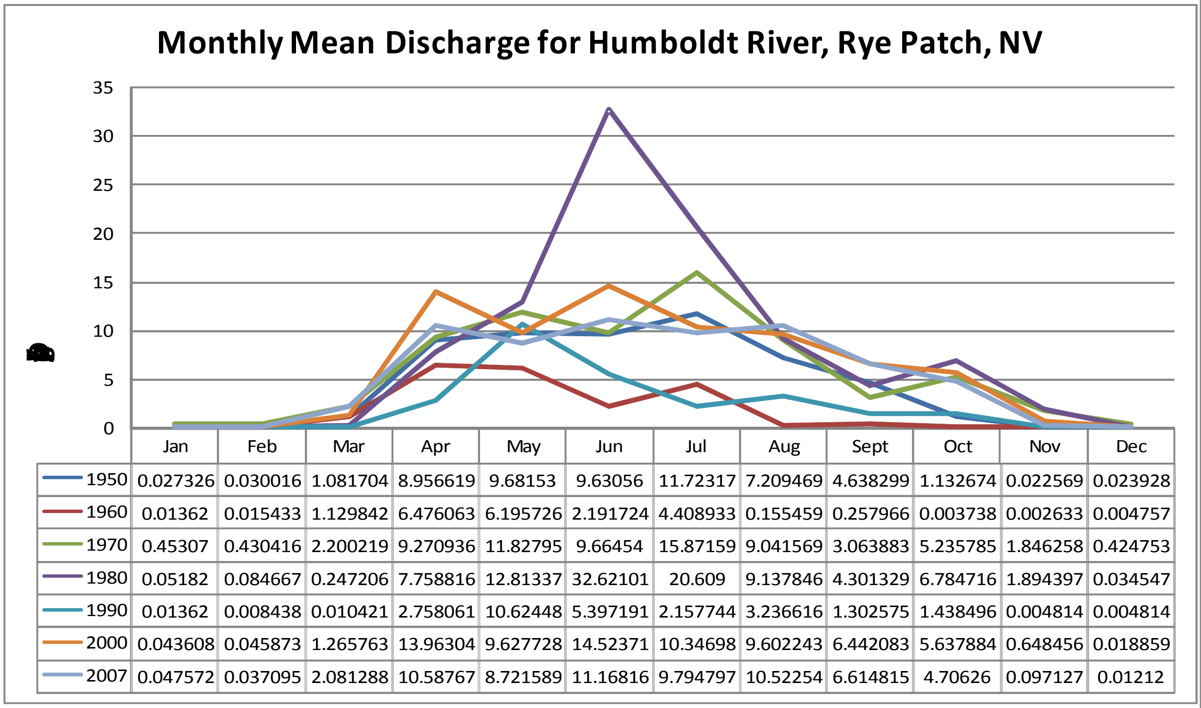


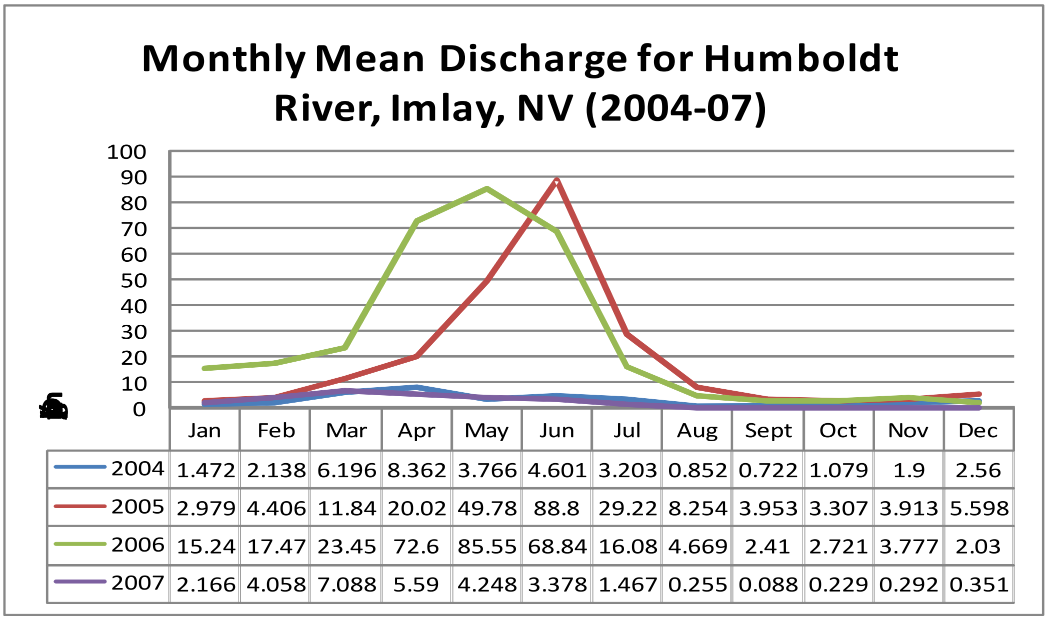
Figure 10.7: Discharge from Imlay, NV in 2000.

Q_{out} is determined for Rye Patch Reservoir by the discharge values posted on the USGS website that can be seen in Figures 10.8-11. All values in the figures below are in cubic meters per second.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1950	0.027326	0.030016	1.081704	8.956619	9.68153	9.63056	11.72317	7.209469	4.638299	1.132674	0.022569	0.023928
1960	0.01362	0.015433	1.129842	6.476063	6.195726	2.191724	4.408933	0.155459	0.257966	0.003738	0.002633	0.004757
1970	0.45307	0.430416	2.200219	9.270936	11.82795	9.66454	15.87159	9.041569	3.063883	5.235785	1.846258	0.424753
1980	0.05182	0.084667	0.247206	7.758816	12.81337	32.62101	20.609	9.137846	4.301329	6.784716	1.894397	0.034547
1990	0.01362	0.008438	0.010421	2.758061	10.62448	5.397191	2.157744	3.236616	1.302575	1.438496	0.004814	0.004814
2000	0.043608	0.045873	1.265763	13.96304	9.627728	14.52371	10.34698	9.602243	6.442083	5.637884	0.648456	0.018859
2007	0.047572	0.037095	2.081288	10.58767	8.721589	11.16816	9.794797	10.52254	6.614815	4.70626	0.097127	0.01212

Figure 10.8: Monthly Mean Discharge for Humboldt River, Rye Patch,NV



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2004	1.472	2.138	6.196	8.362	3.766	4.601	3.203	0.852	0.722	1.079	1.9	2.56
2005	2.979	4.406	11.84	20.02	49.78	88.8	29.22	8.254	3.953	3.307	3.913	5.598
2006	15.24	17.47	23.45	72.6	85.55	68.84	16.08	4.669	2.41	2.721	3.777	2.03
2007	2.166	4.058	7.088	5.59	4.248	3.378	1.467	0.255	0.088	0.229	0.292	0.351

Figure 10.9: Monthly Mean Discharge for Humboldt River, Rye,NV(2004-2007)

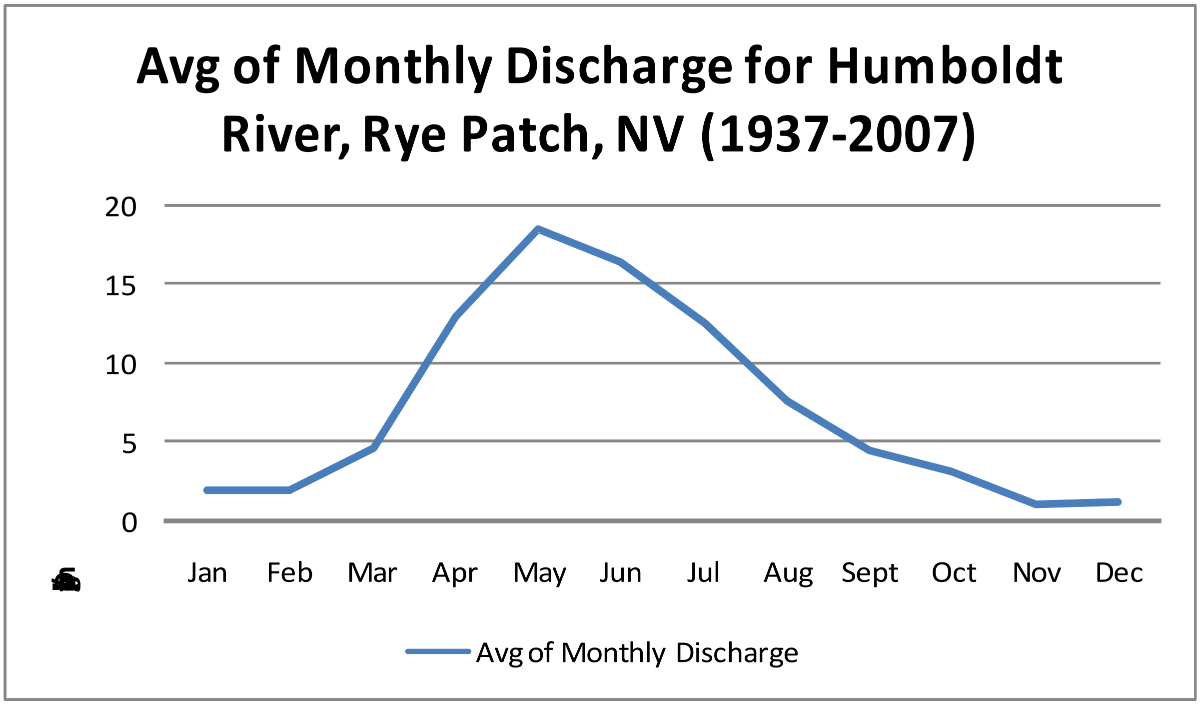
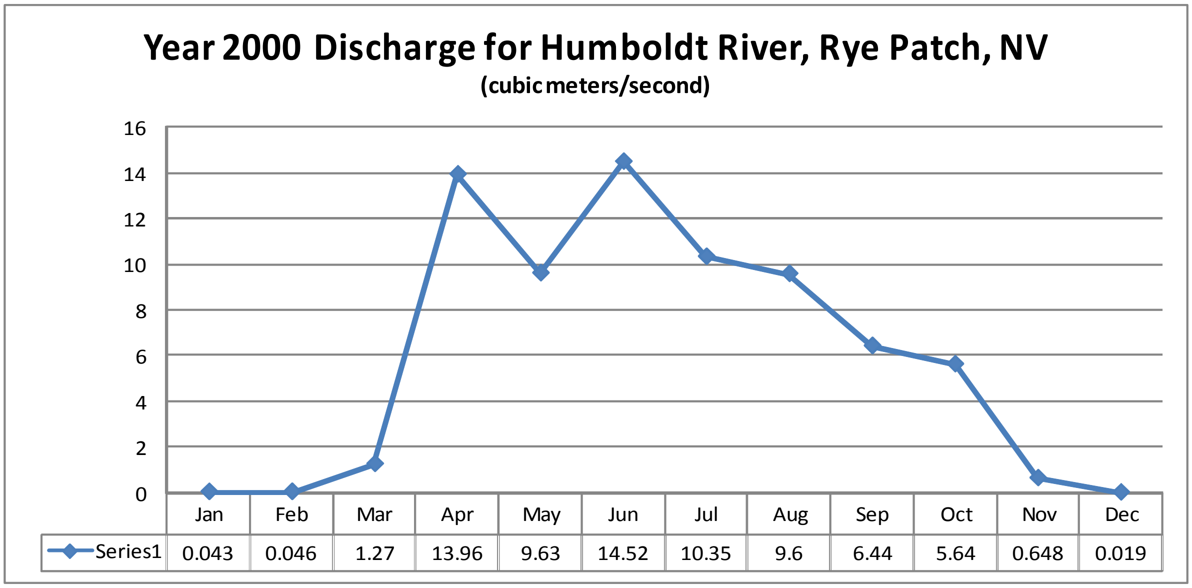


Figure 10.10: Average Monthly Discharge for Humboldt River, Imlay, NV (1937-2007)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Series1	0.043	0.046	1.27	13.96	9.63	14.52	10.35	9.6	6.44	5.64	0.648	0.019

Figure 10.11: Average Monthly Discharge for Humboldt River, Rye Patch, NV (2000)

The final variable to calculate is S, seepage of water through the wall dam and floor. The value of seepage is very difficult to calculate and can only be done at night hypothetically since any water loss during the night is due to seepage alone since evaporation is out of the picture. However, calculating seepage requires the calculation of the lattice structure formed by the foundation and how easily water can diffuse through it. Unfortunately, the Rye Patch Reservoir "is an earthfill structure. A total of 322,900 cubic yards of compacted earthfill covered by 9,800 cubic yards of gravel and 36,200 cubic yards of rockfill and riprap forms the Rye Patch Dam. The foundation is a mixture of clay, sand, and fine gravel." [40] The multiple layers of foundation indeed help prevent seepage, but also make it very difficult to calculate their effectivity. Thus, it is safer for this paper to equate the total amount of water loss due to evaporation and assume seepage is negligible, rearranging the formula to: $\Delta v + S = Q_{in} - Q_{out} - E$

Using the data for the months March through October from Figures 10.1, 10.6, 10.7, and 10.11, the approximate value of water loss due to evaporation can be calculated for those months in 2000.

The following table contains the converted units.

In/outflow:	The inflow and outflow values were found in cubic meters per second, and multiplying by 2629743.83 (average number of seconds in a month) gives us cubic meters per month.
Precipitation	Since Rye Patch Dam and Reservoir contains 11,000 acres of water surface, which is 479,160,000 sq feet, multiplying by 144 gives sq inches. Then multiplied by the annual precipitation in inches per month gives cubic inches per month. This number was then multiplied by 0.0254^3 (number of meters in an inch cubed) to convert to cubic meters per month.
E	The variable E was calculated from the pan measurements multiplied by the pan constant. However, since there are 1752575616 meters squared of surface area, the inches per month of evaporation were converted to meters per month and then multiplied by the surface area in meters to give cubic meters per month.

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[40] U.S. Department of Interior, Beureau of Reclamation: Managing Water in the West. The Humboldt Project <http://www.usbr.gov/dataweb/html/humboldt.html>

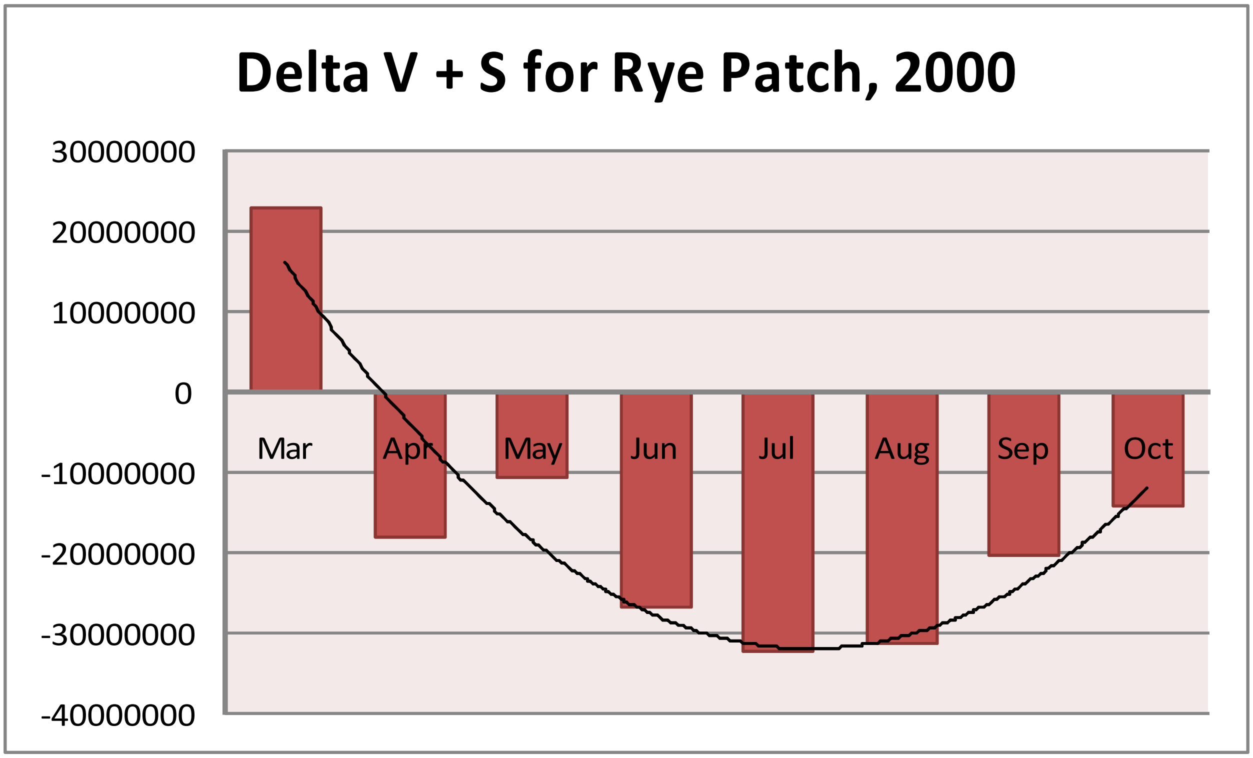
Finally the variables were able to be plugged in for the months of March through October for the year 2000 at Rye Patch Dam and Reservoir.

Figure 10.12: Evaporation Equation Variables

	Mar	Apr	May	Jun
Inflow m^3/month	28795694.94	20906463.45	19118237.64	19118237.64
Precipitation m^3/month	621880.4264	2532749.373	1865641.279	0
Q in (Inflow + Prec) m^3/month	29417575.36	23439212.82	20983878.92	19118237.64
Q out (Discharge) m^3/month	3339774.66	36711223.86	25324433.08	38183880.41
E m^3/month	3146149.609	4943949.385	6258378.467	7827213.177
Delta V + S (m^3/month) =	22931651.1	-18215960.42	-10598932.62	-26892855.94

	Jul	Aug	Sep	Oct
Inflow m^3/month	4312779.88	1919712.996	1919712.996	2445661.762
Precipitation m^3/month	0	542732.0085	655801.177	1831720.529
Q in (Inflow + Prec) m^3/month	4312779.881	2462445.004	2575514.173	4277382.291
Q out (Discharge) m^3/month	27217848.64	25245540.76	16935550.26	14831755.2
E m^3/month	9455409.201	8531068.75	5893730.399	3646480.678
Delta V + S (m^3/month) =	-32360477.96	-31314164.51	-20253766.49	-14200853.59

Figure 10.13: Calculated Evaporation and Seepage for 2000 at Rye Patch Reservoir



Ultimately, if this calculation shows nothing else, it shows the immense amount of water being lost to evaporation in ideal conditions where seepage is negligible, and how that amount increases as temperature increases over the summer months. Nearly 30,000,000 cubic metes of water is lost in June, July, and August, which converts to 24,321.40 foot acres per month. Rye Patch Reservoir has a storage capacity of 213,000 foot acres. Therefore at least one tenth of the storage capacity is lost per month in the Summer. With seepage included, and assuming that the seepage is one order higher than evaporation usually in practice [41], we notice that this water loss is significant comparatively. Therefore ways to prevent evaporation and snowpack melting earlier in the year have and will be investigated.

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41 Craig, I. Methods for Assessing Dam Evaporation – An Introductory Paper. Rep. 11 May 2004. National Centre for Engineering in Agriculture and University of Southern Queensland Toowoomba. 06 May 2009 <http://eprints.usq.edu.au/280/1/Craig_and_Hancock_IAA_paper_04.pdf>

11 Fatty Acid Monolayers and Protective Covers

Living cells have a protective lipid bilayer composed of hydrophobic tails in order to prevent diffusion of certain molecules. This same concept can be applied to fresh water sources by using chemical monolayers composed of fatty acids and alcohols. "Alcohols with 16-18 carbon atoms were found to be the most suitable for the field application."[42] These can be used to decrease evaporation by approximately 30-40% and have been used slightly since the 1950's. One study of protective covers and monolayers stated; "Reduced light penetration and lower temperatures occur under floating and shade cloth covers and dissolved oxygen is lower under floating covers. These factors will limit algal growth but may impact on other flora/fauna. The monolayer did not create any negative impact on the waters physical quality parameters measured."[43]

When the option of pouring $20,000 of stearic alcohol (shown to prevent up to 59% evaporation loss) in order to save $200,000 of fresh water is apparent, the choice is clear. Protective monolayers should be a default condition set for large water storage areas in locations where the wind speed does not exceed 15 mph, otherwise the monolayer will be blown off the surface. However, these chemical monolayers are reapplied every two to four days in order to continuously cover the waterway.

By taking either approach, a substantial volume of fresh water could be saved for better use. Although continuous floating covers may be expensive for larger dams, Dr. P.J. Watts hypothesized, "In the future, increasing cost of water may allow increasingly large sizes of dam to be covered.

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42 Frank E Jones, Evaporation of Water: With Emphasis on Applications and Measurement, Lewis Publishers, 1992. Pg. 105

43 Craig I, Green A, Scobie M and Schmidt E (2005) Controlling Evaporation Loss from Water *National Centre for Engineering in Agriculture Publication* 1000580/1, USQ, Toowoomba.

For the present, economic analysis have implied that chemical covers may represent the best option for evaporation control on large farm water storage."[44]

Additionally, once adapted, other locations will see the benefits, and possibly the dry and arid climates similar to the Great Basin around the world can have a fighting chance of holding out on the battle of fresh water.

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44 Watts, Dr P.J. (2005). Scoping study - Reduction of Evaporation from Farm Dams. Final report to the National Program for Sustainable Irrigation. Feedlot Services Australia Pty Ltd, Toowoomba.

12 A Second Plan for Preserving Fresh Water

Increasing the price of water per unit would also help the Great Basin. The price of water in the United States is very low in comparison to other countries—so low that the price does not even cover the cost of supplying it. For instance, Las Vegas (not part of the Great Basin) currently has the lowest price for water among arid cities. It is no wonder that water is used so wastefully. If the price per unit was raised, consumers would be forced to pay a premium for wasteful water usage. Such a program would encourage water conservation practices such as turning off unused spouts, careful sprinkler monitoring, and more efficient cleansing. It is only right that such a valuable resource as fresh water should be valued highly in economic terms. Investing in sound conservation practices works, as investment in watershed protection has already shown: "Several cities have already found that investing $1 in watershed protection could save from $7.5 to nearly $200 for new water treatment facilities."[45]

The general manager of the Southern Nevada Water Authority, Patricia Mulroy, stated that increasing the price of water "would just irritate people… To simply throw out a gross rate increase, it's not going to create the necessary results. I mean look what's happening with gasoline: people are not using less gas as a result."[46] This is a valid argument against a simple price increase; it prompts the idea of using a tiered block rate structure for the cost of water. In such a scheme, a certain amount of water is allocated to several tiers. The lowest-tier water is priced so that even poverty stricken families can receive the water they need for bare necessities. Any water used over the first-tier amount is purchased at the second-tier price, and so on. In order to encourage effective water management and reduce high volume water use outdoors, each price jump is quite

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[45]

[46] http://www.pacinst.org/reports/las_vegas/hidden_oasis.pdf

drastic. Consumers in such a system would be likely pick a tier affordable to them and stick to it. In a fixed-price system, there is no mechanism which provides this kind of maximum personal capacity.[47]

Action must be taken in order to preserve water within the Great Basin. The efficiency of both indoor and outdoor water use must be improved. Besides the obvious effect of using less water for the same purposes (or the same amount for more people), greater efficiency also cuts down on the energy and chemical costs needed to transport and treat the water. Greenhouse gas emissions would then decrease as well.

By installing water-efficient fixtures and appliances, water demand within single-family homes could decrease by up to 40% and up to 30% in hotels and casinos. "Water-efficient landscapes could further reduce current outdoor demand by 40% in single-family homes."[48] It is very important that new homes have these water-efficient technologies as well. By offering audits and rebates for efficient fixtures, Nevada has already begun making a positive change. For instance, homeowners who purchased a pool cover received a rebate back after their purchase, and over 30 gallons of water per square foot per year are thus saved in pools. Better practices in new housing developments would also help, such as using water-efficient fixtures, managing urban runoff to get water back to aquifers, and building community pools instead of private pools.

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47 http://www.pacinst.org/reports/las_vegas/hidden_oasis.pdf

48 http://www.pacinst.org/reports/las_vegas/hidden_oasis.pdf

13 Cloud Seeding – A Final Option

Cloud seeding is the most ideal solution to the drastic warming the Great Basin is encountering. Cloud seeding is the act of releasing silver iodide and frozen carbon dioxide (dry ice) via aircraft or device into a cloud containing "supercooled liquid water (SWL)." SWL is liquid water that is below the freezing point, and thus when contact is made with the chemical, the temperature and vapor pressure react to form snowpack on the mountains.[49] Cloud seeding performed in many different experiments has been shown to potentially improve snowpack formation by 50-100% if all the SWL above a mountain range was converted.[50] However in actuality, cloud seeding typically increases precipitation by 50%, with a 15% increase in snowpack formation. Considering that snowpack formation is the major source of water to the Great Basin, specifically the Humboldt River, cloud seeding seems like the safest option in preserving the summer months river discharge values.[51] Figure 13.1 on the following page demonstrates how simple Cloud Seeding actually is.

49Super, A. B. and A. W. Huggins, 1993: Relationships between storm total supercooled liquid water flux and precipitation on four mountain barriers. *J. Weather Mod.*

50Boe, B. A. and A. B. Super, 1986: Wintertime characteristics of supercooled liquid water over the Grand Mesa of western Colorado. *J. Weather Mod.*, **18**, 102-107. and

Super, A. B., 1994: Implications of early 1991 observations of supercooled liquid water, precipitation and silver iodide on Utah's Wasatch Plateau. *J. Weather Mod.*, **26**, 19-32.

51 A. W. Huggins, 2006: Summary of Studies that Document theEffectiveness of Cloud Seeding for Snowfall Augmentation. North American Interstate Weather Modification Council, 1-8.

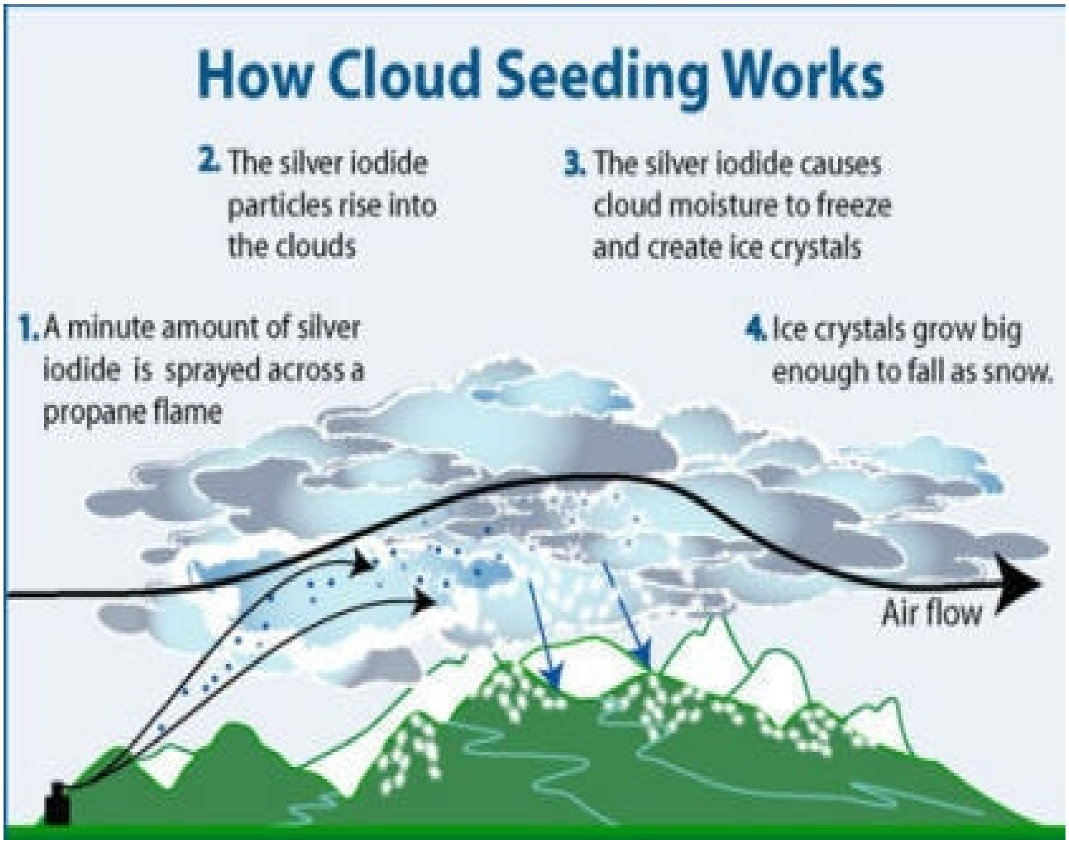

Figure 13.1: Average Monthly Discharge for Humboldt River, Imlay, NV (1937-2007)

[http://cwcb.state.co.us/NR/rdonlyres/A1C68F20-3910-44C7-B95F-B7CDE5855A84/0/SnowyHydroImg0257.jpg]

14 Conclusion

The time to protect our water sources is now. Decisive action must be taken, for "as population grows, we will become even more dependent on irrigation for our food supplies, placing extraordinary stress on fresh water systems particularly in arid and semi-arid regions."[52] "So much water is diverted for human uses that the natural flow of major rivers such as the Colorado, Yellow, and Amu Darya no longer reach the sea during the dry season." The same may soon happen to the Humboldt River.[53] This phenomenon means that the rivers are losing reach and that the aquifers cannot recharge fast enough. Also, the results have shown that inconsistent snowpack melting dates can cause much distortion in the discharge values of a river. "For example, the Humboldt River at Palisade has experienced flows of 1,336,000 acre-feet during one year and only 25,000 acre-feet during another year. With such wide fluctuations, it is difficult to provide adequate and consistent water supplies to users on the system."[54] These are signs of groundwater shortages, climatic problems, and the dangers they carry.

Warmer temperatures do not spell disaster from all points of view thankfully. It is hypothesized that warmer winters will lead to less energy use for heat by millions of people. Additionally "an expected small increase in wintertime precipitation could churn generators to the tune of an extra 1900 megawatts of power – nearly enough to power two cities the size of Seattle."[55] Thus snowpack may form earlier in the Winter than now, bringing spring floods and summer droughts. Once the snowpack begins melting earlier, a shift will occur in the dynamics of river flow

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52 S. Postel, *Where Have All the Rivers Gone?* (World-watch Institute, Washington, DC, 1995)

53 Johnson, Revenga, Echeverria. 2001. Managing Water for People and Nature. Science, vol 292, p.107-108

54*Nevada State Water Plan. Rep. 1999. Nevada Division of Water Resources Department of Conservation and Natural Resources. 05 May 2009 <http://water.nv.gov/WaterPlanning/wat-plan/con-main.cfm>*

55 Service, R.F. 2004. As the West goes dry. Science, vol 303, p. 1124-1127

depended for hydroelectric power production. "As a general rule, however, a 1 percent decrease in runoff produces a greater than 1 percent decrease in hydropower production."[56] Thus less water passes through the turbines of the dam, water pressure is lowered, and the energy output of the dam is lowered by a greater factor. "In the Colorado River's lower basin, for example, a 10 percent decrease in runoff reduces power production 36 percent."[57] The Columbia River basin is accountable for nearly one third of all hydroelectric power produced in the nation (U.S. Bureau of the Census, 1992) and is expected to produce 20% less hydroelectric power by 2060. The Colorado River basin's hydroelectric output is expected to drop 50%.[58] These percentages suggest similar consequences for the Great Basin, but considering the drier climate, the effects may be more extreme.

Nearly 1.5 billion people rely on groundwater as their sole source of drinking water. This water comes from isolated sources underground as well as aquifers, yet the major source in the Great Basin has been demonstrated to be snowpack. Overdrawing groundwater sources can rob streams and rivers of a significant fraction of their flow, and pollution can render aquifers unfit for human use and degrade water quality in adjacent fresh water ecosystems.[59] However, without an abundant formation of snowpack each Winter, regions like the arid basin will become even drier. "The dry conditions during April have prompted a further reduction in the spring runoff forecasts for basins in the Sierra Nevada and upper Sacramento and watersheds in the Humboldt. April through July forecasts now range from 42 to 78 percent of average for the east side Sierra Nevada

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[56] Water Supply and Demand. 07 Jan. 2000. U.S. Environmental Protection Agency. 15 Dec. 2008 <http://yosemite.epa.gov/oar/globalwarming.nsf/content/ImpactsWaterResourcesWaterSupplyandDemand.html>

[57] Ibid

[58] Payne, J.T., Wood, A.W., Hamlet, A.F., Palmer, R.N. and Lettermaler D.P. 2004. Mitigating the effects of climate change on the water resources of the Columbia River Basin. Climatic Change 62 (1-3), p. 234-256.

[59] Johnson, Revenga, Echeverria. 2001. Managing Water for People and Nature. Science, vol 292, p.107-108

basins and 53 to 72 percent for forecast points on the main stem Humboldt River."[60] Hopefully with advances in cloud seeding, an artificial replenishment of snowpack can be performed on a yearly basis, to return snowpack formation to 100% therefore ensuring the strong river flows that are needed. This would be a high priority for regions like Rye Patch Reservoir, because as demonstrated earlier the sources of water for this reservoir is snowpack from the mountains. When snowpack doesn't form to a high enough degree, the reservoir suffers and the evaporation and seepage loss of water can be very large.

Demand for water per capita will surely decrease as new conservation measures are put in place and as new homes are built with water-efficient fixtures.[61] Even older homes will become more efficient as appliances and fixtures are replaced. However, since the population growth has been shown to growing faster than an exponential rate, systems such as the tiered block rate pricing structure could produce great results. These trends not only help limit the overuse of water, but also they engender a mentality that wasting water is unsound economically and impracticable environmentally. With proper regulations, educational programs, and advances in technology, we may avoid the day when there is not enough fresh water to go around. This applies not only to potential water shortages in the Humboldt River Basin and Great Basin, but to all resources everywhere. Ultimately it is up to all humans throughout the world to conserve the resources they use, to nurture the environment which nurtures them, and to live in such a way that human life will still be possible far in the future.

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[60] Water Supply Outlook. Rep. May 2008. California Nevada River Forecast Center and NOAA. 05 Feb. 2009 <http://www.cnrfc.noaa.gov/products/water_supply/2008/ws052008.pdf>.

[61] Hidden Oasis: Water Conservation and Efficiency in Las Vegas. Rep. Nov. 2007. Pacific Institute and Western Resources Advocate. 25 Apr. 2009 <http://www.pacinst.org/reports/las_vegas/hidden_oasis.pdf>.

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