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# *COLORADO RIVER BASIN ALLOCATION IN THE ERA OF CLIMATE CHANGE: THE ROLE OF GIS FOR WATER CONSERVATION MANAGEMENT*

Rica Fulton

Senior Seminar Spring 2013

Abstract:

Climate change has many implications for the Colorado River and the millions of people the lifeline supports. Allocation and water management in the arid west seems to be increasingly complex, as climate change, coupled with population growth, add another perplexing aspect for water managers. Average predictions for Colorado River flows range anywhere between a 6%-20% decrease by 2050, despite the water stored in Lake Powell and Lake Mead, which are already are far below average historic levels. GIS (Geographic Information Systems) and remote sensing technologies have been evolving since the 1970s and are serving as vital tools for sharing, visualizing, analyzing, and manipulating spatial data. GIS technology create excellent mechanisms for water managers, scientists, politicians, and the public interests groups with consistent information on temperature data, precipitation, snowpack, soil types, land use and a multitude of other factors, which determine the health and survival of the river. GIS is a critical device that needs to be utilized for conservation of vital water resources in the Colorado River Basin.

**Rica Fulton**
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**Objective:**

- The goal as an intern with the U.S. Forest Service is to eagerly address natural resource management within the social sciences realm by applying my knowledge gained though the Environmental Studies and GIS education I have received as well as professional experience with the BLM and Mountain Studies Institute.

**Education:**

- Fort Lewis College-Winter 2011-Present, Environmental Studies Policy Option, and GIS Certificate GPA 3.4
  Durango, Colorado
  - GIS courses including Intermediate Geographic Information Systems Python Programming for GIS, and Remote Sensing
  - Sciences courses including Biology and Chemistry.
  - Anthropology, Environmental History, and Environmental policy courses.
- Western Washington University-Fall 2010, Environmental Policy Major
  Bellingham, Washington

**Professional Work Experience:**

- September-present: Paid Climate Education Outreach internship through Mountain Studies Institute (MSI) and funded by National Science Foundation.
  - Duties include working with high-elevation climate change researchers and MSI to create lesson plans for high school students addressing climactic changes to high elevation ecosystems and the overarching affects to the local region.
- June-August 2012: Paid Landscape Conservation Intern position through Southwest Conservation Corps and Bureau of Land Management through the Youth Corps program.
  - Duties included working on a BLM Colorado Climate Change Adaptation Plan, assisting in the step-down process for the Colorado Plateau Rapid Ecoregional Assessment, and other miscellaneous climate-related tasks.

**Volunteer Work:**

- Spring 2013: Logistic Coordinator of SEEDS chapter at Fort Lewis College participating in a San Juan River clean up.
- March 2011: Service project with Fort Lewis College's Outdoor Pursuits on the San Juan River working to remove trash and extract Ravenna Grass, an invasive species along the banks of the river.
- Fall 2010: Participated in a water rights club working to rid the Western Washington University of bottled water.
- Spring 2009: Initiated, organized, advertised, and produced a local fashion show in order to benefit KIVA, a non-profit organization benefiting small business owners in underprivileged countries.

**Work Experience:**

- April 2012-Present: Trip Consultant at Mild to Wild Rafting and Jeep Trail Tours, Durango Colorado.
  - Duties include answering phones, selling trips, customer service, booth sales and misc. office work.
- October 2011 - December 2011: Assistant Manager at Video Shack, Durango Colorado.
- September 2006 - August 2010: Shift Leader at Dairy Queen Durango, Colorado.
- July 2009: Paid Internship at Sweet Potatoes Children's Clothing, Berkeley, California.

**Skills:**

- Great Organizational skills from being proactive in school as well as holding many leadership positions working throughout the years.
- 2004-2008: Camper at Colvig Silver Camps and have a love of the outdoors growing up in Colorado hiking, mountain biking, rafting, and miscellaneous other activities.
- I offer notable writing skills.
- Have experience with ArcMap, ArcCatalog, Microsoft Word and Excel.

**Rica Fulton**

**REFERENCES**

Emily Olson (541)399-0908
Internship Supervisor
Education/ Outreach Coordinator
Mountain Studies Institute
1000 Rim Drive
Durango CO, 81301

Andrew Gulliford (970) 247-7011
Professor/ Academic Advisor
Southwest History Professor
Fort Lewis College
1000 Rim Drive
Durango CO, 81301

Bill Dunkelberger (970) 385-1351
Internship Supervisor
Cooperative Landscape Conservation Coordinator
Bureau of Land Management
15 Burnett Court
Durango CO, 81301

To Whom It May Concern,

It is with great excitement that I submit my application to Oregon State University for the Water Resources Policy and Management Master's program. From my review of various water management programs, it is clear that Oregon State University has an excellent program. I am currently completing my education at Fort Lewis College in Durango, Colorado with a Bachelor's in Environmental Studies, a Geographic Information Systems Certificate, and a Biology Minor.

I have always held an interest in water management and in the spring of 2013 completed my senior thesis on Colorado River Allocation in the Era of Climate Change and GIS as a Tool for Water Management. I believe that the WRPM Master's Program would offer me a great opportunity to expand my knowledge in a very pressing and pertinent sector of natural resource management.

Throughout my college career I have had the opportunity to work in various environmental management positions with the Bureau of Land Management and Mountain Studies Institute, a local non-profit organization. Through both of these positions I have gained a wealth of information mainly on climate change, education, and occasional survey and fieldwork positions. Through this broad field of climate change I have gained the passion for water conservation, as Durango is on the edge of the very arid deserts of Utah and the great San Juan Mountains where water management is notoriously complex.

I believe that my studies within Fort Lewis College degree and GIS certificate coupled with my professional experience I will have adequate skills and passion to become a great fit into the WRPM program at Oregon State University. Thank you for your consideration and time and please contact me with anything else I may need to provide. I look forward to speaking with you in the future.

Sincerely,

Rica Fulton

# United States Department of the Interior

BUREAU OF LAND MANAGEMENT
COLORADO STATE OFFICE
2850 Youngfield Street
Lakewood, Colorado 80215-7093

In Reply Refer To:
1400-361(I)

August 10, 2012

Andrew Gulliford, Ph.D.
Professor of History and Environmental Studies
Department of History
Fort Lewis College
1000 Rim Drive
Durango, CO 81301

Dear Dr. Gulliford,

Rica Fulton has completed work as a Landscape Conservation intern with the Bureau of Land Management (BLM), Colorado State Office Division of Resources and Fire Management under the direct supervision of Bill Dunkelberger, BLM Colorado Cooperative Landscape Conservation Coordinator. Rica provided ten, 40 hour workweeks to the BLM through the Southwest Conservation Corps under agreement with the Colorado Youth Corps Association. The work occurred between June 4, 2012 and August 10, 2012.

As previously agreed to this is a formal letter of reference for the intern and a recommendation to the Fort Lewis Faculty Intern Advisor (Dr. Andrew Gulliford) for a letter grade for Environmental Studies 310 – Community Internship for work performed under the internship.

It was a pleasure mentoring Rica Fulton this summer. She more than satisfactorily performed the following duties that were prescribed during this 10-week internship:

**1.** Assisted with monitoring climate change research, reports, policy, and other information and disseminated it through an internal BLM Climate SharePoint site, via email and in person.

**2.** Assisted with the Colorado Plateau Rapid Ecoregional Assessment report finalization, roll-out, step-down and implementation.

**3.** Assisted in the development of a BLM CO Climate Change Adaptation Strategy.

**4.** Participated on the BLM CO State Office Climate Change Interdisciplinary Team.

**5.** Miscellaneous other duties as assigned in support of the BLM's Cooperative Landscape Conservation initiatives and local field work.

In terms of a letter grade, I would give Rica an A-. I found her to be a quick learner. After I provided initial instructions, context, and background she comprehended and performed assigned tasks proficiently and on time without the need for much additional guidance. Her work products were outstanding with the exception of minor spelling and grammatical errors.

Rica took a very rough initial draft of the BLM Colorado Climate Change Adaptation Strategy, revised

and supplemented it with the latest research and agency specialists' contributions, and produced a well-organized, thoughtful final draft that will ultimately help the BLM in Colorado recognize and integrate climate adaptation throughout its programs and projects. She integrated key findings from the recently completed Colorado Plateau Rapid Ecoregional Assessment into the Climate Adaptation Strategy. She also assisted in two training sessions for agency employees.

In addition, Rica spent several days assisting Tres Rios BLM and San Juan National Forest field crews conduct hydrological monitoring and assessments, performed abandoned mine land remediation maintenance, and took a tour of the Anasazi Heritage Center Curation facilities.

I feel fortunate that Rica has agreed to continue working part-time for me under a volunteer agreement to help see the BLM Colorado Climate Change Adaptation Strategy through to completion. I would be happy to recommend Rica for seasonal employment in natural resource technical work in the short term and feel she is well suited for a variety of entry level, environmental science related career positions upon graduation. Please don't hesitate to contact me for more specific information.

Sincerely,

/s/ *Bill Dunkelberger*

Bill Dunkelberger
Cooperative Landscape Conservation Coordinator

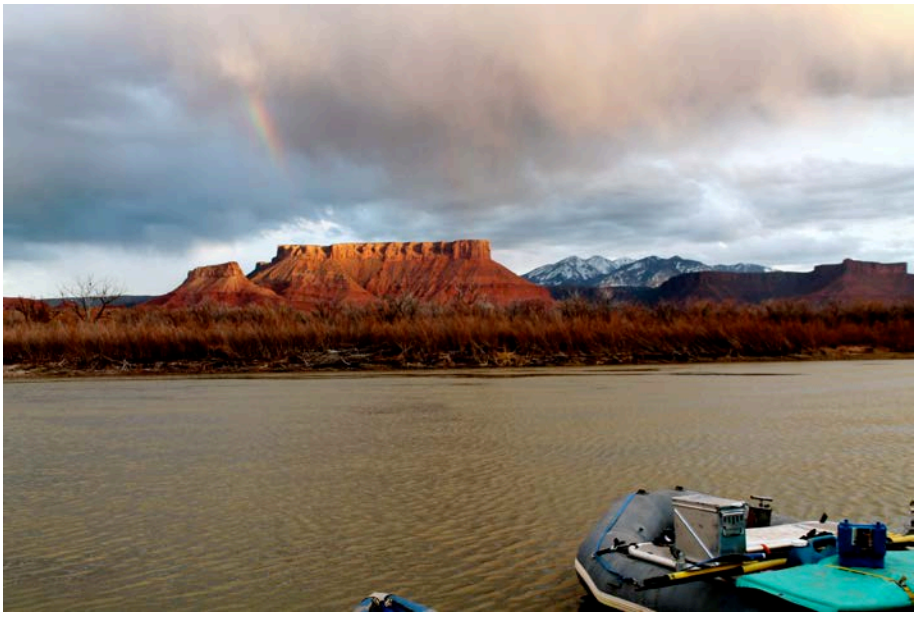
cc: (via email only)
Anna Hendricks, Southwest Conservation Corps
Leigh Espy, BLM CO Deputy State Director

# The Colorado River Basin in the Era of Climate Change: GIS as a tool for Water Conservation Management

Rica Fulton

Environmental Studies Senior Seminar

Spring 2013



"The future of water-and life- in the west will be very different from anything we've come to expect. A willingness to adapt and change to new conditions will be critical to life in the West. The time to start planning is now."[1]

The Colorado River is a main source of water in the Western United States that provides life to over 30 million people in the form of agriculture, hydroelectric power generation, water quality, recreation, and ecological systems. Allocation and management of the river is controlled by major dams and water jurisdiction based off of water laws from the era of growth and settlement of the West, meaning that conservation was not in the diction. In the 21st century other factors have begun to rear their heads such as population growth and climactic changes, which have already started to show effects to the Colorado River Basin. In order to maintain the steadily growing southwestern United States conservation methods, technologies and policies must be altered and polished to conserve the integrity of the basin and the millions who depend on it. It is necessary to discuss water allocation policies in place, population growth, predicted climate change effects to the Colorado River Basins,

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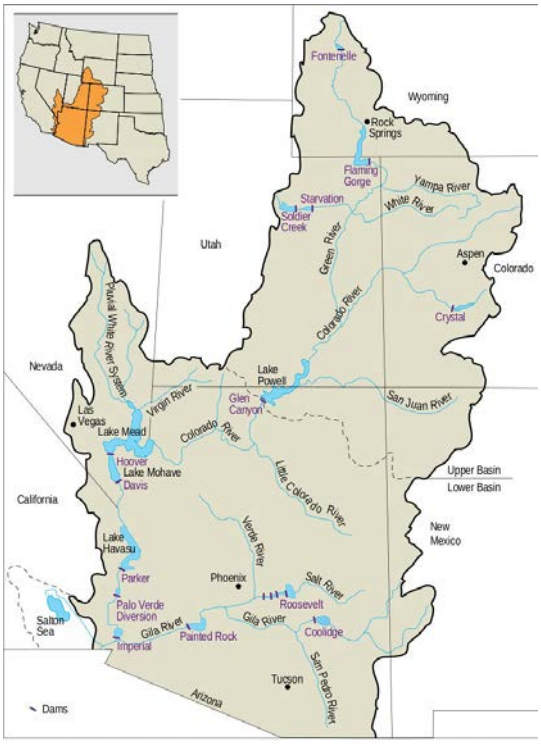
[1] Jennifer Pitt. What Does Climate Change Mean for Water in the Colorado River Basin? *Water Currents.* National Geographic. June 20, 2012. http://newswatch.nationalgeographic.com/2012/06/20/what-does-climate-change-mean-for-water-in-the-colorado-river-basin/

various scenarios and predictions of water flows, applications and the role of mapping and GIS technologies both historically and as a vital tool for the future.

The Colorado River is one of the largest rivers on earth that at one point flowed from the peaks of the Rocky Mountains across the Colorado Plateau all the way into the Gulf of California. The 1,450 mile river and its tributaries flows through seven western states including Wyoming, Colorado, Utah, and New Mexico in the upper basin and California, Arizona, and Nevada in the lower basin. Water is also further allocated to Mexico and various American Indian Tribes through various compacts and agreements. The Colorado River is the main source of life through the vastly arid region of the southwest and containing 29 major dams on the Colorado and it's major tributaries that feed around 35 million people.[2] The Colorado River is becoming increasingly known as "one of the most controlled, controversial and litigated rivers in the world."[3]

[2] Wikipedia. *Colorado River: Engineering and Development.* 2013.

[3] Southern Nevada Water Authority. *Colorado River Law.*




**The Colorado River Basin (243,937 mi2 / 631,960 km2)**

(from USGS Climate Science Impacts on the Colorado River)

Western expansion in the late 1800s and early 1900s was lead by ideologies of development and the takeover of the unknown natural habitat. Water in the wide uninhabited west was viewed as another resource to use and control to the fullest extent of man's desires for industries such as ranching, mining, and lumbering. Such water system used in the west is called prior appropriation, which entails that water rights are not included in land ownership, but the first person to use water from a source has the senior water rights to continue to use their allocated amount water for a specific beneficial purpose. A beneficial purpose usually entails agriculture,

industry, and household uses. Successive water users may then use their amount of water as long as they do not infringe on the water uses of those more senior. Junior water appropriators in times of drought may not receive their full allocation or sometimes none of it. Water rights in the west can be sold along with the appropriation date and amount that was historically decided.

Problems with prior appropriation are circled around the encouragement of water waste in order to continue receiving senior water rights in a "if you don't use it you loose it" mentality. Such law has varied over time within each western state, leading to many conflicts between different rulings between states and countries. Often such conflicts lead to federal law or private contracts taking the ultimate say, which is problematic because it leads to umbrella regulations, which are not always good solutions for all states and water users. Another problem affecting prior appropriation is that the system does not leave room for population growth, especially in the rapidly growing southwestern cities as it was built around small settlements and economic activities. Prior appropriation in modern day ignores the significant changes in function, especially with intensive water control in dams and reservoirs.[4]

[4] Tarlock. *The Future of Prior Appropriation in the West.* 2001. Pages 3, 4.

As the west continues to grow away from being a 'production colony' and into a variety of fully modernized urban regions, prior appropriation is increasingly becoming disparaged.[5] With the rise of environmentalism coupled with threats of climate change and population growth newer solutions to water allocation must be applied in the west.

**The Law of the River**

During the beginning of the 1900s population in western states began to grow along with agricultural industries, leading to concerns about water security. California in particular were concerned with maintaining their share of Colorado River water, despite California state's lack of contribution to the Colorado River. In 1922 the seven states signed the Colorado River Compact to decide the allocation of water rights among the states. The amount of water allocated to each state was based on historical rain patterns giving each basin equal amounts of water. The compact first divided the river basin into the upper and lower basins and requires the Upper Basin states to leave at least 7, 500,000 acre feet during any ten consecutive years.

Colorado River law becomes more complex with the water that is in some cases separately allocated to Native American Tribes along the river. "Under the terms

[5] Tarlock. *The Future of Prior Appropriation in the West.* 2001. Page 5.

of various decisions of the U.S. Supreme Court, including *Winters v. United States,* nations, bands, or tribes of Native Americans who reside on reservations are entitles to such waters as needed to satisfy the purposes for which the reservation was created.[6] Within some forms of environmental justice Native Americans have been known to take a backseat politically, which could rapidly become a problem as drought ravages the southwest

| COLORADO RIVER BASIN DEPLETION PROJECTIONS (Unit: 1,000 af/yr) | | | | |
|---|---|---|---|---|
| | 1990 | 2000 | 2010 | 2020 |
| **Upper Basin** | | | | |
| Colorado | 2,296 | 2,445 | 2,565 | 2,636 |
| New Mexico | 503 | 535 | 641 | 743 |
| Utah | 857 | 951 | 1,030 | 1,073 |
| Wyoming | 495 | 505 | 530 | 539 |
| *Totals* | 4,151 | 4,436 | 4,766 | 4,991 |
| **Lower Basin** | | | | |
| Nevada | 214 | 258 | 304 | 341 |
| Arizona | 1,351 | 2,019 | 2,373 | 2,537 |
| California | 5,162 | 4,916 | 4,823 | 4,622 |
| *Totals* | 6,727 | 7,193 | 7,500 | 7,500 |

*Source: Quality of Water, Colorado River Basin Progress Report, Number 18, January 1997. U.S. Department of the Interior Report.*

(http://www.arizonaenergy.org/WaterEnergy/sharing_colorado_river_water.htm)

[6] Vaux, Henry Jr. *Equity in Policy: Failure and Oppurtunity. Natural Resources Journal* 50.2 (2010):

A series of other laws and agreement concerning Colorado River allocation have been steadily passed after the initial compact in 1922. Major renditions to the compact include:

- The Boulder Canyon Project in 1928 ratified the 1922 compact by authorizing the construction of Hoover Dam, apportioned the lower basin's 7.5 million acre feet (maf) as 2.8 maf for Arizona 4.4 maf for California, and 0.3 for Nevada.
- The Mexican Water Treaty of 1944, which committed 1.5 maf of the Colorado River to Mexico.
- The Upper Colorado River Basin Compact of 1948 which allocated the 7.5 maf between the Upper Basin States giving Colorado 51.75%, New Mexico 11.25%, Utah 23%, and Wyoming 14%.
- The Colorado River Storage Project of 1956 allowed the plan to build Glen Canyon Dam, Flaming Gorge, Navajo and Curecanti dams.
- The Arizona vs. California U.S. Supreme Court Decision in 1964 settled the long standing dispute between the two states over Arizona developing water from the Gila River, which under prior appropriation belongs to California

but runs into the Colorado River. Arizona won, saying that the Colorado River Compact trumps the doctrine of prior appropriation.

- The Colorado River Basin Project Act of 1968 authorized several water development projects in both basins including the Central Arizona Project in which the extra water goes to California in times of shortages.
- The Colorado River Basin Salinity Control Act of 1974 which authorized desalinating and salinity control projects to improve Colorado River water, especially as it goes into the Morelos Dam in Mexico.[7]

Two major dams on the Colorado are the Hoover Dam and Glen Canyon Dam. The Hoover Dam, names after Herbert Hoover who negotiated the Compact, was built just outside of Las Vegas Nevada in the 1930's shortly after the Colorado River Compact allowed the lower basin to build the dam and Lake Mead. The dam provided flood prevention, irrigation possibilities to California and Arizona and hydroelectric capabilities. [8] Glen Canyon Dam and Lake Powell was built near Page Arizona, and finished in 1963. The dam was built for hydroelectricity as well as flow regulation for

[7] Dwyer. Bureau Of Reclamation. *The Law of the River.* March 2008.
[8] http://www.history.com/topics/hoover-dam

the upper basin states. Lake Powell, the reservoir associated with the dam, is the second largest man-made lake in the country.

**Over-Allocation of the Colorado River**

An imperative predicament with the Colorado River Compact is that the Colorado River in the early 1920s was at high water, and the amount of water allocated for each state technically does not always exist in the high majority of years in the natural runoff cycle. "In 1924, just two years after the Colorado Compact was signed, a government hydrologist calculated the actual flow of the river was 10% less than the Compact negotiators assumed" and in 1965 a water engineer estimated the flows were rally 14% less.[9] Such percentages are equivalent to entire states allocations, and sooner or later will create conflict. Inflow from the past 100 years has averaged 16.4 maf, but since 2000 the average has dropped to 15.3 maf.[10] When you take account of population growth and climate change water shortages are surely in the future for the seven states. Dams and water storage can maintain normal water allocation amounts through short periods of drought, but not for the long term.

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[9] Jenkins. *How low will it go? Colorado may face a dry and difficult future of fighting for water.* High Country News

[10] Bureau of Reclamation. *Colorado River Basin Water Supply and Demand Study: A Proposal Submitted for Consideration under the Basin Study Program.* June 2009.

**Population Growth**

Secrets of southwestern United States have rapidly become discovered by the rest of the world and is becoming one of the most desirable places to live. People are attracted to the pleasant climate, open spaces, beautiful scenes that the southwest has to offer, despite the inherent lack of water. In the 20th century the population of the southwest has increased from 2,100,000 to over 50,000,000, the majority of who live in California.[11] Arizona's population grew by 40% in the 1990s, compared to the national average of 13% increase in population.[12] Such immense growth translates into higher costs for water, and more competition.

According to the U.S. census, population growth in the southwest is rising and it is estimated that by 2030 more than 60 million people will live in the region. California would have over 46 million, and Nevada, Arizona, and Utah would be in the top 5 states with the highest population growth.[13] General domestic needs of the population are not the main usage of water resources; landscaping, and agriculture

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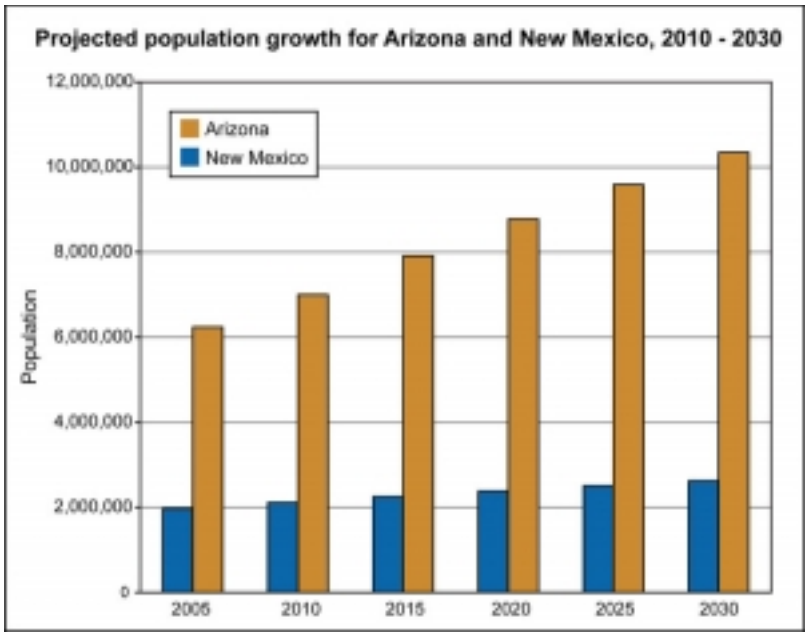
[11] MacDonald. *Water, climate change, and sustainability in the southwest.* Proceedings of the National Academy of Sciences of the United States of America. Vol. 107, no. 50. 2010

[12] Owen, Gigi. *Drought and People.* University of Arizona. 2008.

[13] MacDonald. *Water, climate change, and sustainability in the southwest.* Proceedings of the National Academy of Sciences of the United States of America. Vol. 107, no. 50. 2010

require heavy amounts of water to compensate for the lack of natural precipitation. It is estimated that suburbs in the arid west use seven times more water per capita than cities in the east. It is also suggested that with this rise in population, the west would require more than 86% of its total stream flow to meet human use at current per-capita use. [14] Numbers such as these suggest an overwhelming need for conservation of Colorado River water resources.




http://www.southwestclimatechange.org/impacts/people/drought#urban

What population growth means in this magnitude is conservation. The idea of conservation needs to be set into policy, paradigms, and management strategies.

[14] MacDonald. *Water, climate change, and sustainability in the southwest.* Proceedings of the National Academy of Sciences of the United States of America. Vol. 107, no. 50. 2010

Water management has traditionally been built around the ideas of manipulation of water instead of altering it for demand. Many obstacles exist with lowering demand including the opposition to water restrictions, time and money restrictions, and uncertainty of outcomes. New technologies must be put into place in order to prove to policy makers, water managers, and the public that water conservation laws are needed even in the name of golf courses and water-heavy crops.

**Climate Change to the Colorado River Basin**

Climate change has become a looming threat to the world's water supply with rising temperatures and melting glaciers becoming more apparent every day. For the Colorado River and its arid climate, projections for future climate change and water supply don't seem promising. The headwaters of the Colorado in the Rocky Mountains play a huge role in the amount of runoff, as about 70% of the annual runoff comes from high-elevation snowpack.[15] Mountains are highly susceptible to climactic changes, making forecasts of decreased snowpack especially worrisome. According to the IPCC, annual temperatures in the Southwest could rise by 4.5-9 degrees

[15] Western Water Assessment, Colorado Water Conservation Board, and CU Boulder. *Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation.* 2008. P. 14.

Fahrenheit during this century.[16] Warmer temperatures, even with average precipitation amounts, will lead to earlier and faster snow runoff in the spring.

Studies of the Upper Colorado River Basin have shown averages of 6%-20% decreases in runoff by 2050 compared to the 20th century average. Many various climate models exist, and it is impossible to predict the exact flows; but based on various past averages from observed, gauged, and proxy climate data scientists can make a fairly accurate prediction for the future. The storage of the Colorado River is another indicator of available supply and drought. As of 2008, Lake Powell was at 61% capacity and Lake Mead 46%. "The 2000-04 period had an average inflow of 9.9 million acre feet per year, which was lower that the direst period during the dust bowl years of 1931-35."[17] Although it is noted that water levels of the Colorado was not a driving factor of the dust bowl, drought and temperature increases of that magnitude are becoming more regular.

Precipitation has been a somewhat variable and unknown component to climate change researchers in the southwest. According to University of Colorado Boulder's Tim Seadset precipitation amounts will stay somewhat the same in a year,

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[16] Bolin et al. *Water resources, climate change, and urban vulnerability; a case study of Phoenix, Arizona.* Local Environment. Vol. 15, No. 3, March 2010.
[17] WWA, CWCB, and CU Boulder. *2008.p. 28.*

but the timing of precipitation amounts will change and more water will become evaporated with rising temperatures and rapidly decreasing soil health in some areas. Tarlock et al. suggest that precise impacts on water resources are difficult to predict because of so many different conditions varying regionally, although the IPCC states that impacts will be "drier than average conditions."[18]

Snowpack predictions are some of the most important and complex to understand as pertaining to water management. According to Mountain Studies Institute and Colorado U.S. Forest Service 'Climate Initiative' decreases in projected snow-water equivalent are expected. In elevations below 8,200 feet decreases are expected at between 20%-60% by 2040-2069 and above 8,200 feet snowpack is anticipated to decline between 10%-20%. Such decline in numbers paired with warmer average temperatures denote runoff in the spring will be much earlier and water will evaporate much more quickly.

For the southern Rocky Mountains, dust coming from the deserts and plains of northern Arizona and Utah are blowing onto the snowpack in the spring adding to a quickened runoff. Economic and recreational activities such as grazing and off-road vehicles break up the top soils and kill much of the vegetation leading to eroded soils

[18] Tarlock. *The Future of Prior Appropriation in the West.* 2001. Page 8.

that are easily taken by winds. The dust then in turn blows onto the snow in the mountains leaving the white snow encrusted with dirt. The dirt decreases the albedo, or reflectivity of the snow and absorbs more heat, making it melt off much more rapidly. The dust-on-snow phenomenon shows the multitude of human impacts centered on economics that affects the Colorado River.

**Implications**

Implications for the users of the Colorado River will vary regionally, with an overall trend of decreased flows. For example, Phoenix Arizona is one of the most quickly growing cities in the United States with over 4 million people as of 2007 al getting their water from the Colorado, the Salt, and the Verde Rivers. It is suggested that the variability of water security varies within the city based on a mix of water sources, water providers and service areas and water seniority, as well as economic status of residents.[19] For residents of Phoenix and its suburbs, this means the reduction in landscaping water and non-Indian agriculture, which are main users of water. Some measures have been discussed but no serious policies have been put into place for water limitations.

[19] Bolin et al. *Water resources, climate change, and urban vulnerability; a case study of Phoenix, Arizona.* Local Environment. Vol. 15, No. 3, March 2010.

**GIS as a tool for water management in the face of climate change:**

Geographic Information Systems(GIS) is a modern mapping data and analysis software that combines traditional cartography with sophisticated data analysis capabilities to let us "visualize, question, analyze, interpret, and understand data to reveal relationships, patterns and trends."[20] The first GIS systems have been around since the 1960s and is rapidly becoming more advanced and widespread within its inter-data capabilities as well as availability to users. Such geographic technology is revolutionary by directly integrating visual resources and geographic relationships easily to compare, manipulate, and understand. GIS data competently connects geographic information displayed on maps to an attribute database which holds the geospatial information associated with map features. GIS technology is an asset to countless industries and resources such as health, transportation, planning, science, conservation, policy and more.

Humans now live in a time where it is overwhemingly easy to access information through the internet. In ways that freedom is overwhelming, but for scientists it has become a portal to share information to create solutions at a much quicker rate then ever before. As years go on, technology grows at quicker rates For

[20] Esri Inc. *What is a GIS? http://www.esri.com/what-is-gis*

GIS, this means that different parties can all post data on the web that can be shared, in some cases for free. For natural resource managers, this means that different sectors can easily share information between states such as policy makers, water managers, scientists, and the public.

**GIS For Water Management**

In terms of water management, GIS is a vital instrument for water conservation planning. "Sometimes GIS is referred to by users as mearly a tool but there is ample historic precedent showing that a tool can stimulate science, and provoke new ways of thinking about problems."[21] GIS has the ability to visualize complex scientific spatial data in ways that can be shared, processed and analyzed. Water management requires understanding of all aspects of the watershed in question such as water sources, terrain surface, watershed, land cover, human land use, elevation, rainfall, temperature, snowpack, soils, atmospheric conditions, and more. GIS aids as a comprehensive tool to combine these factors and observe the spatial relationships between all dynamics involving water management.

An example of GIS as a tool for water management comes from Indus Basin in India, which is an area of exponetially rising populations with a limited water supply.

[21] Seth. *DIS: A Useful Tool in Urban Water Management.* Pg. 2.

A hydrological model was set up the basin which includes climactic data including temperature, precipitation, relative humidity, and solar radiation in which the values can be used for predicting future values. Digital Elevation Models (DEM) is used to identify accurate elevation, slope, and aspects.other layers included in the model include landuse and soil data, drainage data, socio-economic data, administrative data, and hydrographic data.

Integrating the model output provides a simple mechanism to understand variability of water quantity and quality variables in the watershed in order to address changes in water availability and provides sufficient information on hydraulic and environmental sustainability. Having a common geospatial platform is vital in the Indus Basin for integrating information on water resources to provide long term information for water management decisions. [22] This model can serve as a model for other river basins around the world, including the Colorado using existsing DEMs, soil and landuse, socio-economic data, and more and integrate it into different models using the International Panel on Climate Changes various scenarios for temperature and precipitation.

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[22] Patil and Gosain. *GIS Framework to Evaluate Impact of Climate Change on Water Resources.* I.I.T. Delhi.

The range of applications for GIS software can help not only in the big pictures of climate change and water management, but also in individual cases. Agriculture and irrigation are two of the main water consumers of the Colorado River, and as less water is becoming available GIS can be used as a tool to map out areas with different soils types, environmental conditions, and moistures levels in order to decide proper crops to grow that will be successful and economically viable. GIS models are important in combining spatial and temporal information into one single analysis. GIS has the capability for displaying data on maps for easy visualization by farmers, which makes it more likely to come up with agreements for water conservation strategies.[23] Another strength of GIS is it's real-time monitoring capabilities, allowing the system to update data as crops grow, and as water levels change. Overall, GIS is a great tool for agricultural water management.

**GIS as a Solution for Colorado River Waters**

The widespread array of use for GIS leads a proposal to be the creation of a public platform that holds geospatial information as regards the Colorado River Basin and all of the interrelated aspects to management. Such platform would be internet-

[23] Belmonte et al. *GIS tools: applied to the sustainable management of water resources: Application to the aquifer system.* Agricultural Water Management, Vol 40. May 1999. Pages 207-220.

based and enable different users to add and share data sets, create maps, visualize and discuss spatial relationships, and a multitude of different other topics. Different categories could be included for different interest groups such as agriculture, recreation, policy and more. Aerial photos from the United States Department of Agriculture as well as Landsat satellite images of the river would be included and updated frequently to assess changes to different regions of the river. The consistency of Landsat images ensures accurate observations and analysis for all viewers.

The first step of such a multi-faceted platform would have to be an interest group, government agency, scientist, or a free-willed individual who has the time and skill to create such a complex program. Other sites with similar capabilities are slowly appearing within Esri, Inc., the creator of the ArcGIS program and other GIS data hubs. Scientific platforms are also becoming more common; an example of this is "Data Basin" which was developed by a team from Conservation Biology Institute with the "strong conviction that we can expand our individual and collective ability to develop sustainable solutions by empowering more people through access to spatial data, non-technical tools, and collaborative networks."[24] Data Basin has a wide range of

[24] Conservation Biology Institute. *About Data Basin: A better solution.* http://databasin.org/about

uses in that it has the ability to support different groups where members can actively communicate environmental issues and discussions of their interest. Different entities such as governmental agencies, educational institutions, private interest groups, companies and more all can create, manage, and share information through different portals and groups.

A Colorado River portal would have similar capabilities to Data Basin's remarkable spatial sharing abilities, but would be specialized to solely Colorado River conservation. Such platform would be user-friendly, and with adequate marketing and publicity it could become vastly known throughout the region. The unique ability to add and combine data, create maps, Great numbers of western citizens could be aware of the tool's value and importance to the liquid resource holding the arid lands together.

**Satellite images as tools for water managers**

Earth resource satellites have proven to be a valuable resource for the past 40 years with a widespread array of uses. Landsat satellites are product of a joint federal program between NASA and USGS that began in the 1970's have continued to improve both spectral and spatial capabilities. In terms of water management true-color Landsat images enable viewers to see change of the same area over time within

water levels, snowpack, sediment loads, and other characteristics. The spectral (as defined as a region in the electromagnetic spectrum) component of Landsat images is that it enables the user to manipulate the different bands in order to see different components of the image. For example, in false color images vegetation health is seen more efficiently through detected moisture levels.

Landsat images can be helpful in determining evapotranspiration (ET), as defined as volumes of water from the soil into the atmosphere. Calculating the ET of irrigated crops is vital managing water resources as to how much is being used, how much is being wasted through drought, disease, insects and other factors, and as a tool for weather forecasting. ET has been used to develop water budgets, monitor aquifer depletion, understand water land use change, to optimize irrigation to protect endangered species, and to monitor water rights compliance.[25] At a larger scale, ET modeling can be used in general circulation modeling of regions effecting the energy and water cycles. Taken as a whole, Landsat images have an easy to understand, and have an immense amount of uses for water management.

**Conclusions**

[25] Anderson et al. *Use of Landsat thermal imagery in monitoring evapotranspiration and managing water resources.* Remote Sensing of Environment. USDA-ARS, Hydrology and Remote Sensing Lab. University of Idaho. August 2011.

Climate Change in the Colorado River Basin is rapidly becoming a serious threat to the allocation of the already over-distributed precious waters that supply millions of people in the west. Temperatures in the southwest are predicted to rise at rates greater than any other area in the United States except Alaska, leading to earlier snowmelt, drought, erosion, and overall depletion of water supply and quality. Population growth in the area is growing at comparable rates to maximum temperatures, meaning that as the land's carrying capacity is decreasing, human ignorance is allowing more and more humans to populate the arid west, which is creating ever-growing water shortages.

In this era of climate change, water managers, policy makers, and scientists are in immense need of new tools to comprehend, analyze, share, and manipulate climate data. Geographic Information Systems (GIS) is the technology that needs to be utilized to a much greater extent in order to perform complete these actions. GIS should become available on a platform that is easily accessible for all parties as well as having the capabilities to be a data-sharing portal in order to create up-to-date, complete images showing the availability and well being of the Colorado River. Remote sensing technologies such as aerial and satellite photography can be utilized alongside GIS and can be included in the same analysis to visualize changes in the

river basin. The time for water conservation in the west is now, and as human population grows it cannot be possible to comprehend changes without GIS.

## References Cited:


Anderson et al. *Use of Landsat thermal imagery in monitoring evapotranspiration and managing water resources.* Remote Sensing of Environment. USDA-ARS, Hydrology and Remote Sensing Lab. University of Idaho. August 2011.

- This article explains the use of Landsat thermal images in order to measure temperature changes and evapotranspiration rates. This is extremely helpful in monitoring regional areas quickly and deciding areas on the ground that need further research or conservation work. The article points out Landsat's unmatched capabilities for water resource management and its continuity for the future.

Belmonte et al. *GIS tools: applied to the sustainable management of water resources: Application to the aquifer system.* Agricultural Water Management, Vol 40. May 1999.

- Although somewhat outdated, this article called for sustainable exploitation of water in a manner that incorporates a great number of spatial and temporal variables. This article describes a case study of GIS as a tool for managing the Mancha Oriental aquifer system. This system is highly useful and elaborate for its time and is a great model for GIS uses.

Bolin et al. *Water resources, climate change, and urban vulnerability; a case study of Phoenix, Arizona.* Local Environment. Vol. 15, No. 3, March 2010.

- This study described Phoenix's water supply and maps the different sources areas of use. Also, different suggestions for conservation are brought up for when drought will inevitably overcome Phoenix's water supply.

Bureau of Reclamation. "Colorado River Basin Water Supply and Demand Study Final Study Reports." January, 2011. Web. 29 Jan. 2013. http://www.usbr.gov/lc/region/programs/crbstudy/finalreport/index.html

- This is a series of good reports with predictions, and other great information as it relates to management decisions. I will use much of this as valuable

information for my project, as it is somewhat similar to what I am planning on doing.

Conservation Biology Institute. *About Data Basin: a better solution.* http://databasin.org/about

- Data Basin is an analysis and mapping platform that is used to house environmental groups and projects spatial information. Data Basin is unique in that users can upload, manipulate, and view various spatial data. I would like to use this website as a model for a potential Colorado River data platform.

Dwyer, Colleen. Bureau of Reclamation. *The Law of the River.* March 2008.

- This source eloquently goes over the various laws, compacts, and agreements that involve Colorado River Allocation. Such information is vital in understanding how water is allocated and how to fix outdated policies.

Esri Inc. *What is a GIS? http://www.esri.com/what-is-gis*

- Esri has been creating GIS software for over 40 years and it is important to hear how they describe their products.

Hundley Jr., Norris. "The Colorado Waters Dispute." *Foreign Affairs* 42.3 (1964): 495-500. *Academic Search Premier*. Web. 30 Jan. 2013.

- This source is a good policy opinion piece with suggestions for improved allocation strategies. Also, Mexico is brought up and how their crops are being ruined because of too much salinity.

Jenkins, Matt. "How low will it go? Colorado may face a dry and difficult future of fighting for water."*High Country News.* March. 2009. http://www.hcn.org/issues/41.4/how-low-will-it-go/article_view?b_start:int=6&-C

- This article includes what drought means for less-senior water users. This source also has good facts on population growth, number of users who use water from the Colorado. This article also has numbers on what the real

amount of water available is. “In 1924, just two years after the Colorado Compact was signed, a government hydrologist calculated that the actual flow of the river was 10 percent less than the Compact negotiators had assumed. In 1965, a water engineer named Royce Tipton estimated that the river's reliable flow was really about 14 percent less.”

MacDonald, Glen. *Water, climate change, and sustainability in the southwest.* Proceedings of the National Academy of Sciences of the United States of America. Vol. 107, no. 50. 2010

- The author discusses the exceptional drought of the southwest and discusses various climate models. He discusses food security with rising populations, river security, and various other impacts of climate change. He suggests that meeting sustainability in the southwest will require more planning and cooperation than ever before.

National Center for Atmospheric Research. “Climate Change Scenarios.” *NCAR GIS Program.* 2013. http://gisclimatechange.ucar.edu/

- This source will be vital to gaining climate change GIS data that I can download and create my own maps. There are different scenarios, temperature, and precipitation data all with the ability to manipulate dates and areas of study.

Owen, Gigi. *Drought and People.* University of Arizona. 2008.

- *Drought and People* explains the interrelated nature of drought and human actions and regional impacts. This source connects economics, water supply, urban populations, in an important way.

Patil and Gosain. *GIS Framework to Evaluate Impact of Climate Change on Water Resources.* I.I.T. Delhi.

- Patil and Gosain lay out a well-developed framework on analysis for climate change on specific rivers. They describe a case study that they have developed to evaluate impacts from climate change which is a great model for rivers such as the Colorado.

Pitt, Jennifer. What Does Climate Change Mean for Water in the Colorado River Basin? *Water Currents.* National Geographic. June 20, 2012. http://newswatch.nationalgeographic.com/2012/06/20/what-does-climate-change-mean-for-water-in-the-colorado-river-basin/

- Pitt illustrates the uncertainty of water security in the southwest in the Colorado River Basin. Hotter temperatures drive water demand even higher, while the atmosphere also takes more water into evaporation. Pitt combines Bureau of Reclamation studies and comes up with the loss of 1, 800,000 acre feet loss of water in about 40 years.

Seth, Indranil. *DIS: A Useful Tool in Urban Water Management.*

- This article points out many useful aspects of GIS for water management. This provided a great background and framework that I could apply to the Colorado.
-

Tarlock, Dan. *The Future of Prior Appropriation in the West.* Natural Resources Journal. Vol. 41, pages 769-793. 2001

- Tarlock provides amazing insight onto problems with water management. He goes over climate change, prior appropriation and the future of water management. This source was imperative to learn about impacts and ramifications of prior appropriation.

Vaux Jr., Henry. "Equity in Policy: Failure And Opportunity." *Natural Resources Journal* 50.2 (2010): 517-538. *Academic Search Premier*. Web. 16 Jan. 2013.

- Equity in Policy : Failure and Opportunity this article from the Natural Resources Journal brings up environmental justice issues when it comes to water allocation for Native Americans from the Colorado River. The main topics include economics and equality when it comes to natural resources. It is important to have an economic viewpoint with solutions when it comes to changing the ways of river allocation.

Western Water Assessment, Colorado Water Conservation Board, and CU Boulder. *Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation.* 2008.

- This is an invaluable resource to water managers and policy makers in the west. So much research and time went into this comprehensive report which I used much background and ideas from.

# Colorado River Basin Allocation in the Era of Climate Change: the Role of GIS in Water Conservation

Rica Fulton Environmental Studies Senior Thesis
Spring 2013

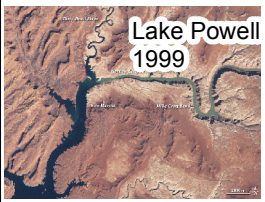

## Project Objectives

- Apply interdisciplinary studies with policy, science, and GIS
- Apply climate change research and experience to a specific hydrological case study
- Visualize the future of human use of the Colorado River
- Understand and elaborate on GIS for water management and climate change implications

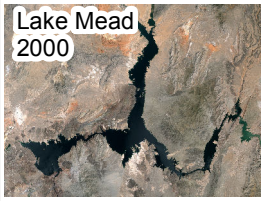
## Methods

- The study originated from the vital need of water in the rapidly growing southwestern United States and the importance of the Colorado River
- Historical information of Colorado River allocation including the Colorado River Compact and other water law.
- Scientific sources were also necessary in order to analyze climactic changes to the Colorado River basin
- GIS data visualize certain trends such as temperature and precipitation changes which are validated with attributes.
- Satellite and aerial photos that have been taken of the United Stated since the 1970s are also valuable resources for water management to visualizechanges in water levels and land cover.

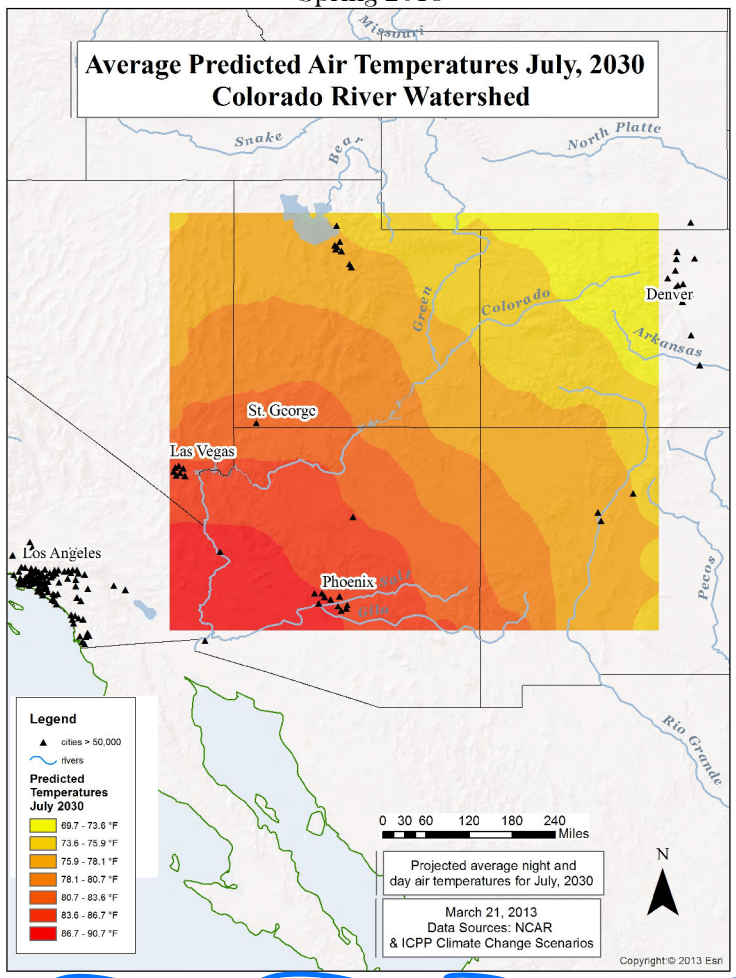
"Scientists have used Landsat data to follow the growth of cities, monitor the use of groundwater, track shrinking glaciers and map coral reefs. Satellite images have revealed the march of bark beetles through western U.S. forests and captured the destruction wrought by natural disasters."
- http://www.climatecentral.org/news/nasa-to-launch-new-earth-observing-satellite-15581









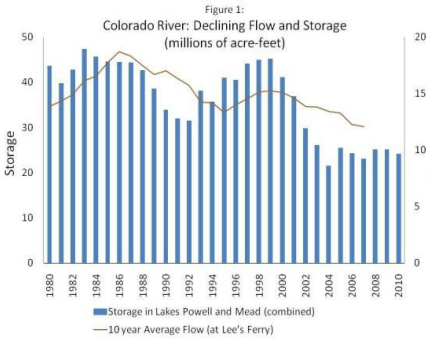



## Abstract

Climate change has many implications for the Colorado River and its millions of users. Allocation and water management in the west has always been complex, and climate change coupled with population growth is adding a whole new aspect. Some average predictions for Colorado River flows are between a 6%-20% decrease by 2050, despite the water stored in Lake Powell and Lake Mead, whose levels are already far below average. Using GIS and remote sensing technologies, would provide water managers, scientists, politicians, and the public with valuable, consistent, and easy to understand maps and information to allocate Colorado River water in times of conservation.

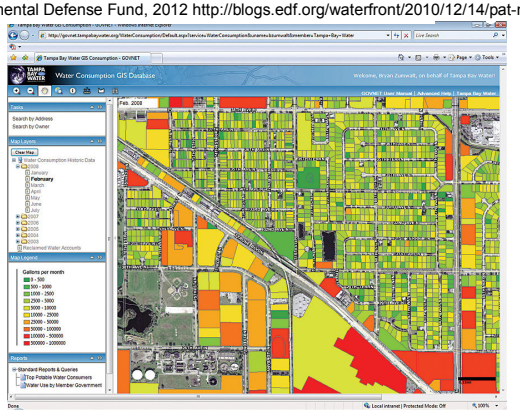
## Conclsions

- Climactic changes and population are both growing at unprecedented rates.
- GIS and satellite imagery are technologies that greatly need to be utilized in for water conservation
- Prior appropriation methods are outdated and wasteful and new approaches to water management are needed.





Environmental Defense Fund, 2012 http://blogs.edf.org/waterfront/2010/12/14/pat-mulroy-fire-brimstone



The city of Tampa Bay Florida created a GIS based system that shows the city and water consumption values by gallons of use. http://www.esri.com/news/arcnews/winter0809articles/tampa-bay-water.html

## Connection to Env. Studies Program

Fort Lewis College's Environmental Studies program has been a widespread array of different classes that all together help to explain the connection between humans and the various environments the planet is composed of. The disposition of my project encompasses the interdisciplinary nature of the Environmental Studies program learning goals and objectives. By analyzing climactic changes to the Colorado River basin and applying the effects to water allocation policies, along with utilizing my GIS education I am blending policy, earth sciences, andmy GIS certificate into a complete project.
Specifically I am "understanding the role of humans in environmental change and the importance of stewardship" by explaining what effect human populations and activities have on the landscape and promoting new technologies for the sake of conservation.
Another direct aspect of the Environmental Studies program goals and objectives in my project is "understanding the roles of local, state, national, and international environmental policies." The rules and policies governing the allocation of the river are intensely complex and interchanging from many national compacts, and earlier western prior appropriation policies.
Overall, Environmental Studies has given students the ability to analyze, interpret, and understand the way humans interact with our environment.

References:
-Esri, INC
-NASA, USGS. Landsat imaging.
-Mountain Studies Institute, US Forest Service. Climate Assesment. 2009.

I would like to acknowledge the Fort Lewis College Environmental Studies department including Rebecca Austin, Scott White the GIS Certificate Manager, Mountain studies Institute for providing me with knowledge and skills needed for professional circumstances, and peers for ideas and support.