Water Knowledge

Uniting Community and Technology to Restore the Santa Fe River

An Interactive Qualifying Project Report

WORCESTER POLYTECHNIC INSTITUTE

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I. ABSTRACT

Water scarcity is problematic throughout the world, especially in Santa Fe, New Mexico. The Water Team was tasked to help the Santa Fe Watershed Association (SFWA) to revive the Santa Fe River by improving people's relationships with water. First the team created a system using Google Maps and Java coding to create maps that link to data collected by the city. These maps will automatically update when the city modifies data spreadsheets. Second, the team created a model to serve as a foundation to show the interaction of water in the environment within the Santa Fe River Watershed. A phone application was designed to increase public interaction with the river. This project has provided the city of Santa Fe with the ability to transform its methods of publicizing watershed data and increasing community involvement in the Santa Fe Watershed.

Cover Photograph: http://en.wikipedia.org/wiki/File:Santa_Fe_River_-_August_2007.jpg

II. EXECUTIVE SUMMARY

The Santa Fe Watershed

Water conservation continues to be a concern in the city of Santa Fe. The U.S. Census data shows an increase in population, which in turn increases the demand for water. Due to the low precipitation in Santa Fe, the environment cannot supply enough water to support the growing population. In order for the citizens to allow enough water for the natural environment such as the Santa Fe River, the community needs to work together to restore and maintain the Santa Fe watershed. In order to improve awareness and community participation in the restoration of the watershed, communication needs to be improved between the organizations that collect watershed information.

This project assists the Santa Fe Watershed Association in the restoration and protection of the Santa Fe River and its watershed by consolidating watershed information and presenting it in an accessible format that facilitates public awareness and participation. This project was accomplished by identifying and accessing the sources of available watershed information, constructing a way for various visualization programs to link to these sources via the internet, allowing analyses of the attained information through interactive participatory tools, and creating a method for involving the public in watershed restoration through mobile technology.

Identifying Major Sources of Data

The project began with the identification of major sources of watershed data in Santa Fe. The team conducted interviews with various organizations in the City to locate watershed information. This project determined that the three major sources of watershed information are the city of Santa Fe, the Santa Fe County, and the United States Geological Survey. Most of the data on the watershed was received as Geographic Information System (GIS) layers. The City was determined to be largest source of information released in the format of GIS layers as well as spreadsheets. The GIS layers were accessed by obtaining copies of the layers while the spreadsheets were accessed by sharing documents through Google Documents.

Linking the Information to Provide Visualizations

This project provides interactive visualizations of the collected data. Google Documents was used as a platform to store the city's spreadsheets. This project uses Javascript and HTML to produce a Google Map based on the information entered in the spreadsheet. This process was used to generate maps of the Buckman Wells that monitor the water level of the watershed, the domestic wells located within the watershed boundaries, the stream flow gauges along the Santa Fe River, and the locations that local schools conduct water quality data collection. These maps update automatically when the owner of the data changes

the content of the spreadsheet. The maps can be publicized on websites owned by the Santa Fe Watershed Association, the city of Santa Fe, and the Teachers' Coalition.

Allowing Watershed Information Analyses through Participatory Tools

The group's third objective was to allow analyses of the attained watershed information through interactive participatory tools. This was completed through the use of technologies available through the Santa Fe Complex, specifically the sand table. To apply the sand table to the watershed, the group produced a model using agent based modeling software called Netlogo. The model was constructed with underlying geographic information system layers concerning elevation and various boundaries within the Santa Fe Watershed. The integration of water-affecting variables with the foundation of watershed geology and topography produced a model capable of predicting interactions between citizens, natural forces, and the water within the watershed. The team also described in detail a method for analyzing the watershed information using the watershed model and the BehaviorSpace tool in Netlogo, providing a foundation with which the model's accuracy can be verified in the future.

Involving the Public through Mobile Technology

One of the project's main components was designing a Smartphone application that will involve the community in data collection. The application will do this by allowing the user to take photographs of the Santa Fe River along its length and apply labels showing the condition of the river at that point. These pictures will be sent to a server where they will be organized into a library of photographs that portray the condition of the river over time. The convenience of this application lies in its simplicity. The phone will prompt the user to collect data when they pass by one of the data locations, which gives them the option to collect data or not. The application also allows the user to view the past information collected along with some simple visualizations of the condition of the river. An interactive mockup was produced showing how the screens of the application will be linked together. This design has future potential to be funded, developed, distributed and used.

Conclusion

By accomplishing these four objectives the Group will encourage the community to participate in and improve the possibility of a complete restoration of the Santa Fe Watershed. Encouraging community involvement will have lasting benefits to our sponsor, the Santa Fe Watershed Association, and the community. The sharing platform created will allow easy maintenance and access of the information on the Santa Fe Watershed. The watershed model will help with future predictions of watershed conditions. The phone application provides a photograph library of the river's condition along with involving the community with the restoration efforts and increasing the sense of stewardship over the river. These objectives will aid

the Santa Fe Watershed Association in involving the community in the river restoration efforts and ultimately will establish a foundation of powerful technology that improves the current information-sharing and education efforts.

AUTHORSHIP PAGE

This section explains which members of the group worked on specific sections on the project. Also listed here is which member worked on formatting the final Group CD. By looking at this page you can see who did what and how the Group members' time was spent.

Formatting the Water Knowledge CD: Andy

Report

I. Abstract: Sam

II. Executive Summary

       i. The Santa Fe Watershed: Olivia

       ii. Identifying Major Sources of Data: Olivia

       iii. Linking the Information to Provide Visualizations: Olivia

       iv. Allowing Watershed Information Analysis through Participatory Tools: Will

       v. Involving the Public through Mobile Technology: Sam

       vi. Conclusion: Sam

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    a) Move 1: Olivia

    b) Move 2: Sam

    c) Move 3: Sam, Andy

    d) Move 4: Olivia, Will

    e) Move 5: Andy, Sam, Will

2) Background

    a) Introductory Paragraphs: Olivia, Andy, Sam

    b) Water Management in United States: Olivia

    c) Water Management in the Southwest: Olivia, Sam

    d) Water Management in Santa Fe

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1. INTRODUCTION

Water usage is a growing worldwide concern. The world uses an average of approximately 1 acre foot (ac-ft) (318,000 gallons) per person each year[2]. In places such as the Middle East, the amount of freshwater available per person has declined by 50% since 1950. Africa is experiencing similar water shortages; approximately 30% of the population suffers from water scarcity due to the effects of climate, increasing water need, and mismanagement of existing resources[3]. Since 1950, the United States' growing urban population and higher standard of living has caused the total water demand to almost triple[4]. Currently, the United States uses approximately 2 ac-ft on a per capita basis, nearly double the world average. In 2005, the United States used approximately 393 million ac-ft of freshwater[5]. In order to prevent the demand of freshwater from exceeding the supply, water conservation techniques need to be implemented and the people need to become educated on these issues, especially in dry areas such as the Southwest United States.

Water conservation is especially pertinent to the people of Santa Fe because their demand will soon exceed the supply of their major source of surface freshwater, the Santa Fe River. The river originates in the mountains of the Santa Fe National Forest, northeast of the city, and meanders forty-six miles across the county before flowing into the Rio Grande. The Santa Fe community receives 40% of their water from the Santa Fe River, with the remaining water drawn from the local Rio Grande aquifer. Water from the river seeps through the soil and replenishes the aquifer, creating natural water storage and purification[6]. As the aquifer is depleted and the water table drops, however, wells around the city must be drilled deeper to reach water. Since the 1950s, the average well depth has increased by almost 200 feet in some areas[7]. Due to poor management in the past, the Santa Fe River has been severely depleted, contributing to a sharp decrease in the water table. According to Santa Fe's Long Range Water Supply Plan, the city's water demand will exceed

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[2]Water Footprint Network, "Waterfootprint.Org: Water Footprint and Virtual Water " http://www.waterfootprint.org/?page=files/home (accessed 3/1/2011, 2011).
[3]Eglal Racked, Eva Rathgeber and David B. Brooks, *Water Management in Africa and the Middle East Challenges and Opportunities* (Ottawa: International Development Research Centre,[1996]).
[4]Mary Ann Dickinson, *Water Conservation in the United States: A Decade of Progress* (Sacramento, California: California Urban Water Conservation Council,[2001]).
[5]J. F. Kenny and others, *Estimated use of Water in the Unitied States in 2005* (Reston, Virginia: U.S. Geological Survey,[2009]).
[6]Santa Fe Watershed Association, "The Santa Fe Watershed Association," http://www.santafewatershed.org/ (accessed February 15, 2011).
[7]Paige Grant, *Santa Fe River Watershed Restoration Action Strategy* (Santa Fe, New Mexico: Santa Fe Watershed Association,[2002]), http://www.nmenv.state.nm.us/swqb/Santa_Fe_WRAS-2002.pdf (accessed 2/22/2011).

its minimum supply of 15,300 ac-ft per year by 2021[8]. In order to mitigate this, private organizations in Santa Fe are actively engaged in the restoration and protection of the Santa Fe River[9].

The Santa Fe Watershed Association (SFWA), along with the city of Santa Fe as a whole, has taken numerous steps in the effort to fully restore and preserve the Santa Fe watershed. Through education, they have encouraged community members, especially younger generations, to take interest in restoration. The SFWA has also proposed and implemented various water conservation techniques. They are currently working in the political field to enact laws that will give "water rights" back to the river, essentially making a portion of it untouchable[10]. This will ensure a constant flow of water to support local wildlife and recharge the underlying aquifers. The city of Santa Fe has even invested in accessing alternate sources of water through various methods, specifically the $216million water supply project known as the Buckman Direct Diversion Project (BDDP). This system, which began operating in January 2011, consists of twenty-six miles of pipeline stretching from the Rio Grande to Santa Fe[11]. With this pipeline operating, the city will decrease its dependence on the river allowing it to flow and recharge the aquifer.

Many organizations in New Mexico are concerned about the future of the Santa Fe watershed and have been actively working toward its restoration. These organizations include the Santa Fe Watershed Association, EarthWorks, the Nature Conservancy, WildEarth Guardians, the city of Santa Fe, the Santa Fe County, and the Office of the State Engineer. Each organization has its own goals and methods for accomplishing these goals. An improved method of sharing data and information would aid these organizations in their efforts and allow them to work together. Also, the community would benefit because access to this information would provide awareness and facilitate participation, further unifying restoration efforts.

This project is intended to assist the Santa Fe Watershed Association in the protection and restoration of the Santa Fe River and its watershed by identifying available information and helping interested organizations share information to facilitate public awareness and participation. In order to achieve our mission, we have identified sources and collected available Santa Fe watershed information from the city of Santa Fe, The County, and the United States Geological Survey. Also, we will show the benefits and relative ease of information sharing via the Internet through free software provided by Google. We will then facilitate analyses of attained information through interactive participatory tools such as a sand table. In addition, our

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[8]City of Santa Fe, *Long-Range Water Supply Plan,* 2008.
[9]Santa Fe Watershed Association, *The Santa Fe Watershed Association*
[10]Ibid.
[11]Claudia Borchert and Amanda King, *Annual Water Report*
(Santa Fe, NM: Sangre de Cristo Water Division,[2010]) (accessed 2/2/2011).

project will provide the organizations and community with a method for updating the information through mobile technology. Upon completion, these objectives will allow the community to investigate any details concerning the watershed. Interactive visualization tools and organized informational sharing will help to assist the association by providing up-to-date information to the community.

2. BACKGROUND

The Earth's resources are gradually being depleted by human use. As displayed in Figure 1, the Middle East, northern Africa, and the western United States are currently experiencing high water stress[12]. Water stress can be caused by a variety of factors including local climate, geography, increased population, and water resource management[13].
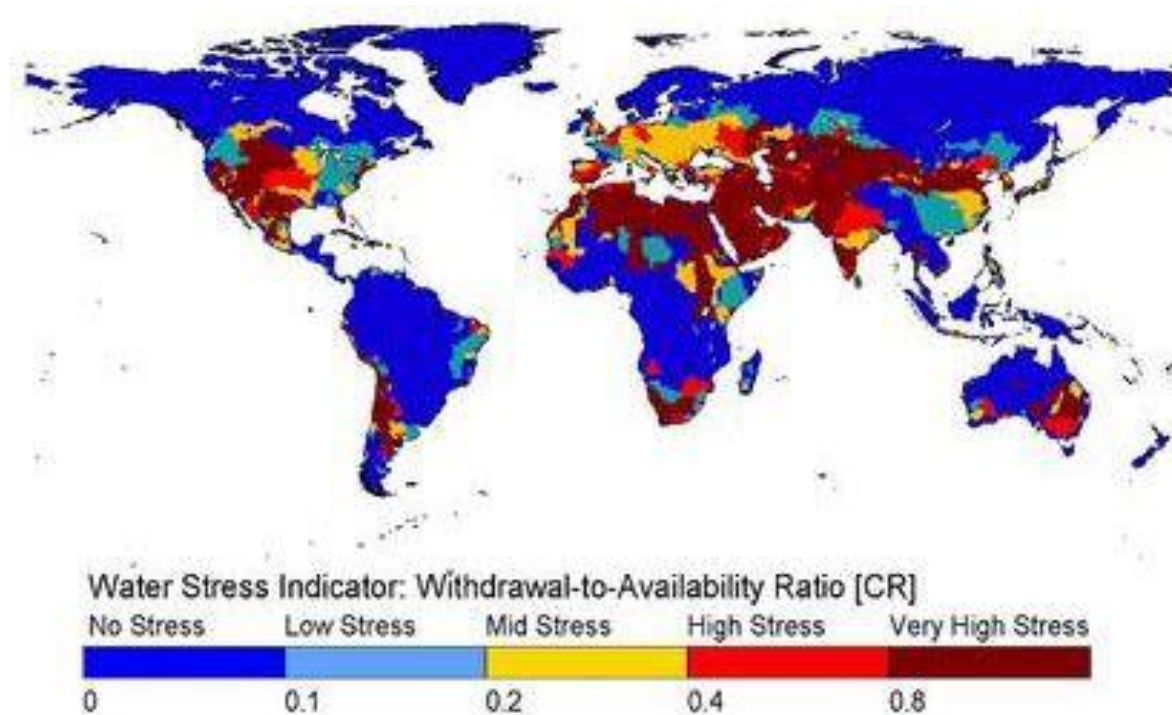
Figure 1: World Water Stress[14]

In order to prevent further water scarcity in the world, governments and organizations have implemented various water conservation techniques. Some of these areas, like the Middle East and Africa, have high water stress caused by dry climate and population growth. These regions have put water conservation plans into effect that involve water storage and the reuse of treated wastewater. In areas of water scarcity, it is common for the government to control the distribution of water and irrigation services[15]. However, conserving water requires the efforts of the entire community, not just the government.

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[12] The indicator of water stress is based on the ratio of water withdrawal to total renewable resources.
[13] World Water Council, "Water Crisis," http://www.worldwatercouncil.org/index.php?id=25 (accessed 2/20, 2011).
[14] Ibid.
[15] Julia Bucknall, *Making the most of Scarcity: Accountability for Better Water Management Results in the Middle East and North Africa* (Washington, D.C.: World Bank, 2007), 235, Table of contents only

Communities must intelligently manage available water to ensure a future supply. To that end, large networks of water storage and transportation infrastructure have been created in various countries. For example, Libya's Great Man-Made River was built to transport water to people in northern parts

of the country from the aquifer under the Sahara Desert. Other methods of water storage include dams, which are used in arid climates to help recharge groundwater by creating reservoirs for communities[16].

In order for communities to maintain an adequate water supply, it is important to protect the groundwater available in the region. Many places will pump groundwater and use it as a surface water source when alternate surface sources have dried up. This can help maintain consistency in flow patterns even during times of drought, which allows for the cycling of nutrients and removal of toxins within the ecosystem. Groundwater temperature is relatively constant throughout the year, so it is able to provide cooling in hot weather and heating in cold weather. In addition to providing more consistent ecosystem temperatures, groundwater is low in dissolved oxygen, which allows more sunlight to pass through and therefore more photosynthesis to support plant life. Groundwater is an important supplier of carbon, nitrogen, sulfur, phosphorous, and metals to freshwater ecosystems[17].

2.1 Water Management in the United States

In the United States there has been increased concern about water conservation, especially in the last twenty years. Recently, policies on the federal and state levels have been implemented because of the increasing water demand due to population growth and a higher standard of living in the country. Some states are particularly concerned about water supply because of the effects of local geography and climate[18].
Western states, specifically those west of the Mississippi River, experience low precipitation and lack a consistent natural supply of water. The states of most concern are California, Colorado, Arizona, Nevada, New Mexico, Washington, Texas, and Utah. California, for example, has dry climates and desert landscapes

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http://www.loc.gov/catdir/toc/ecip072/2006032526.htmlhttp://bibpurl.oclc.org/web/17465http://go.worldbank.org/WDPAMJ5290.

[16] Refer to Appendix A for information on hydrology.

[17]Paul L. Younger, *Groundwater in the Environment : An Introduction* (Malden, MA; Oxford: Blackwell Pub., 2007).

[18]Dickinson, *Water Conservation in the United States: A Decade of Progress*

with only six percent of the nation's available water supplying eight percent of the nation's population. It is also the most highly populated state in the U.S., so these factors combine to increase water scarcity[19].

Various methods have been developed to conserve the limited water supply. The federal government started the Reclamation Service in 1902 to build dams and aqueducts to supply irrigation water. The Army Corps of Engineers has also built many dams for flood control. By 2001, fifteen states had implemented federal conservation programs mandating water utilities to develop water efficiency programs. In that same year, states that developed the most active conservation programs were Arizona, California, Colorado, Connecticut, Florida, Kansas, New Jersey, Oregon, Texas, and Washington. Many of these programs include conservation methods such as leak detection programs for utility piping, plumbing fixture replacements, evaluations of household water use, evaluations of commercial and industrial water use, drip irrigation, education programs, and ordinances in communities to prevent wasteful usage of water[20].

Certain states and regions have developed their own plans for water conservation in order to provide for their populations. In 1978, California adopted standards to conserve water from to showerheads and faucets. The state's major water agencies and environmental organizations signed a memorandum in 1991 to use water more efficiently in order to aid in the restoration of the Bay-Delta Estuary. California also constructed a major system of water storage and delivery in order to transport water in northern California, where it is in greater supply, to southern parts that are in need of it. The system uses over 1,000 federal, state, and local reservoirs to supply over 14.4 million acre-feet of water[21].

2.2 Water Management in the Southwest

The population in the Southwest has increased steadily, especially for the last century, further straining the region's water supply. The withdrawal of groundwater for domestic use in the Southwest has increased to approximately 10 million acre-feet per year. Watersheds in this region already struggle to supply for the current population, not to mention future population increases. The drying of this region's watersheds is mostly due to a lack of winter precipitation, changes in atmospheric flow, and reduced moisture[22]. The Rio Grande is a major river in this region, stretching almost 2,000 miles from Colorado to the Gulf of Mexico. However, because of a limited water supply, the fifth longest river in North America has difficulty supplying the 9 million people that depend on it. Parts of the river, especially the middle stretches, often dry up

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[19] Ibid.

[20] Ibid.

[21] Ibid.

[22]Glen M. MacDonald, "Water, Climate Change, and Sustainability in the Southwest," (2010),http://www.pnas.org/content/107/50/21256.full.pdf+html.

completely in the summer. Farmers deeply depend on the Rio Grande, as 80% of its water is used to irrigate their crops[23].

New Mexico is located in a semi-arid climate, which is characterized by low precipitation and high temperatures. Because of the dry climate, the area is prone to forest fires, which can be devastating to the community. While the climate limits the water supply, water demand in the area continues to grow as the population increases.

2.3 Water Management in Santa Fe

According to the 2010 Census, the City of Santa Fe has 75,764 residents[24]. However, while the population is increasing, the flow of water to the reservoirs is not. When surface flow is not enough to meet the needs of the city, groundwater is used to bridge this gap. Excessive use of groundwater, which has accumulated over thousands of years, causes the water table to lower[25]. Often, the rate at which this water is withdrawn is much faster than the rate at which it is naturally replenished. The graph in Figure 2 shows the amount of surface water available divided by the population of the city (river flow into reservoirs per capita) along with consumption rate per capita and the city population. If water management is not improved, the city will not be able to meet its water demand by as early as 2021[26]. This means that in the future there will not be enough freshwater to support the city's needs, unless something is done to alleviate this water stress.

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[23]Fred Pearce, "When the Rivers Run Dry," in *When the Rivers Run Dry* (Boston: Beacon Press, 2006), 9-11.
[24]U.S Census Bureau. "2000 U.S. Census." U.S. Census Bureau. quickfacts.census.gov/qfd/states/35/3570500.html (accessed 2/12, 2011).
[25] Younger, Paul L. *Groundwater in the Environment : An Introduction*. Malden, MA; Oxford: Blackwell Pub., 2007.
[26]City of Santa Fe. *Long-Range Water Supply Plan*, 2008.
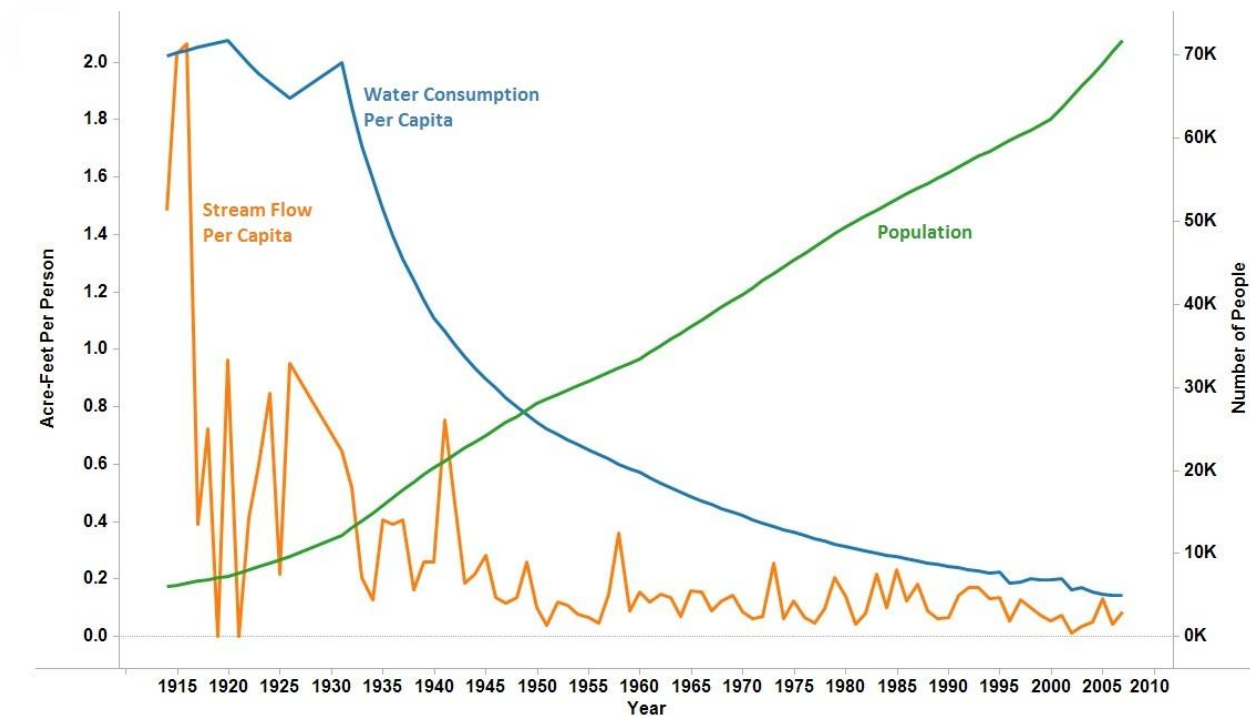
Figure 2: Water Consumption vs. River Flow vs. City Population[27]

The Santa Fe River is a major source of water supply to the city. It is a tributary of the Rio Grande that runs through Santa Fe in northern New Mexico. Its watershed spans 285 square miles and forms the central third of the Rio Grande Watershed, which includes the Tesuque Watershed to the north and the Galisteo Watershed to the south. The Santa Fe River watershed was identified as a Category I watershed in New Mexico's Unified Watershed Assessment, meaning it is in urgent need of restoration. The river stretches forty-six miles, beginning in the Sangre de Cristo Mountains, and flows through the state capital of Santa Fe, providing 40% of the city's water[28]. The city collects this water with the Nichols and McClure reservoirs in the upper watershed.

The health of the Santa Fe Watershed depends upon the health of its surrounding environment, including the Santa Fe National Forest. The Santa Fe National Forest is located northeast of the city and covers approximately 1.6 million acres of land. The elevation of the national forest ranges from 5,300 to 13,103 feet[29]. This forest is important to the health of the watershed because it encompasses the city's two major reservoirs: the McClure and Nichols Reservoirs. The Nature Conservancy, a local environmental

[27] Data compiled from http://www.santafenm.gov/DocumentView.aspx?DID=4882 and the U.S. Census Bureau
[28] Grant, *Santa Fe River Watershed Restoration Action Strategy*
[29] USDA Forest Service, "Santa Fe National Forest," http://www.fs.fed.us/r3/sfe/ (accessed 2/10, 2011).

organization, states on their website that these major reservoirs could become useless if a disastrous fire swept through the forest. A fire broke out ten years ago and burned for two weeks, damaging the forest to the point that even deeply rooted trees could not survive in the existing soil. The fire caused debris and ash to travel down the mountains and into the watershed through streams, rivers, and lakes. These forest fires occur when the forest is in poor health, and they threaten the security of the water supply in a region of water scarcity[30]. The United States Forest Service works in the area to limit the spread and severity of wildfires in the region and protect the water supply.

2.3.1 Government Regulations

The government must implement mandatory practices, regulate the distribution of water, and construct infrastructure to aid in water conservation. The citizens of the community must participate through efforts to conserve water in their daily routines. If all members of the community work together to increase the efficiency of water use, then Santa Fe can successfully exist with its limited water supply by using the water it already has more effectively. The city's current water supply sources are shown below in Figure 3.

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[30]The Nature Conservancy, "New Mexico: Using Fire to Protect Water," http://www.nature.org/wherewework/northamerica/states/newmexico/science/art32845.html (accessed 2/15, 2011).
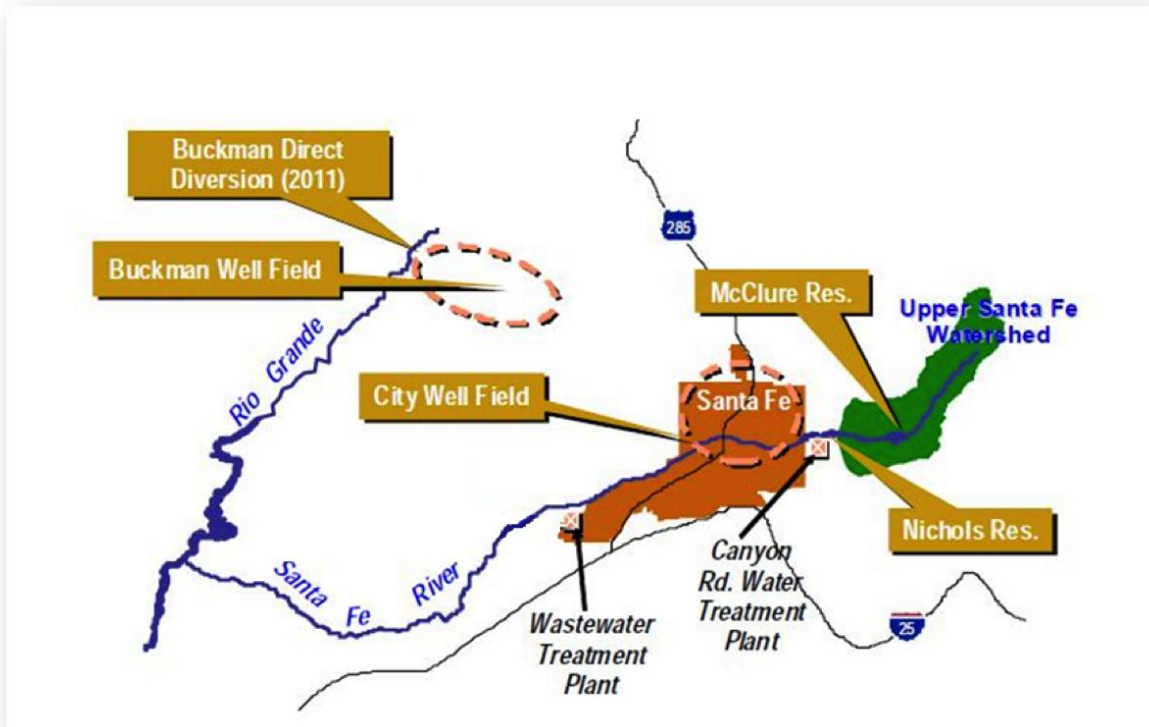
Figure 3 Santa Fe City Water Sources[31]

The city has four major sources of water: the Santa Fe River, the Buckman Well Field, City Wells, and the newly operational Buckman Direct Diversion Project. In addition, there are 696 private wells in the city. The Santa Fe River is collected in the McClure and Nichols Reservoirs, located north of the city in the Santa Fe National Forest. Although the average annual flow of the Santa Fe River is approximately 5, 040 ac-ft each year, the actual water stored in the reservoirs varies with annual precipitation and snowpack. The Buckman Well Field is located north of the city and is actually located outside of the Santa Fe River Watershed. This is the largest source of fresh water, as it has the ability to provide up to 10, 000 ac-ft to the city each year. These wells are also monitored to keep track of the water table levels. The city wells are located within the city limits and are capable of delivering up to 3, 500 ac-ft of water to the city each year.

In January of 2011, the Buckman Direct Diversion (BDD) Project, a major project funded by the Santa Fe County and The City of Santa Fe, began operation. The map of the BDD Project is shown in Figure 4. This project will collect water from the Rio Grande northwest of Santa Fe and transport it via a 26 mile-long pipeline to residents and businesses in Santa Fe County. The BDD project cost the county and city a

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[31] City of Santa Fe. *Long-Range Water Supply Plan*, 2008.

combined $216 million[32], with about $17.5 million covered by State grants and low-interest loans. Another $11 million was contributed by Las Campanas, a community on the outskirts of Santa Fe that relies on the city for its water[33]
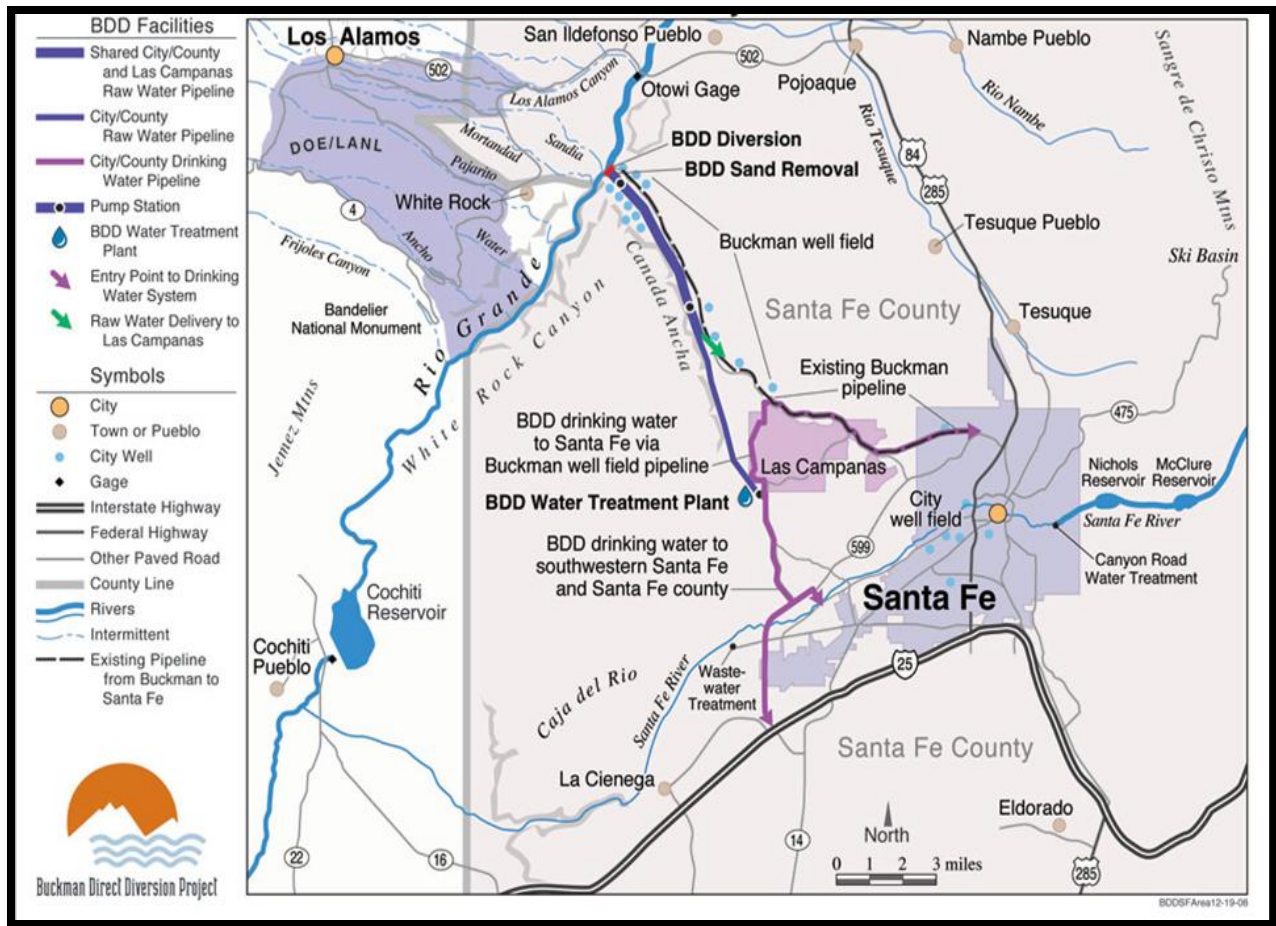
Figure 4: Buckman Direct Diversion[34]

Federal permits limit the amount of water that the Project can divert to about 8,730 ac-ft per year with 5,230 ac-ft distributed throughout the City of Santa Fe annually. About 1,800 ac-ft will be sent to Las Campanas and 1,700 ac-ft will be distributed to the rest of Santa Fe County. The pipeline has the capacity to deliver up to 46 ac-ft a day but will typically operate at half of its full capacity. Before the BDD Project, the City of Santa Fe drew about 5,040 ac-ft per year from the Santa Fe River. The average annual flow through the river is about 5,000 ac-ft, meaning the city can withdraw virtually all water from the river (see Figure 5).

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[32]Borchert and King, *Annual Water Report*

[33] Ibid.

[34]Buckman Direct Diversion Project, "Buckman Direct Diversion Project," http://www.bddproject.org/index.htm (accessed February 1, 2011).

City Water Sources Prior to BDD

City Wells
3,586 ac-ft
19%

Santa Fe River
5,040
27%

Buckman Wells
10,000 ac-ft
54%
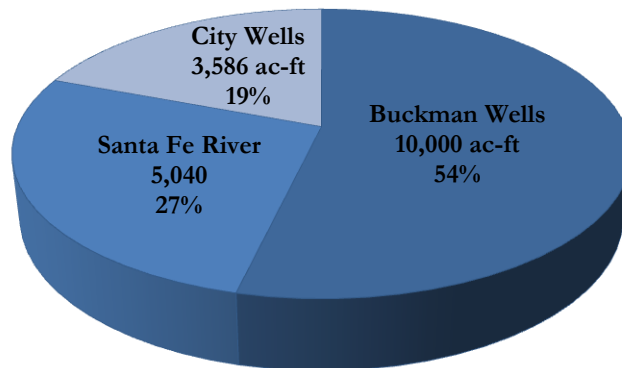
Figure 5: Santa Fe Water Availability 2010[35]

Santa Fe's projected water distribution for 2011 is displayed in Figure 6. With the additional water from the Buckman Direct Diversion, the city will draw less water from the Santa Fe River, therefore reducing the stress on the river and ultimately the aquifer. This new source of water will allow the city to annually release between 300 and 1,000 ac-ft of water back into the Santa Fe River. This will allow the river to flow again, which in turn will slowly recharge the underground aquifer and provide a consistent water source in times of drought[36].

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[35] City of Santa Fe. *Long-Range Water Supply Plan*, 2008.
[36] Ibid.
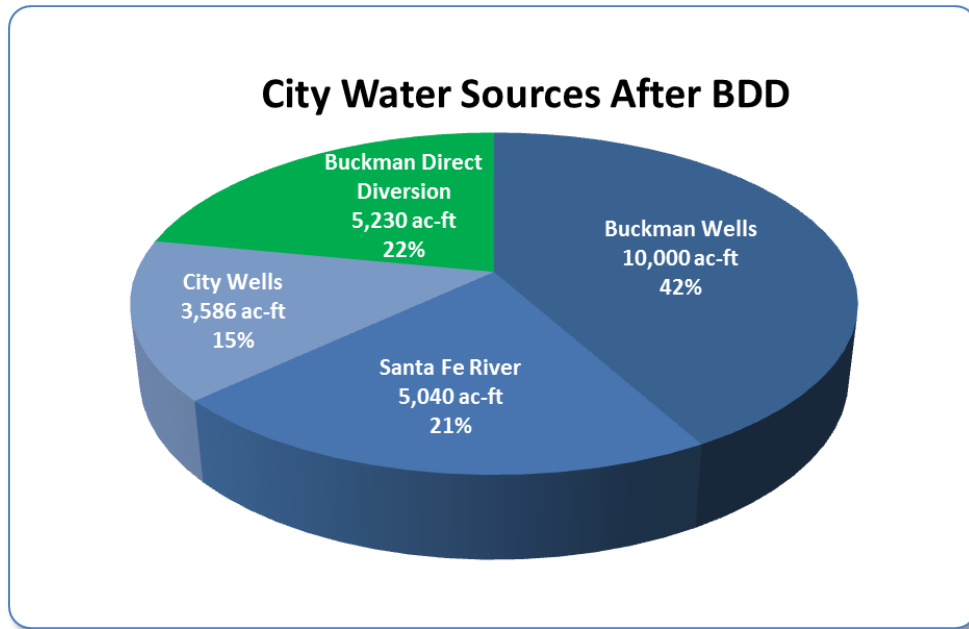
Figure 6: Santa Fe 2011 Projected Water Availability[37]

The Buckman Direct Diversion Project also benefits the local economy. A study by the University of New Mexico Bureau of Business and Economic Research estimated the economic benefits of the BDD Project to be $287.2 million per year. The project has also generated more than 500 jobs since its inception[38].

The New Mexico Office of the State Engineer administers the water resources used in the state by determining the distribution of the surface and ground water supply. It monitors and supervises streams and rivers, such as the Santa Fe River. The Office of the State Engineer has a program pertaining to water use that inventories the withdrawals of surface and groundwater organized by category, county, and river basin. It also provides water-use data and reports measuring the water needed for irrigation and other uses. The Office of the State Engineer's Water Conservation Program organizes activities for water conservation for the State of New Mexico. The program encourages water conservation among citizens, aids in the development of other water conservation programs, and supports the development of state government policies on water conservation[39].

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[37] City of Santa Fe. *Long-Range Water Supply Plan*, 2008.
[38] Ibid.
[39]Office of the State Engineer, *Water use and Conservation*

The city government of Santa Fe, New Mexico has also implemented various projects in order to conserve water. It has enacted water restriction laws such as a ban on daytime, outdoor water use during the summer months. From May 1st through October 31st, outdoor watering of plants is prohibited between the hours of 10 A.M. and 6 P.M.; disobeying this law is punishable by a fine of $20 to $200. The City of Santa Fe offers rebates for citizens to offset the cost of purchasing new toilets in addition to rebates for high efficiency washing machines and other appliances. Before 1994, toilets used an average of 3.5 to 5 gallons of water per flush. Now, low-flow toilets use about 1.6 gallons of water per flush. Since the average person flushes a toilet 5 to 7 times each day, low-flow toilets save an average of 23.8 gallons of water per person each day[40]. The City of Santa Fe also encourages water conservation through an increase in water rates, which represent the cost per amount of water usage. On January 11, 2011 the city increased water rates by 8.2% to encourage citizens to limit their water usage. The city will continue to increase water rates by 8.2% each year for the next five years. Revenue from these rate increases will help continue water rebate programs and fund future water conservation efforts. Also, the city has implemented projects to evaluate its water supply, such as the Camino Canada Monitoring Well Project. This project consists of drilling a 2,500 foot deep well to use as a method of monitoring the quantity and quality of the water in the aquifer.

Another common method of water management in Santa Fe is known as xeriscaping, a subcategory of permaculture. This practice encompasses different landscaping techniques that reduce water use and help retain water. Selecting plants that need little water is a major component of xeriscaping. Arranging plants with similar sunlight needs together also minimizes wasted water. Spreading compost and mulch helps to retain water, and shaded areas reduce water evaporation. Sprinklers with large water droplets and low angles as well as drip irrigation systems reduce water lost to evaporation. Installing rain sensors on irrigation systems will prevent them from operating when they are not needed. Collecting and storing rainwater will provide a source of freshwater during dry periods. Another source of water for landscapes is gray water, water that has previously been used for bathing, laundry, and dishwashing[41]. These techniques make better use of the city's existing water supply.

2.3.2 Contribution of Organizations to Restoration Efforts

Since fresh water and the natural environment are vital to human life, various organizations have formed to restore the environment to its state before the impact of humans. These organizations each have a specific area of focus and work toward environmental restoration through different approaches.

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[40]City of Santa Fe, *Long-Range Water Supply Plan,* 2008.
[41]Roger L. Kemp, *Cities and Water : A Handbook for Planning* (Jefferson, N.C.: McFarland & Co., 2009).

The Santa Fe Watershed Association (SFWA) is working to restore the Santa Fe River to its natural form. It has been directly involved with the community in many ways through its efforts to increase public awareness and participation in the restoration of the watershed. They have provided access to areas of the upper watershed to the community by hosting scheduled nature walks through the area. The SFWA takes elementary students outdoors on a regular basis to experience the river in fun activities such as collecting and classifying water insect species. They have taken a special interest in educating younger generations about water management, and have organized projects to restore and clean up the Santa Fe River. They lead interesting discussions in area school classrooms about the importance of the watershed to the community and why its restoration is necessary for the local environment as well as the long-term storage of water for future droughts. The SFWA regularly hosts events in the community that encourage public participation and interest in the local environment such as yearly fishing derbies and river festivals[42].

Besides the SFWA, there are various other private organizations that work to protect the environment using different methods. Like the SFWA, the WildEarth Guardians work to restore wild rivers and wildlife. This organization is headquartered in Santa Fe but also works in others parts of the Southwest. They offer programs that focus on wildlife, wild places, wild rivers, and climate and energy. They have worked to achieve their goals through legal action to protect the endangered plants and animals that depend on the river ecosystems of the Rio Grande, Pecos, San Pedro, and Verde Rivers. They also work to restore degraded streams by planting trees, and have planted over 60,000 cottonwoods and willows along steams such as La Jencia Creek, Bluewater Creek, and Rio Puerco[43].

EarthWorks is another organization active in the restoration of the Santa Fe River. EarthWorks is a national organization founded in 1993 as a non-profit group dealing with environmental services. It works with the causes and effects of "climate change and natural resource degradation to promote healthy ecosystems and healthy communities" in Santa Fe County and its watershed. They encourage the Santa Fe community to live peacefully with its natural environment and provide services

[42]Santa Fe Watershed Association, *The Santa Fe Watershed Association*
[43]WildEarth Guardians, "WildEarth Guardians about Us,"
http://www.wildearthguardians.org/site/PageServer?pagename=about (accessed 2/7, 2011).

for the restoration and protection of the natural environment. Like the Santa Fe Watershed Association, EarthWorks achieves its goal through methods of education, land stewardship, and watershed restoration. Like the SFWA and WildEarth Guardians, EarthWorks also uses tools such as regional networking, local government jurisdiction, and resource management agencies on local, state, and federal levels to achieve its goals. In order to further involve the public, EarthWorks provides workshops, forums, fieldwork, service projects, and other tools to encourage the community to improve its relationship with the environment[44].

The Nature Conservancy is a national organization with offices present in every state in the U.S. In Santa Fe, its mission is to "protect ecologically important lands and waters for nature and people"[45] and deal with major conservation threats. Since the organization was founded in 1951, it has protected over 119 million acres of land and 5,000 miles of rivers all over the world. Its methods include using scientific solutions, pursuing solutions that are pragmatic and avoid confrontations, and partnering with other organizations as well as businesses and governments. In Santa Fe, the Nature Conservancy focuses on the protection of the national forests to prevent forest fires since this forest contains the two major reservoirs for the City of Santa Fe. The Nature Conservancy focuses on the risk of a fire in the national forest because of the catastrophic damage it could cause to these reservoirs. The Nature Conservancy has developed a long-term approach to protect the water supply for Santa Fe by creating a water fund. Using money from the community to pay for the restoration of the watershed, they ensure that the forest remains healthy[46]. Because of their focus on this aspect, the Nature Conservancy has collected information regarding the health of the National Forest as well as best practices on fire mitigation strategies.

Each organization is an advocate for the natural environment, therefore they need to have access to all of the information involving Santa Fe's environment. Currently the organizations need to contact a member of the city's water division in order to receive data that has been collected regarding the watershed. Most of the fieldwork and data collection is done by the government organizations such as the city, county, Office of the State Engineer, and United States Geological Survey. The private organizations can gain access to this public information by inquiry, but they do not automatically receive the latest watershed data collected. The system of sharing data on the Santa Fe watershed between governmental organizations, private organizations, and the public needs to be improved in order to make better use of the collected data and allow for improved restoration and protection efforts.

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[44]EarthWorks, "EarthWorks about Us," http://www.earthworksaction.org/about_us.cfm (accessed 2/2, 2011).

[45]The Nature Conservancy, *New Mexico: Using Fire to Protect Water*

[46] Ibid.

2.4 Technology

There are various useful technologies that were discovered to be beneficial when helping the Santa Fe Watershed Association restore the Santa Fe River by prompting community involvement. These programs include SimTable (used in conjunction with a sand table), Netlogo, GIS Cloud, as well as Photoshop CS5. Software such as these will allow the group to quickly create high quality deliverables when addressing the group's objectives.

2.4.1 Sand Table Visualization through SimTable

A sand table is a powerful modern visualization tool that consists of a physical table of sand onto which an image produced from real-world information such as watershed topography is projected. The user can interact with the table by physically moving the sand and use a laser pointer to interact with the program itself. When the laser is visible by the camera it is recognized by the software driving the process (in our case, SimTable) enabling the user to turn features on and off at will. This method of visualization and information analysis is superior to standard computer modeling in that it provides understanding based upon multi-sensory interaction versus the alternative: visually restricted and low-interactivity computer modeling. With standard computer monitoring, the visualization is projected onto a much smaller screen than the sand table thereby producing a lower quality experience. A very powerful and useful visualization that is already used for interactive analysis by sand table technology is a fire model. Figure 7 shows SimTable software displaying elevation on a sand table.
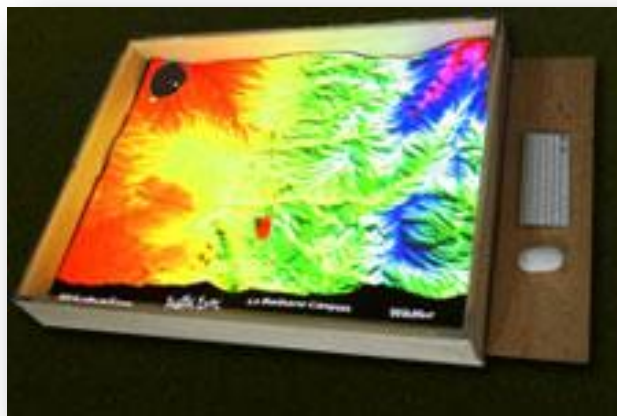
Figure 7: SimTable Showing Topography[47]

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[47] http://simtable.typepad.com/.a/6a0120a7df94b5970b0134882a12a2970c-800wi

Through various inputs the sand table simulates a realistic occurrence of a forest fire specific to the Santa Fe Watershed, as displayed in Figure 8. The user can start a fire by using a laser of even a lighter, which will be read by the infrared camera. These simulations give the sand table incredible applications in fire prevention and forest fire planning. Organizations such as the Forest Service and emergency response units within the city can apply specific parameters to this model and view the outcome with a time lapse of their choosing. This is extremely powerful because they can use the model to make predictions that have the potential to save thousands of lives as well as thousands of dollars in destruction of property. Emergency response teams have access to the information necessary to make important evacuation decisions in case of an actual fire and are able to more efficiently direct citizens out of the path of danger. We put this highly useful technology to the task of visualizing the water cycle in the Santa Fe Watershed.
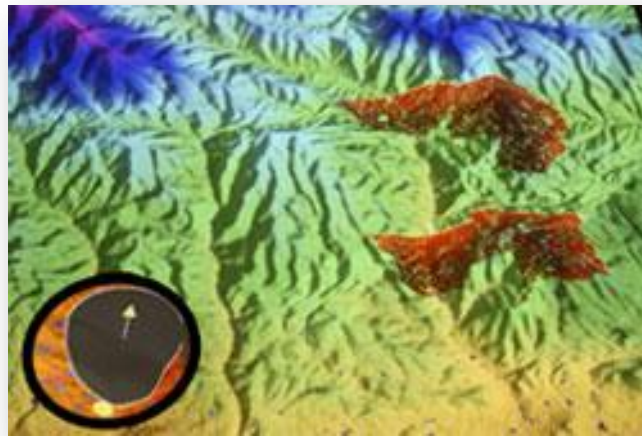
Figure 8: SimTable Displaying Fire Model[48]

2.4.2 Netlogo

Netlogo is agent-based modeling software that uses rudimentary code and simple concepts to create sophisticated models. Within Netlogo there are various ways to create user control. One such method is by creating buttons which serve as a means for turning information on and off such as turtle (the term for individual agents within the model) characteristics. Example buttons are shown in Figure 9 below. Another means for

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[48] http://ve09orig.files.wordpress.com/2009/09/newtable2.jpg?w=250&h=167

creating control is through sliders. A slider gives the user control over a given parameter, allowing for it to be changed within the range that the creator allows. Example sliders are shown in Figure 10 below.
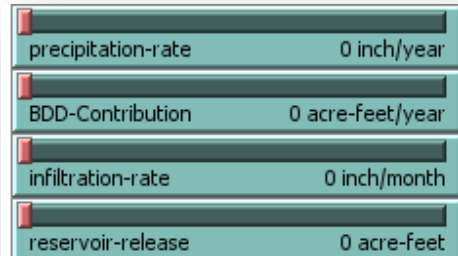
Figure 9: Example Sliders

Figure 10: Example Buttons

2.4.3 GIS layers

GIS layers are layers that are compiled by a variety of different minor layers, called metadata, with which various programs can map and visualize. The metadata files contain detailed portions of information which, when combined with the other metadata files, come together to form a flexible layer that allows for powerful visualization and information inquiry. Figure 11 below exemplifies a visual description of GIS layers and the various metadata components that form them. Common extensions associated with many GIS layers include projection, AutoCAD Shape file, and others.
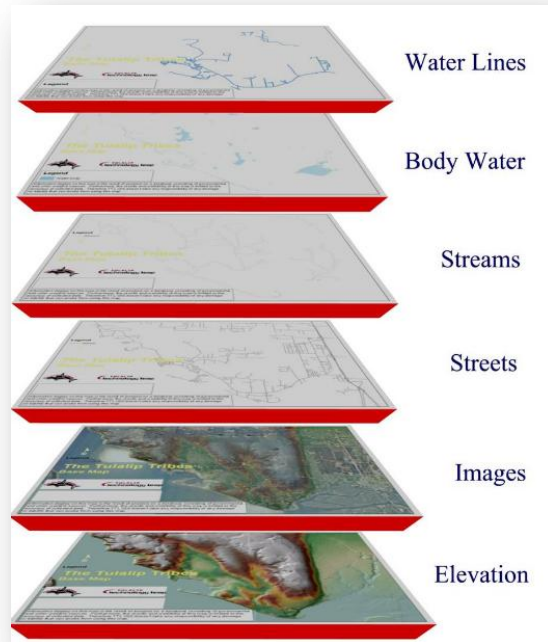
Figure 11: Example of GIS Layer Composition[49]

2.4.4 GIS Cloud

An information-sharing program that is of interest to the group is called GIS Cloud. The ability to share with GIS Cloud sets it apart from other GIS mapping software and will serve the group well by creating a location online where useful GIS (geographical information system) layers can be stored and easily accessed. Although GIS Cloud is extremely useful for sharing and accessing GIS layers online, it lacks the extensive editing and file conversion capabilities of other GIS based programs such as ArcGIS. But GIS Cloud is useful as a platform to store GIS layers so that the layers can be exported onto individual workspaces.

2.4.5 Photoshop CS5

Photoshop CS5 is the newest edition of the popular graphical software Photoshop. It's a great tool to use for graphic design because the program incorporates a layer element.

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[49] ...ibes-nsn.gov/Portals/8/images/tulalip_map_layers_lrg.jpg

This allows the user to create various layers in the image and control the order of them. There are also many templates available on the Internet, which include premade layers that the user can manipulate to build complex images.

3. METHODOLOGY

This project aims to assist the Santa Fe Watershed Association in the restoration and protection of the Santa Fe River Watershed by consolidating information and presenting it to the public. We accomplished this through four sequential objectives:

1) Identifying and accessing sources of available watershed information.
2) Constructing a method for linking the watershed data to various visualization programs via the Internet.
3) Allowing analyses of the attained information through interactive participatory tools.
4) Designing a Smartphone application for involving the public in watershed restoration.

Our area of concentration is the Santa Fe Watershed, as shown in Figure 12. The watershed information we are searching for is presented in many different formats including spreadsheets, maps, graphs, charts, and reports. The project spans seven weeks, from March 20th to May 7th, 2011. Historical information is also beneficial to the community because it allows projections to be made for future planning.
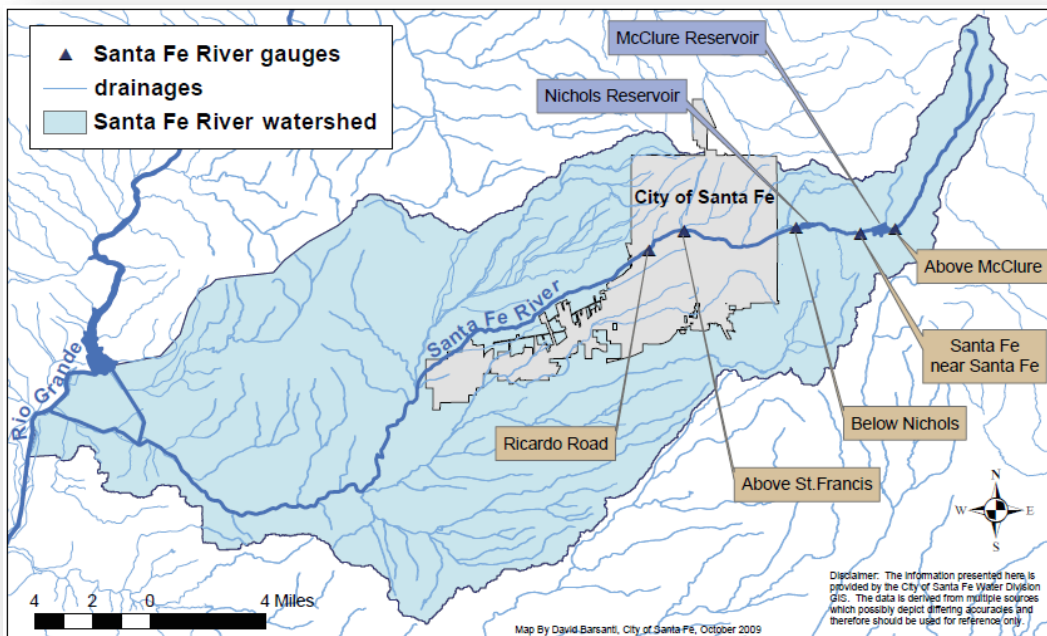
Figure 12: Map of the Santa Fe Watershed[50]

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[50] Claudia Borchert and Amanda King, *Annual Water Report*
(Santa Fe, NM: Sangre de Cristo Water Division,[2010]) (accessed 2/2/2011).

3.1 Identifying and Accessing Sources of Useful Watershed Information

In order to accomplish the first objective, the team identified information that is useful for the project. A list of the topics that would benefit the organizations involved and community can be seen in Table 1.

Water Supply	Water Use
Stream Flow	Buckman Production Depths
Precipitation	Buckman Monitoring Wells
Aquifer Levels	Domestic Well Depths
Groundwater Recharge	City Water Consumption
Watershed Boundary	
Reservoir Water Supply	

Table 1: Watershed Information to Obtain

The team identified the organizations that possess information relating to these topics. These organizations include the City of Santa Fe Water Division, the Santa Fe County, and the United States Geological Survey. Interviews were conducted with the City of Santa Fe and the Santa Fe County. During the interview, the team inquired about watershed information and referenced our list of topics as shown in Table 1 in order to attain the most relevant information as opposed to all of the available information.

Firstly, the team met with the Santa Fe County's Geographic Information System (GIS) department to attain useful watershed GIS layers. Amanda Hargis, the GIS Coordinator, met with the team to discuss needed GIS layers. Also in attendance was Shelley Cobau, who is the Building and Development Manager in the Growth Management and Land Use Department of the Santa Fe County, and Arnold Valdez, Senior Planner from the Planning Division of the Santa Fe County. These people were assets in the mission to locate the watershed data because they referred the watershed team to the United States Geological Survey (USGS) website for more available data. The GIS department provided the team with GIS layers, although due to ownership rights, the county was unable to release all of the GIS layers. The team then visited the USGS website and downloaded watershed information in other formats. The USGS and the Santa Fe County's GIS Department were two major sources of watershed information.

Next, the team met with Rick Carpenter from the Water Division of the City of Santa Fe. Rick Carpenter referred the team to Claudia Borchert from the city's water division. Claudia Borchert is Water Resource Coordinator for the city's water division. The team met with her to introduce the project and obtain more information on Santa Fe's watershed. Claudia Borchert was the most important source of information on the

Santa Fe watershed. She provided the team with information in various formats and was a constant source of data throughout the project.

3.2 Constructing a Method for Linking Watershed Data to Visualization Programs

After identifying these sources, the group researched the best platform for sharing the information. The group explored options such as Dropbox, Microsoft Access, and Google Documents. Google Documents was determined to be the best option because of its user-friendly interface and high versatility. The group contacted the most prominent source of data, Claudia Borchert from the City of Santa Fe, and set her up with a Google account. She immediately saw the capabilities of Google Documents and obtained a Gmail account. The group met with her on several occasions to determine specific ways with which she could use the sharing platform to her benefit. She determined that posting her Buckman Wells spreadsheets on Google Documents would be most beneficial since it is a valuable piece of information to publicize. The spreadsheets that she updates on the Buckman wells on a quarterly basis were then uploaded from her local hard drive to a spreadsheet on Google Documents. The team was granted access to the spreadsheets that she uploaded onto her Google Documents and shared these documents with Felicity Broennan, the executive director of the Santa Fe Watershed Association. The group created a method for the major sources of watershed information to share data through a platform, Google Documents, and a method to access the information in order to use this publicized data to create visualizations.

Once Claudia Borchert from the city's water division publicized the spreadsheets of Buckman well data through Google Documents, the team was able to create interactive visualizations. The team used Google Maps API and Google Spreadsheets API to create a method for turning the spreadsheets into interactive Google Maps. The team publicized the Buckman well spreadsheet titled "Water Level Trends for Buckman Monitoring Program area wells" as a webpage in Google Docs and used the URL to code a map. The basis of the code was generated using a generator[51] found online. By entering the spreadsheet key into a prompt on this website, the generator displayed the code that would provide a basic map of the spreadsheet. The team took this Javascript code and then modified it to add more features to the placemarks on the map, such as links to more data, graphs of Buckman well production, and data obtained from certain columns in the "Water Level Trends for Buckman Monitoring Program area wells" spreadsheet. The graphs that were generated in the placemark's information window were created using a Google Charts Gadget. The graphs were created using the data from another spreadsheet entitled "Buckman Wells' Productivity and Water Level (1981-2010)". A graph was inserted using Google Charts gadget on a separate sheet of the spreadsheet and

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[51] http://gmaps-samples.googlecode.com/svn/trunk/spreadsheetsmapwizard/makecustommap.htm

then publicized as its own web page. The team added code so that the graph could be embedded in the placemark window.

Other maps were created using code obtained from the online generator[52] and added lines of code. The team created a map of the domestic wells that are located in the watershed using the data from a GIS layer provided by the Santa Fe County's GIS Department. The spreadsheet file that produced the GIS layer was formatted in Microsoft Excel and then uploaded to Google Documents. It was publicized as a webpage and then turned into a map with each domestic well represented as a placemark. The map was coded by the team using the generator[53] for the basis of the code. The team then added code to show the location of the well, the elevation, and the depth of the well in the information window of each placemark.

The team also created a map of the stream flow gauges that are located along the Santa Fe River. This used the longitude and latitude coordinates of the stream gauges to provide a map of the locations of the gauges. The team added sheets of the spreadsheet for each stream gauge. The team then used Google Charts Gadgets to make a chart of the stream flow gauge data. Code was added in order to display the graph in the information window of the placemarks. Another map the team created was for the WPI Beaver Instinct team. This map uses the spreadsheet that the Beaver Instinct team had already created and publicized on Google Documents. The team was granted access to this spreadsheet "Data Collection Locations" where various schools in Santa Fe conduct water quality testing. The longitude and latitude locations of the data collection points were entered in the spreadsheet so that the team could use the online generator[54] to create a Google map. Once the basic map was created, the team added code to add content to the placemark's information window. This concluded the process of creating interactive maps based on the collected data.

3.3 Allowing Water Information Analysis through Interactive Technologies

The group's third objective is to allow analyses of the attained watershed information through interactive participatory tools. This was completed by applying useful technologies to the Santa Fe watershed, specifically the sand table. To apply the sand table to the Santa Fe watershed, the group developed a watershed model. This model (as shown in Figure 22) was developed using an agent-based modeling software called Netlogo. The base of the model was created using underlying geographic information system layers concerning the topography of the Santa Fe watershed displaying elevation and various boundaries. User and agent interactivity with these layers was implemented via sliders and buttons (discussed in the Background section of the report),. To make sure that this model came to fruition the group utilized modeling and information

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[52] http://gmaps-samples.googlecode.com/svn/trunk/spreadsheetsmapwizard/makecustommap.htm
[53] http://gmaps-samples.googlecode.com/svn/trunk/spreadsheetsmapwizard/makecustommap.htm
[54] http://gmaps-samples.googlecode.com/svn/trunk/spreadsheetsmapwizard/makecustommap.htm

sharing programs.

3.3.2 Creating an Interactive Watershed Model for Santa Fe

Netlogo was used to generate the watershed model because it is relatively easy to use, it allows easy import of GIS layers, and it is used at the team's workspace, the Santa Fe Complex. With GIS layers providing information on the Santa Fe watershed the group was able to construct a model that displays the water collection in the watershed based on its topography. In order to create the elevation necessary for the interaction of the individual agents in Netlogo, it was first necessary to convert the elevation layer to an ASCII text file (refer to Appendix E for details surrounding this process). In constructing the Watershed Model the focus was to provide the user with the greatest possible control to make it a powerful visualization tool. Netlogo's ability to easily import GIS layers allowed the group to quickly generate the foundation for agent interaction.

Within the watershed model the group maximized user control by providing control over many important parameters that affect water. Such control gives the model the flexibility necessary to predict the effects of many situations within the watershed, such as an extreme population increase, drought, or flash flood events. This control was provided to the user through sliders and buttons created in Netlogo (described in the Netlogo section of the Background).

Upon completion of the watershed model, the sand table was used to demonstrate the model.. This required, downloading Netlogo onto the sandtable computer's hard drive and transferring the necessary files for the model to run properly. . Refer to Appendix G for details about running the model from the compact disc provided by the Group. The convenient and novel idea of the sand table is that it allows for 3-D visualization through the manipulation of the sand with programs that would otherwise be 2-D, thereby enhancing the user's interactive and educational experience.

3.4 Updating Information through Mobile Technology

The final portion of the project consists of creating a highly detailed mock-up of a useful phone application related to the watershed. Since this is only a mock-up, the design will need to be developed in order to have a finished and presentable Smartphone application. The phone application will be a tool for members of the community to use to gather data. They will do so by taking photographs of the river at specific locations along its length. These photos will be labeled according to the condition of the river at that location and will be sent to a server. This will create a library of photographs that show the condition of the river over time. This application will also have educational uses for the local schools that collect river data. The phone

application would be applicable to these students in their data collection process as well as other good citizens of Santa Fe.

The team brainstormed with the Santa Fe Watershed Association staff as well as met with various experts on phone application technology in order to realize what features would be best for the app. David Perez is an entrepreneur and software developer who has a new company that creates a Smartphone application platform called Appliciti. The team discussed ideas with David Perez along with another local developer, Greg Malone, and created the basis of our application. Also, several meetings were held with Felicity from the Santa Fe Watershed Association and Francois-Marie Patroni, who is the President of the Board of Trustees for the SFWA. Their feedback was most useful since the phone application will be hosted by this organization. After receiving feedback from the sponsors and experts on mobile applications, the team researched various apps that are currently on the market. This research was conducted to determine aspects that make a mobile app successful and and most useful. After reviewing capabilities of the Smartphone, the team determined the best way the application could use the internal hardware of the phone such as GPS, camera, and compass. Various applications that utilize crowd-sourcing were also investigated. Crowd-sourcing is a method of distributing tasks to a group of random individuals and can prove to be a useful feature in Smartphone applications. The team analyzed why certain crowd-sourcing applications were unsuccessful and discovered that failure is usually attributed to a lack of participation. A method to create incentives to increase public participation was determined. This would be done through a rewards system that gives the user coupons to local businesses after a certain amount of data collection. The research conducted on other mobile applications and phone features was an important aspect in developing the idea for the phone application.

Figure 13: Mobile Application Snapshot

A mock-up of the ideal phone application was created so that it could potentially be developed into a functional phone application. The mock-up was created using Adobe Photoshop CS5 and HTML5 coding. This created an illusion of functionality by linking the Photoshop images together with the coding which allowed anyone interacting with the mockup to click from page to page and explore the features on the app. The application design will only be a useful if it is developed beyond this mockup. Figure 13 displays a snapshot of the augmented reality screen of the mobile application.

4. RESULTS AND ANALYSIS

After completing our objectives the group successfully produced results that will aid the Santa Fe Watershed Association in its mission to restore the Santa Fe River by actively involving the community with modern technologies. These results consist of the determination of the major sources of watershed information in Santa Fe, automatic visualizations that are linked to data spreadsheets, an interactive model of the Santa Fe watershed that integrates the use of the sand table, and a mock-up of a mobile phone application that actively involves the community.

4.1 Santa Fe's Major Sources of Watershed Data

Major sources of watershed information include the public utilities such as the City of Santa Fe, the Santa Fe County, and the United States Geological Survey (USGS). These sources have independently obtained data as each one has a different method for conducting fieldwork as well as acting as separate data repositories. There is inefficient overlap of data between these sources because each utilizes and publicizes the shared data for its own purposes.

4.1.1 The City of Santa Fe

The public utilities of Santa Fe possess the most data on the watershed. The City conducts and obtains most of the data involving the watershed since they are responsible for maintaining the City's water supply. One piece of information the City possesses is information involving the Buckman Direct Diversion Project. Any data collection conducted that involves the diversion or the Buckman wells is publicized by the city's water division. The City's water division also possesses annual water reports annual information regarding precipitation, water consumption, water demand and sources, domestic wells, and water rates. The water division at the City also obtains all of the reports on stream flow that the various river gauges collect. The City's supply of GIS layers overlaps with most of the county's supply. GIS layers involved locations of domestic and Buckman wells, county and City boundaries, satellite imaging of the City, a watershed boundary, population, and topography.

Received Data	Format of Data			
	GIS Layer	**Spreadsheet**	**Map**	**Report**
Watershed boundary	✓			
Buckman wells	✓	✓	✓	✓
River outline	✓			
Rio Grande outline	✓			

Received Data				
Domestic wells	✓			
Stream flow		✓	✓	
City Boundary	✓			
Precipitation		✓		
Upper watershed boundary	✓			
Water consumption		✓		✓
Reservoir Water Supply	✓	✓		✓
Water Rights		✓		

Table 2: Data Supplied by the City of Santa Fe

The city's water division is the most important source of watershed information. Most of the information is publicized on their website, can be inquired for, or can be shared through Google Documents.

4.1.2 Santa Fe County

The Santa Fe County was a significant contributor of data regarding the Santa Fe Watershed. All of the data obtained from the county in the form of GIS layers. The County possesses a large amount of GIS layers because they have collected GIS layers from other sources such as the Office of the State Engineer and the city. Therefore, their collection encompasses all of the GIS layers available for the County. The County provided useful GIS layers such as geological and municipal boundary lines and surface water information. The Team determined that the County is a significant source of GIS layers, but due to ownership rights, the County cannot release all of its GIS layers to the public.

	Format of Data		
Received Data	GIS Layer	Spreadsheet	Map
County boundary	✓		
Elevation layer	✓		
Contour lines	✓		
Satellite imaging	✓		

Table 3: Data Supplied by Santa Fe County

4.1.3 United States Geological Survey

The USGS is another major source of information involving the Santa Fe Watershed. The USGS is referenced by the city of Santa Fe as one of their major sources of information. It is important because of its wide range of information involving the Watershed and its publication of this information. The USGS's

website contains real-time data as well as daily data. It also has a record of measurements of the depth to water in wells. The USGS has a significant amount of raw data gathered through its monitoring programs. Data can be obtained by downloads from the website. A minor drawback of the USGS website is that some data types are not available to download upon request. Also, the data downloaded can be in such large quantities that the information is difficult to analyze. We found that GIS layers of information such as elevation were most useful from USGS. It is a notable source of watershed data in the Santa Fe area, but the organization of the large amount of data is difficult to sort.

	Format of Data		
Received Data	**GIS Layer**	**Spreadsheet**	**Map**
Elevation	✓		
Monitoring wells		✓	
Well depth to water		✓	
Underground Geology			✓

Table 4: Data Supplied by the USGS

4.2 Visualizations Linked to Major Sources of Data

Although the collection of valuable data involving Santa Fe's Watershed is very important, providing analyses of the data utilizes the information in the best manner. Automatically forming this raw data into a form that can aid in the analyses of Watershed information is a crucial piece that was missing from the process. By automating maps and graphs to be formed from the collected raw data, scientists and engineers can now easily conduct analyses on collected data. Please refer to Appendix D for detailed instructions on how to maintain the automated maps.

4.2.1 Interactive Automated Mapping of the Monitoring Buckman Wells

In order for the city of Santa Fe to determine the water supply, the levels of water in the Buckman Wells are monitored and recorded. These wells are important for documenting the change in water level through time. The City monitors and records these wells manually four times a year. The data is then put into a spreadsheet that ends up in a water report and is publicized via a link on the city of Santa Fe's website.

Figure 14: City's Google Spreadsheet of Buckman Wells

The Team has provided the City with a better method for this process. The data in the spreadsheets would be put to better use if it was displayed in a format was that easier to understand. The Team developed a method that generates maps based on the specific spreadsheet. This new process uses Google Spreadsheets, Google Charts and Google Maps to provide automated visuals of the Buckman Wells. The City will still monitor and record the Buckman Wells water levels in the same manner, but the spreadsheet displayed in Figure 14 is now stored and updated on Google Docs so that the spreadsheet is immediately publicized when changed. This spreadsheet is in the same format that the City is familiar producing. It lists the name of the well and the depth of the well, change in water level, and the recent non-pumping water level of the well, but now each well that is listed in the spreadsheet is represented as a placemark on the map as displayed in Figure 15.
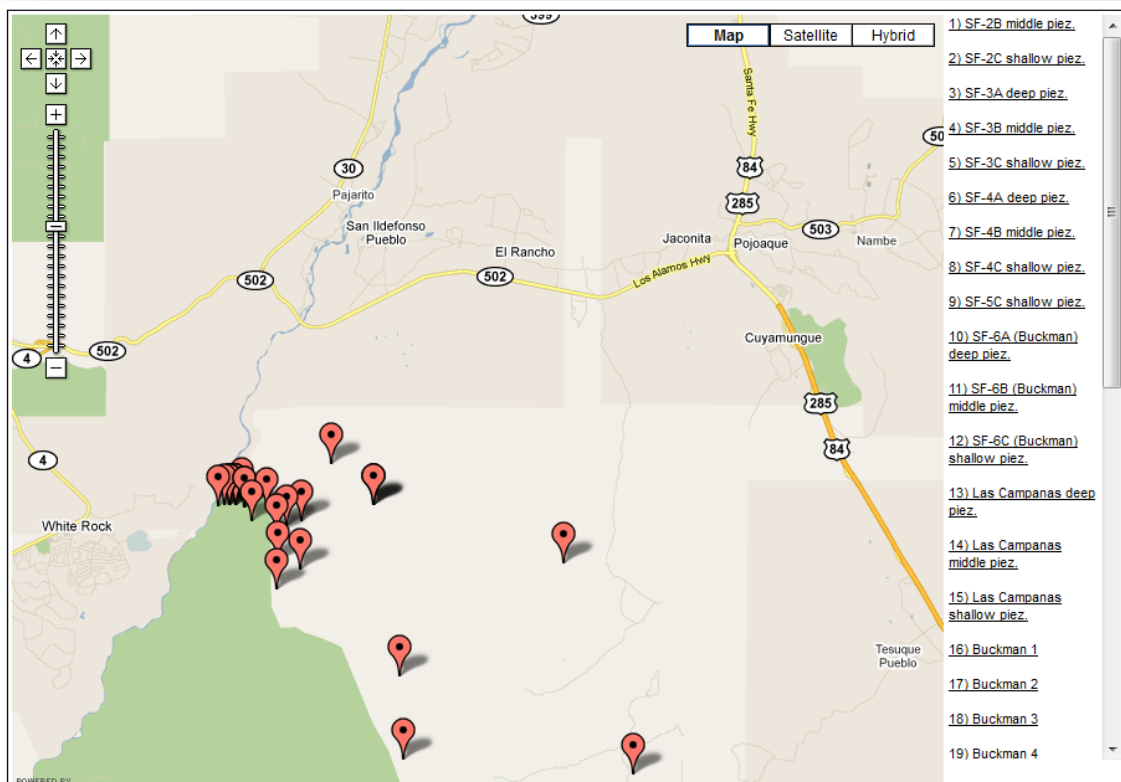
Figure 15: Map of Buckman Wells

Each placemark displays information relating to that specific well (displayed in Figure 16) such as the name of the well, the water level rate of change, the recent non-pumping water level, and the total depth of the well. Also, each placemark contains links to more information on Buckman Wells. There is a link that refers the viewer to the spreadsheet that the map is based on in order to view all of the data. There is a link that brings the viewer to a spreadsheet of historical data on the Buckman Wells that displays the productivity and water level from 1981-2010. The placemark also contains a graphical representation, as displayed in Figure 17, of the historical data on the Buckman Wells. The graph shows the monthly production of each Buckman Well since 1981. This map helps the public to make better use of the available information.
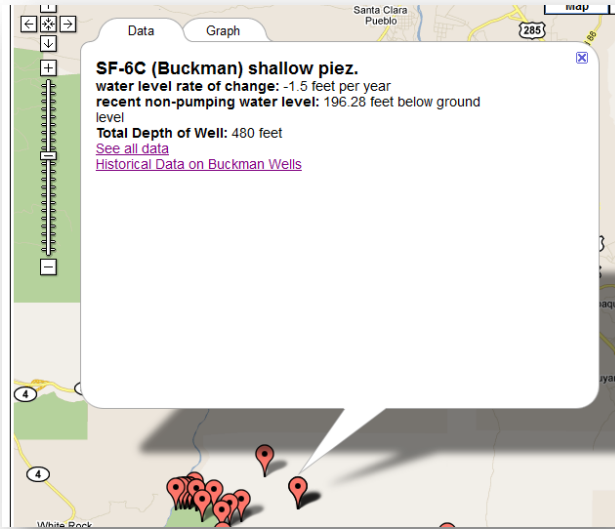
Figure 16: Placemark Information Window Data Tab
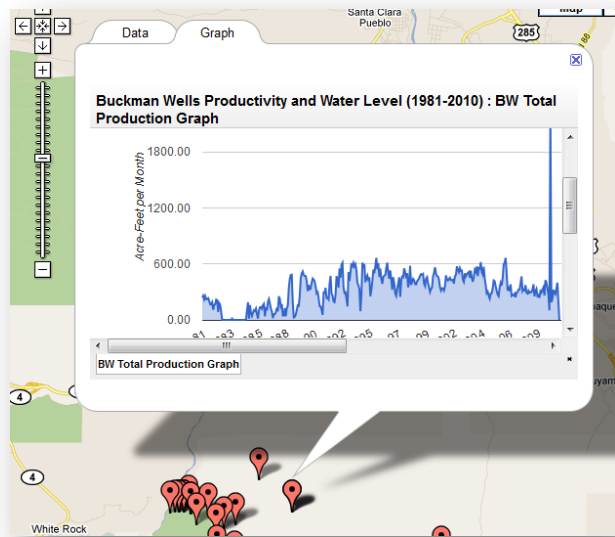
Figure 17: Placemark Information Window Graph Tab

4.2.2 Mapping Locations of Water Quality Testing Conducted by Schools

Another use of the visualizations is to publicize the local field work done by members of the community. The Santa Fe Girls' School and the Santa Fe Indian School have certain locations along the river that they visit and conduct water quality testing on a weekly basis. The team worked together with the Beaver Instinct Team from Worcester Polytechnic Institute to create a map of their spreadsheet of data. The Beaver Instinct Team

worked with these schools and kept a spreadsheet of the schools' locations of data collection. Water Knowledge created a map of the data locations that will update whenever another location is added. Each data collection point is marked with a placemark and expands to display information, as displayed in Figure 18 about the school and its data collection. It also provides a link to their webpage on the Google site created by Beaver Instinct. This map will be publicized on the team's Google site so that visitors can see the schools' points of data collection. This map can then be publicized on the Santa Fe Watershed Association's website in order to display an example of community involvement and education.
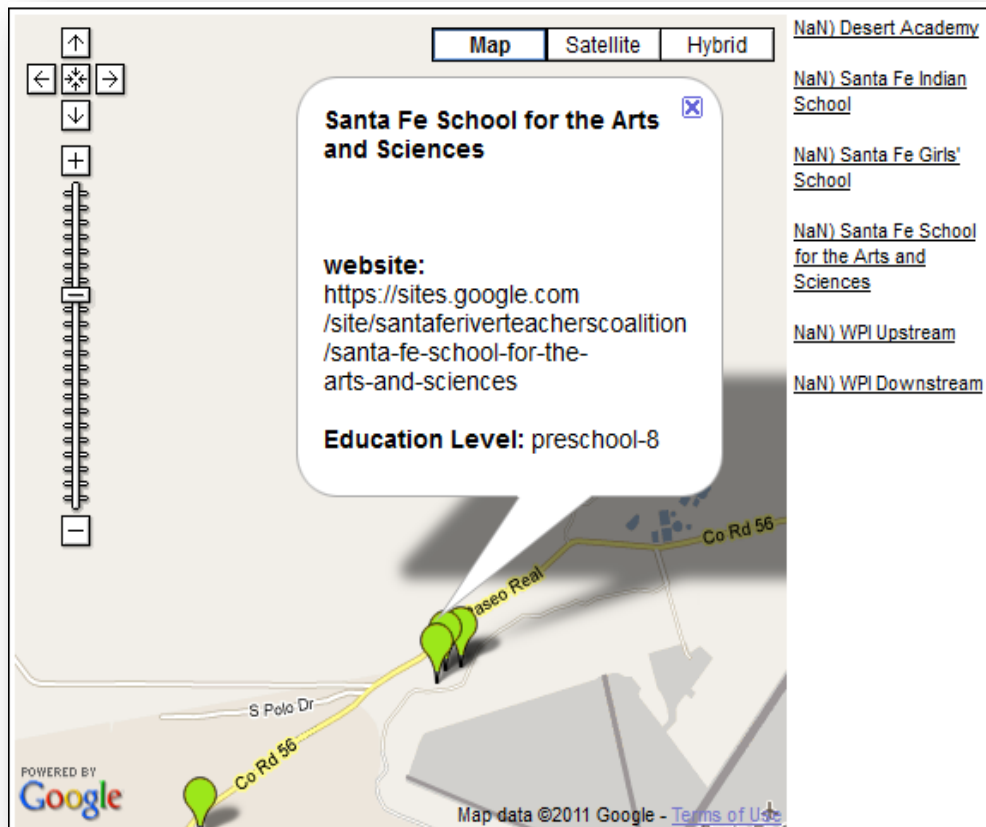
Figure 18: Map of Schools' Data Collection Locations

4.2.3 Mapping the Locations of the Domestic Wells in the Watershed

The city of Santa Fe's water division is currently in the process of gathering data regarding the domestic wells. As the City obtains data regarding each well, they will be able to insert the information into the spreadsheet and display it on the map shown in Figure 19 that the Team has created. This map shows the locations of the

domestic wells located within the Watershed boundary. Each placemark represents a domestic well and can be clicked on to view the information window for the well. Currently the information window displays the title of the well and the elevation of the well. Since the collection of domestic well data is an ongoing project, this spreadsheet titled Watershed Wells will act as a platform for data as the city conducts field work. The spreadsheet was coded so that it will display changes to existing information as well as data added regarding the well depths.
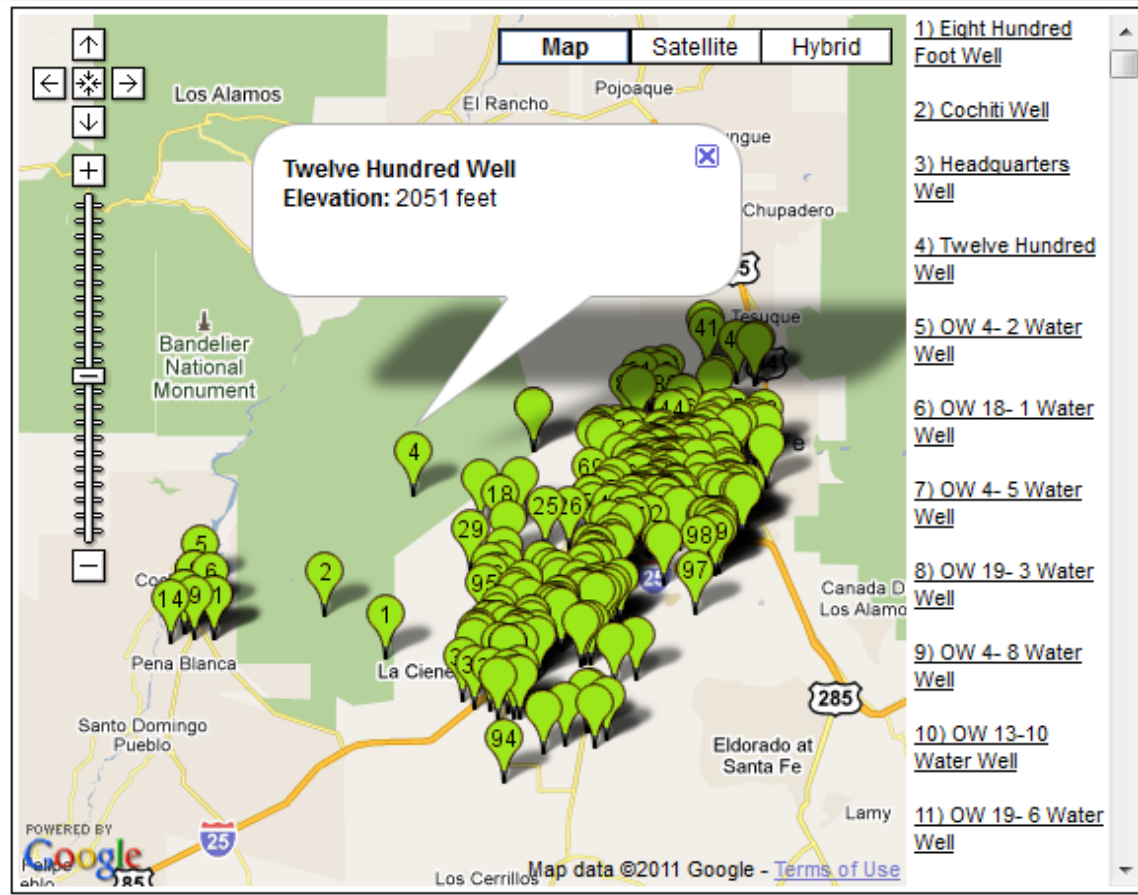
Figure 19: Map of Domestic Wells in the Watershed

4.2.4 Mapping the Stream Gauges along the Santa Fe River

Another visualization that the team provided is an interactive map of the stream gauges (as displayed in Figure 20)along the Santa Fe River. This map is based off of a spreadsheet on Google Documents titled "Stream Flow Gauges". This map displays the locations of the gauges. Each gauge is represented by a

placemark that can be clicked on in order to view the information window. In the information window there is the name of the stream gauge and a graph displaying the stream flow of all of the gauges. The spreadsheet that provides the information for this map acts as a platform for the stream flow data. Since the accurate stream flow data could not be obtained, the cells are filled with place-holding data so that the city can open the spreadsheet and enter the accurate stream data once it is collected. This map can be publicized on the city's website to display the flow of the Santa Fe River.
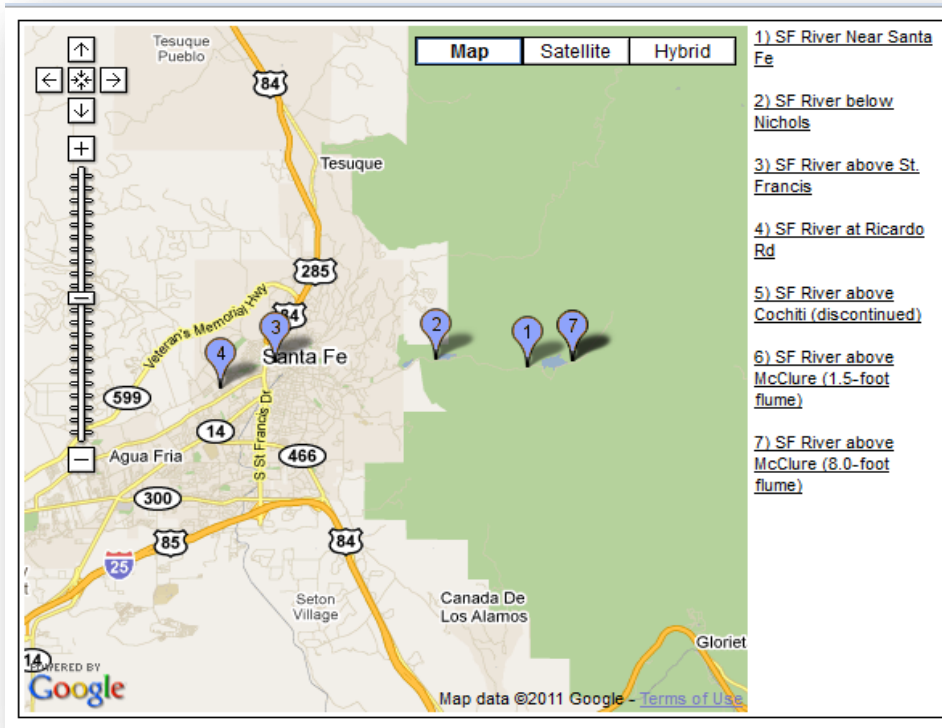
Figure 20: Map of Stream Gauges

4.2.5 Publicizing the Santa Fe River through an Interactive 3-D Tour

In order to get the public more in touch with the Santa Fe River, we provided the Santa Fe Watershed Association with a 3-D tour of the Santa Fe River. It begins in the Sangre De Cristo Mountains where the runoff collects. The video then travels along an outline of the Santa Fe River that was created by importing a GIS layer of the Santa Fe River that we obtained from the City's GIS layer collection. The tour shows the topography and landmarks in the area as it travels along the river until it empties into the Rio Grande. Since the River is dried up in certain areas most days, it is hard to visualize the complete path of the Santa Fe River. This video will allow visitors of the Santa Fe Watershed Association's website to completely visualize the

River. This way the public, including the citizens of Santa Fe, can become more familiar with an important piece of Santa Fe's Watershed. A screen shot of the 3-D tour is featured in Figure 21.
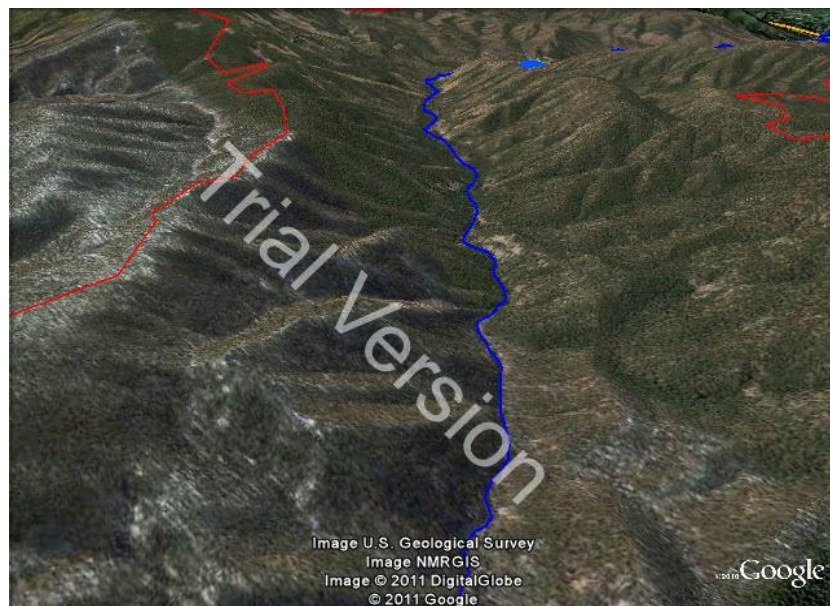
Figure 21: Google Earth Tour of the Santa Fe River

4.3 Interactive Model of the Santa Fe Watershed

The group has worked on developing the Watershed Model as well as a method for analyzing it. The final product of the model (as seen in Figure 22) functions according to sliders corresponding to water-affecting variables, buttons linked to GIS layers, and monitors displaying changes in water counts within various boundaries. The model is based upon a water bank system, where the changeable parameters affect how much water is available for use within various geographical and municipal boundaries. A successful integration of these variables with the foundation of watershed geology and topography produced a model capable of predicting interactions between citizens, natural forces, and the water within the Watershed. The Team also determined a method for analyzing the model by comparing historical water information with corresponding information produced and recorded by the model. This analysis will not be conducted on the Group's Watershed Model but the Team will describe the process in detail.
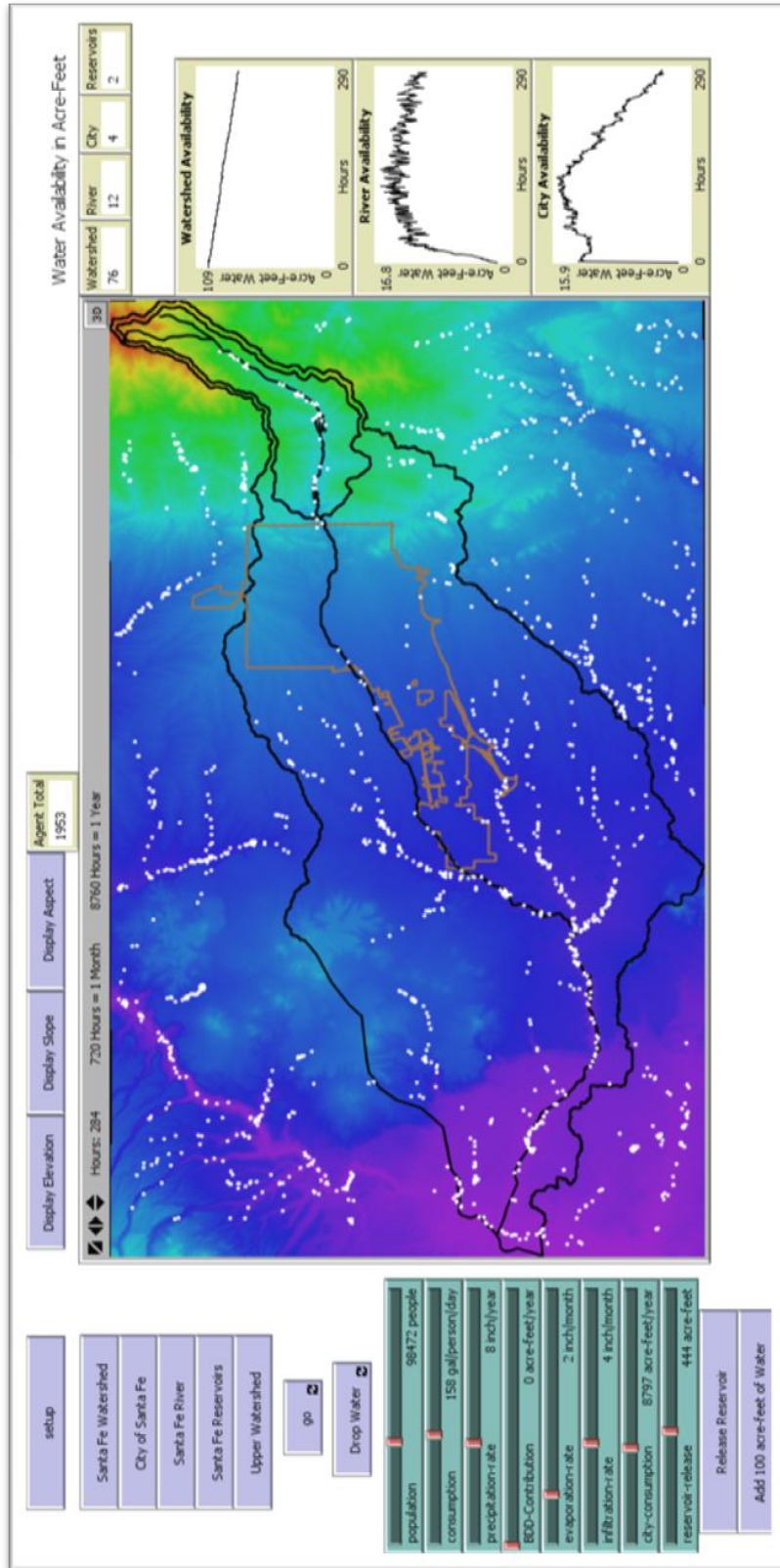
Figure 22: Watershed Model

<u>4.3.1 Model Functionality</u>

The Watershed Model consists of three basic sections of information: GIS layers which are interactive through buttons, water associated variables which are interactive through sliders, and water availability counts which are displayed through monitors and graphs. It is first necessary to begin with the foundation of the model composed of GIS layers. The model's foundation consists of six different working layers concerning the topography in and around Santa Fe: elevation, the Santa Fe Reservoir, River, City, Upper Watershed, and Watershed boundaries (seen in Figure 23). These layers appear within their respective locations over the elevation layer when their corresponding buttons are clicked by the user. These layers are extremely important because they not only control the interaction of the agents within the model but visually focus the user by providing relevant boundaries.
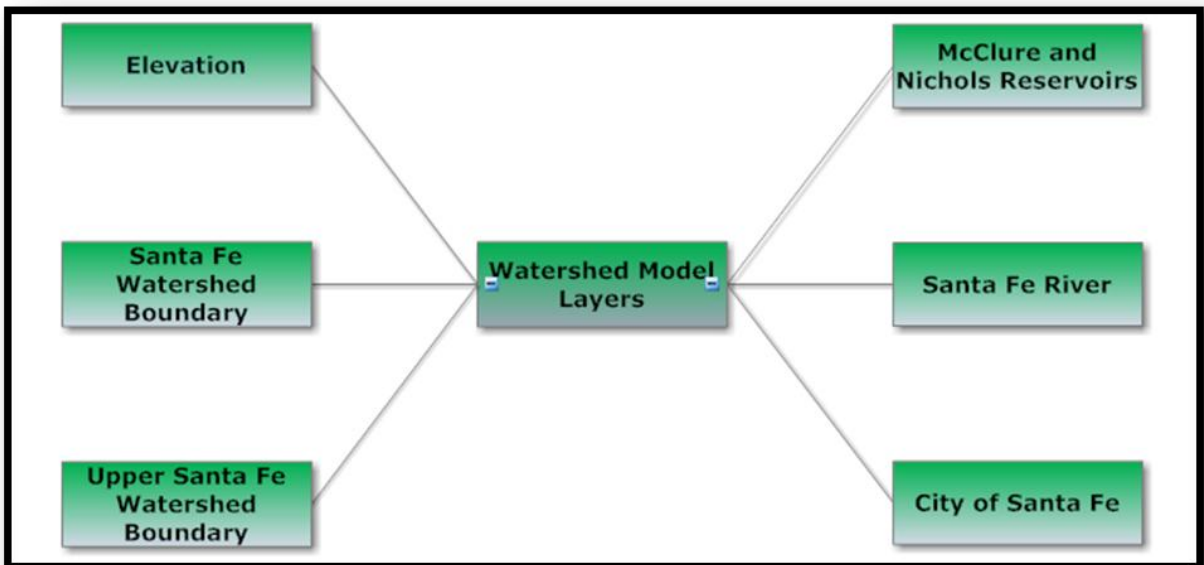
Figure 23: Watershed Model GIS Layers

The next section of the Watershed Model deals with water-affecting variables and their corresponding interactive sliders. Within the model there are six different variables that affect the water: per capita water consumption rate, population, Buckman Direct Diversion contribution, infiltration rate, precipitation rate, and evaporation rate (seen below in Figure 24). By changing the sliders values the user can control how much the respective variable affects the availability of water within given boundaries in the model. These sliders give

the user complete control over the variables, thereby increasing the model's flexibility by allowing it to simulate as many situations as possible.
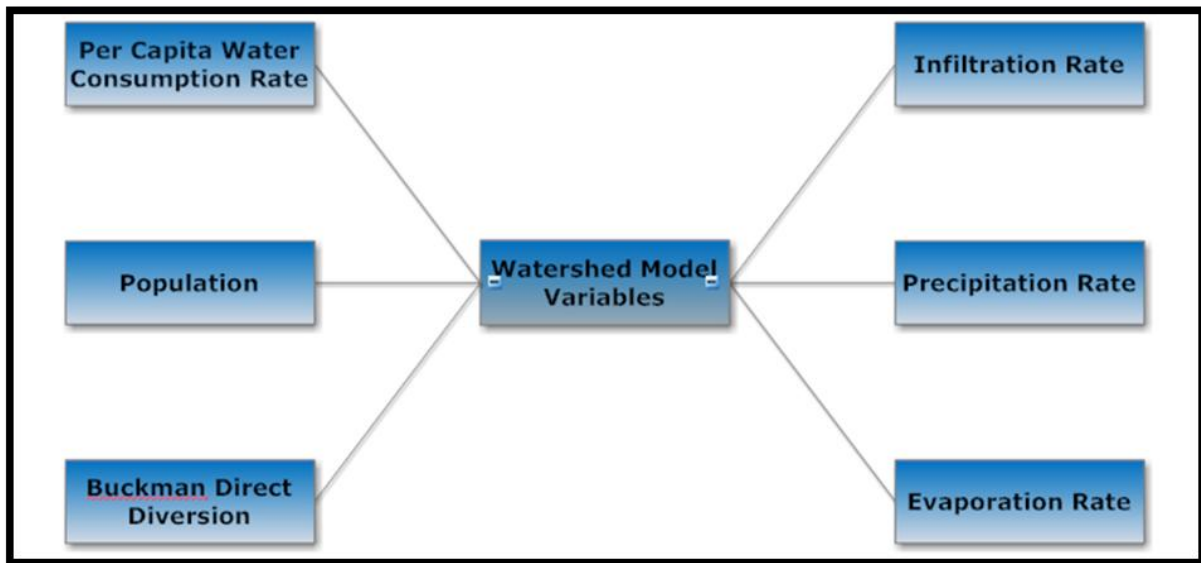
Figure 24: Watershed Model Variables

The final portion of the Watershed Model concerns water monitoring tools which allow the user to view the effects of variable changes via various water meters coupled with their corresponding graphs. The water meters display the volume of water available within the entire Watershed, the Santa Fe River, the McClure and Nichols reservoirs, and the City. These values and their corresponding graphs are the most essential part of the model because they are the indicators of the entire system. The indicators within the Watershed Model are shown in Figure 25.
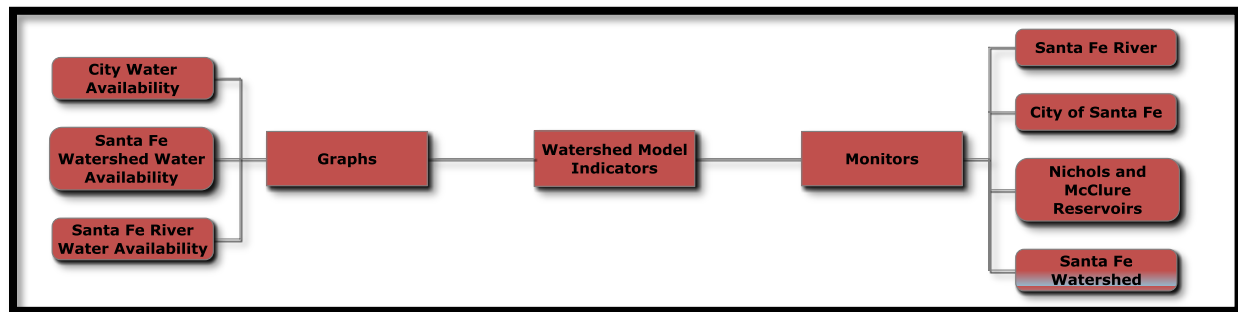
Figure 25: Watershed Model Indicators

To conduct the model in its entirety, the "setup" button must be hit on the view on the sand. This will load the information from the selected GIS layers including the elevation as an image of the Watershed. The

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elevation information should then be used to shape the sand to create the three-dimensional view of the Watershed. The desired values of the parameters must be selected via their corresponding sliders. To begin the simulation the user must hit the "go" button. As time elapses, precipitation (white spheres) will form or disappear according the amount that precipitates, is consumed, evaporates, or infiltrates into the soil. With Netlogo modeling in conjunction with the physical topography provided by the sand, our model provides a powerful visualization that forecasts the amount of available water within Santa Fe Watershed while simultaneously demonstrating the power and capability of sand table technology. Figure 26 displays an image taken of the Watershed Model displayed on the sand table using SimTable software.
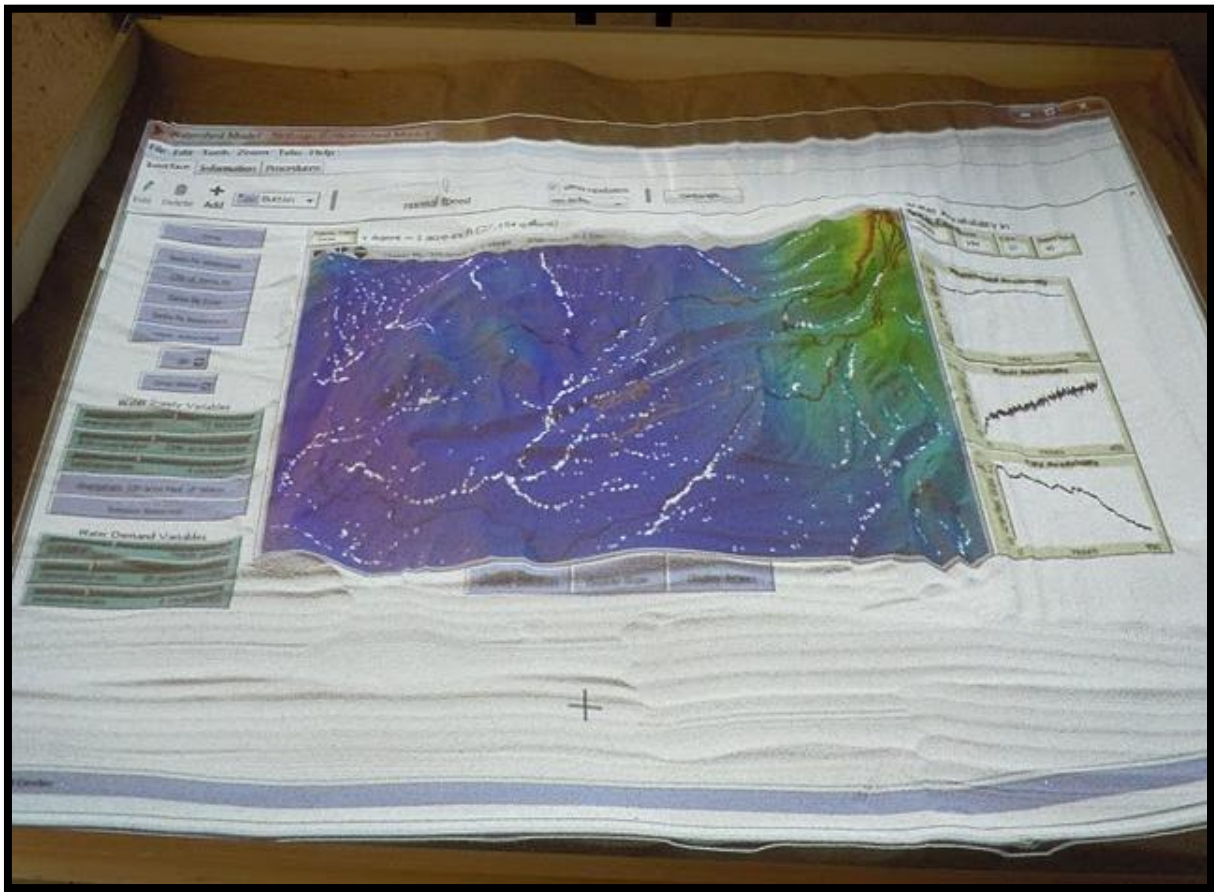
Figure 26: Watershed Model Displayed on Sand Table

4.3.2 Model Analysis

In order to quantify and analyze the error associated with the model it was necessary to construct a method for comparing the model to historical watershed information. First, the group determined the parameters that would be of most interest for making predictions to be city population, annual city water consumption rate, and annual precipitation rate. There are two major reasons for choosing these variables, it is well known that they have a large effect on the water availability within the City's water sources, and the Group already had

historical information with which to compare the model information. After determining the variables to use for the analysis the Group determined specifically how to carry out the analysis.

The model analysis would be conducted by generating a series of graphs based on historical information and comparing them to corresponding model data. The group chose the dependent variable in all of the generated graphs to be reservoir volume. Reservoir volume was chosen because it is affected substantially by all of the aforementioned parameters and so would serve as a suitable indicator of parameter changes' effects on the model. The parameters of most interest (city population, daily water consumption rate, and annual precipitation rate) were all plotted as either independent variables or in addition to reservoir volume against time for both the model and historical information. Please refer to Appendix H for a detailed description of how to carry out the analysis using the BehaviorSpace tool within Netlogo. The Group fully understands that there are many different variables at play that could be affecting the graphs shown, but for the sake of simplicity within this model analysis the Group would assume that all changes shown by the volume of the reservoir are the direct result of the given independent variable.

The graph in Figure 27 would be generated the comparison of historical information versus Watershed Model information, annual precipitation rate and reservoir volume against time.
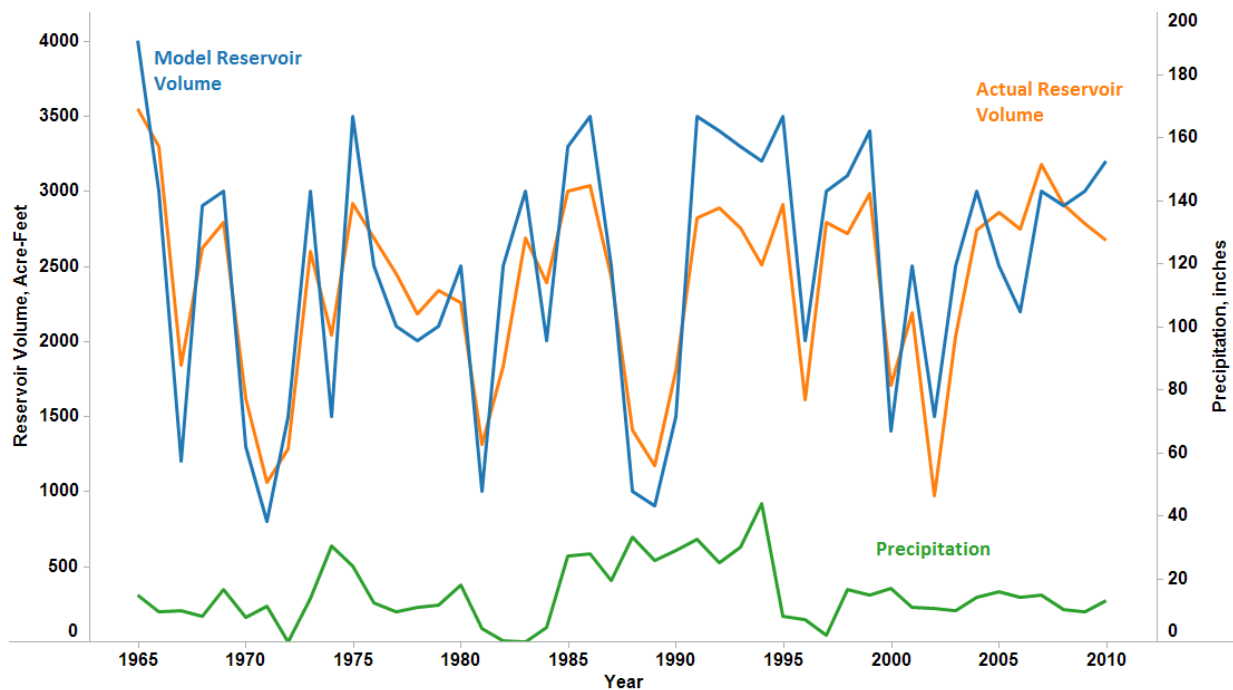
Figure 27: Water Consumption and Reservoir Storage versus Time

The second graph that would be generated, city population versus reservoir volume, is shown in Figure 28.
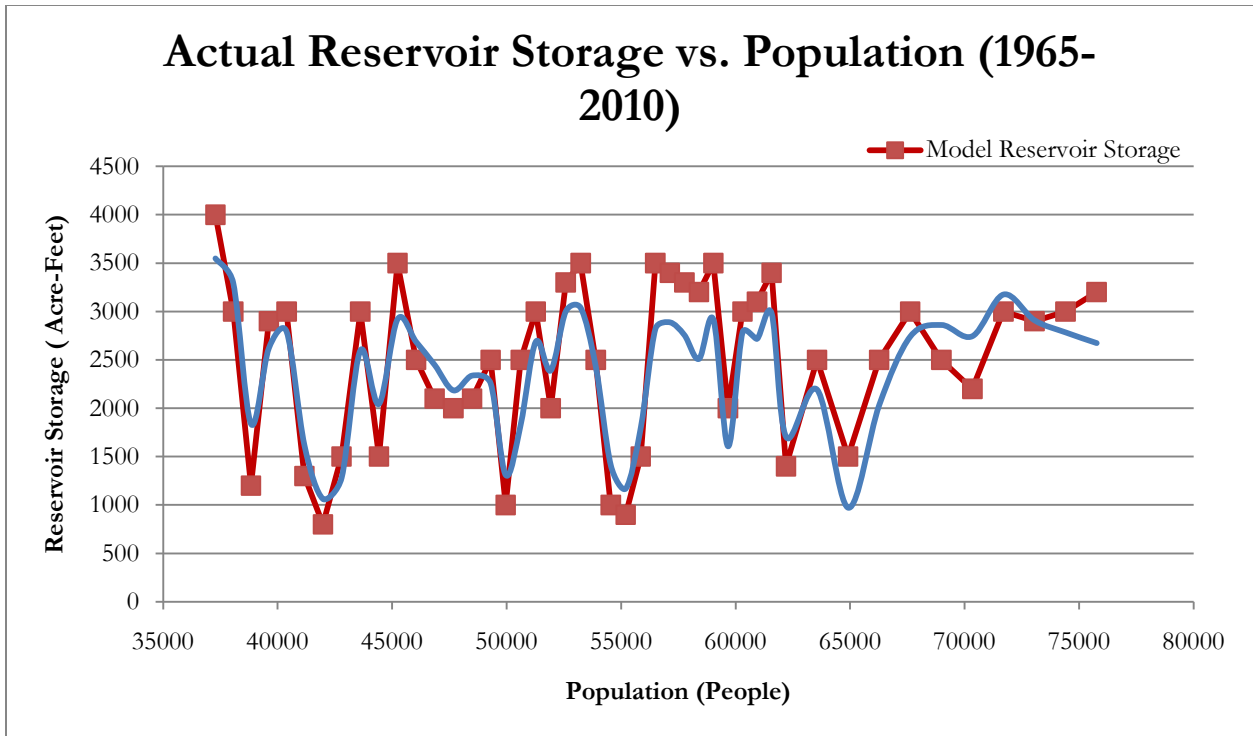
Figure 28: Population versus Reservoir Storage

The third and final graph that would be generated, annual city water consumption rate and reservoir volume versus time is shown in Figure 29.
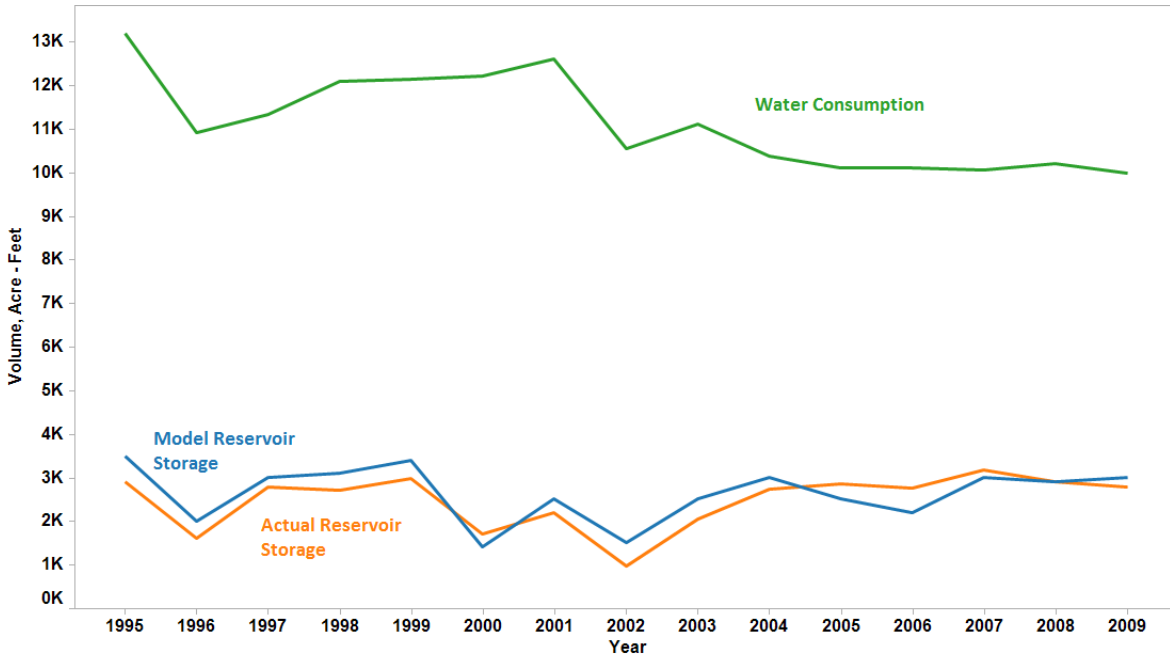
Figure 29: Annual Water Consumption and Reservoir Storage versus Time

These three graphs of historical versus model generated data would allow for direct analysis between the model and reality, thereby providing the necessary information for numerical statistics to be created and conclusions drawn. If the conclusions show modeling inaccuracy, demonstrating the unreliability of the model, then more changes should be made and the process continued until the final product is reliable enough to be used confidently by water management officials.

4.4 Smartphone Application

After weeks of work, the Team produced an interactive mock-up of our Smartphone application. This is not a functioning Smartphone application but a series of screenshots created in Photoshop and linked together with HTML5 coding. This gives the appearance of functionality and creates an interactive experience that displays the potential of the application. One of the reasons the Team created an interactive mock-up was to ease the work of the developers who may eventually produce this application. Modeling how the application functions will reduce the work the future developers will need to do.

The application was designed to increase the community's involvement with the river restoration efforts. The application does this by allowing the user to capture images of the river at specific GPS locations within the City and attach labels to the photo that pertain to the condition of the river. This will then automatically update to a server creating a photographic library of the condition of the river over time. Ideally this would be publically viewable on a website where anyone can analyze the photos and see the change in the Santa Fe

River over time. The application also includes map visualizations of the data and a catalog of the previous data collected by the user which will be explained in greater detail below.

Figure 30: Augmented Reality Displaying Collection Points

The application can be opened in two ways. One method is by opening the application from the home screen of the phone. The other method takes advantage of an interesting mechanism in the application. This mechanism is a GPS-triggered collection prompt. That means that when a user passes by the GPS coordinates of a collection point, his or her phone will notify them and ask if they are willing to perform a data capture. Answering "yes" will open an augmented reality view of the surrounding area with the local collection points displayed in Figure 30. Augmented reality is a display technology that overlays information on the camera feed of the phone. It connects information to GPS locations so the information can be physically explored by moving. By clicking on a collection point, the user enters the photo collection page as displayed in Figure 31.
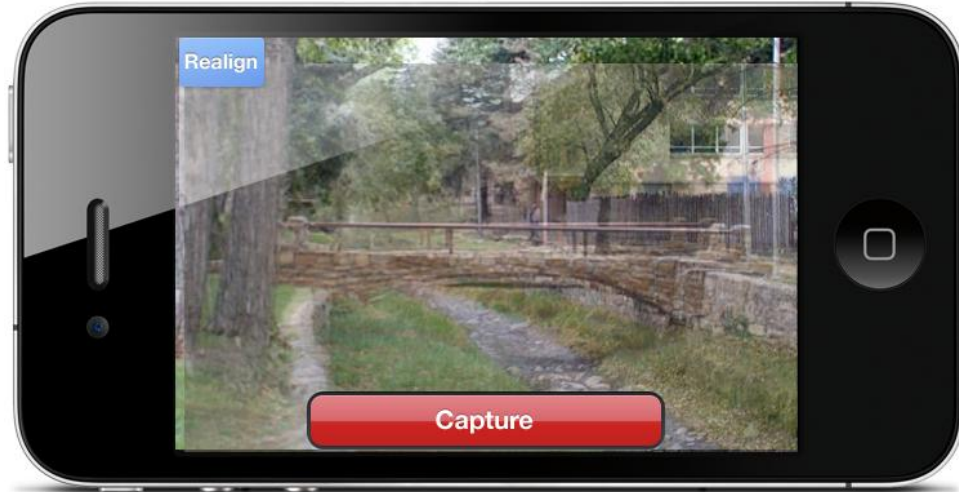
Figure 31: Onion Skin of Previous Image

On this screen, an image of the last picture taken at this location appears as an opaque layer over the phone's video feed. The user aligns the phone with the previous image and captures a new image. Then the user is brought back to the Collect page (as displayed in Figure 32) which is the main page of the application.
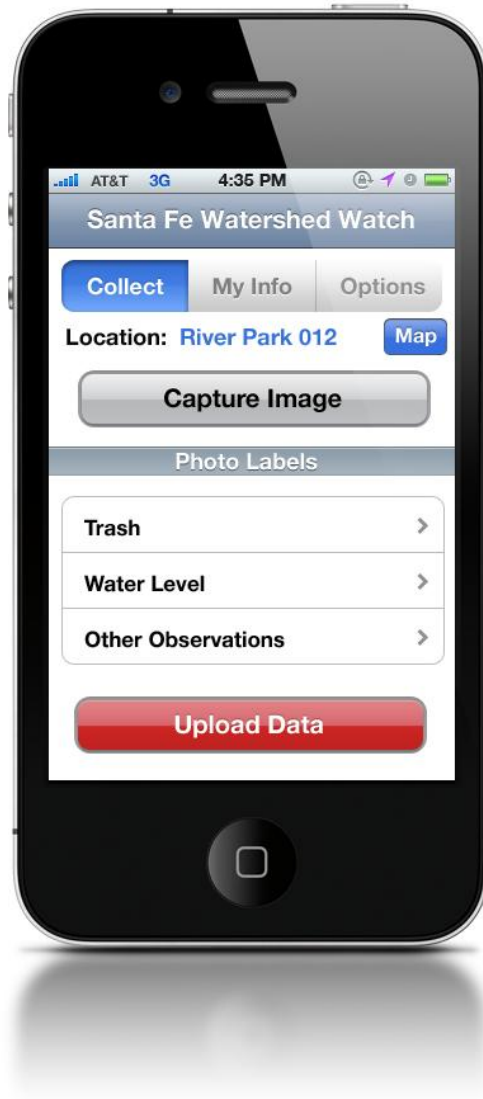
Figure 32: Collect Page

The Collect page displays which GPS location the user is near. The "Map" button takes the user to the map visualizations, as displayed in Figure 33 and 34. The Capture Image button goes to the augmented reality view. The Photo Labels section is where the user applies the appropriate labels to the recently taken photo. The main parameters are Trash and Water Level. The Other Observation label is used to apply unique labels to photos like "animal tracks", "flood event", or anything that the user feels is necessary to describe their data capture. Once the photo is taken and the labels are applied, the information can be sent to the server by pressing the "Upload Data" button.

Figure 33: Map View and Trash Layer

Figure 34: Depth Layer and Zoomed Out Depth

The Map feature located on the Collect page is a way to visualize the data that is collected by the application, as displayed in Figure 32. Using Google Maps the user can view where the data collection points are located. The user can also apply various layers to the maps in order to visualize the trash distribution, flow depth distribution, and frequency of collection at the points. By zooming out on the map while the layers are on, the user can see trends along the length of the river, as shown in Figure 34.

The MyInfo page, as shown in Figure 35, is a catalog of the data collections made by the user. Here the user can view how many collections he or she has made and the location that he or she collects at most frequently. The user can also look at your rewards. This application would have a business that supplies funding in exchange for advertisement in the application. This same business would ideally supply coupons that the user would gain after collecting a certain amount of photographs, creating an incentive to use the application. Going to the My Rewards page shows how many captures the user must take until his or her next reward. From the MyInfo page the user can also access a list of all of the past collections he or she has made. Here the user can view all of his or her previous photos and his or her corresponding labels.
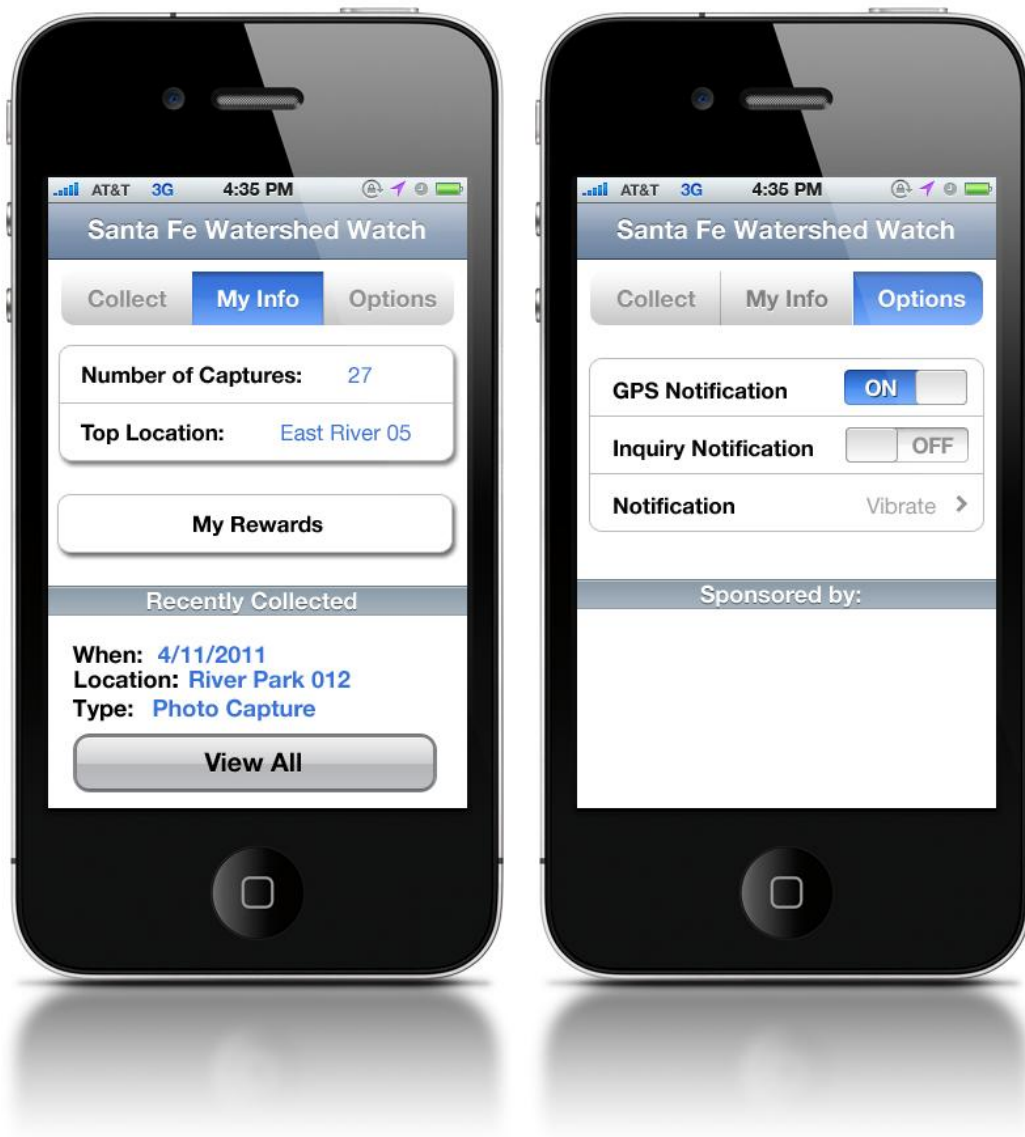
Figure 35: MyInfo Page and Options Page

The final page for the application is the Options page. This is a simple page that contains a few parameters that the user can toggle on and off. The user can choose to have GPS triggered prompts for data collection. The user can also choose to activate inquiry notifications. And inquiry notification is specific to a certain data parameter. For example, if the user is a person who is very concerned with the trash in the area, the application will specifically ask about the waste in the river when he or she walks by a GPS location. The user can also choose whether or not the notification method is by tone or vibration. The rest of this page is dedicated to more advertisement for the rewards organization.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Sources of Watershed Information and Providing Visualizations

This project presented the three major sources of watershed information in Santa Fe. The Team determined that the government organizations contain most of the collected data regarding the Watershed. In order for the community to easily access information about the Watershed, it would be beneficial if each organization made an effort to reorganize the information presented on their website. In the future, the City would benefit from transferring all of their local documents on Google Documents. This way they can easily share documents between employees. They can also publicize certain documents easily because Google Documents will generate a URL for a publicized spreadsheet. Increased use of Google Documents by the city of Santa Fe would ease communication and sharing of documents between organizations and the public.

The visualizations that were created during this project will be a beneficial tool for engaging the community. The City and the Santa Fe Watershed Association would benefit from using the HTML code provided by the Team to embed the generated maps on their websites. These maps, when posted on the public websites, will provide an interactive method for the public to access information about their water level and supply. It would be beneficial to the City if they kept the spreadsheets updated so that the maps can provide the public with the most up-to-date information. Also, as the City undergoes their current project to obtain information about all of the domestic wells in the City, they can enter the information into the "Domestic Wells" spreadsheet so that the map of domestic wells can provide updated information. The spreadsheet created to host the stream gauge information could be utilized by the City. The City can enter the collected data on the stream flow into the spreadsheet that provides the information for the map. The code created by the Team is a great tool for Santa Fe to publicize data regarding the water supply for the community.

5.2 Watershed Model

Local non-profit environmental organizations such as the SFWA will be able to use the model along with the sand table as an educational resource. The completed model also provides the foundation of a complex watershed model for either a future project group or the Santa Fe Complex to use in the future. By integrating the proposed recommendations, the model could become reliable enough to give users the confidence to base future decisions on its outcome. Also, in the future the model could be applied to any watershed in any location, given the necessary information. It would simply be a matter of switching out the base GIS layers for watershed specific layers and shifting the appropriate parameters to match the watershed of interest. After completing the model, the sand table was used to display and interact with it.

The model is not accurate enough for analyzing the water management of the City because of the many factors of the water cycle that are not included. However, the Watershed Model still serves its two major purposes. It exemplifies the benefits of new visualization technologies, such as the sand table, and provides a strong foundation for the Santa Complex or a future WPI project group to complete with proper funding and time. With the necessary modifications, the Watershed Model could be utilized for answering real world questions that would better prepare water management officials to make important decisions.

5.2.1 Model Recommendations

Here is a comprehensive list of recommendations that the Group has determined would be most likely to make the Watershed Model as accurate as possible.

1. Change the weather patterns to better reflect reality

- Make the model reflect realistic weather patterns that are specific to the local climate
- Allow the user to simulate isolated summer monsoon showers

2. Create more user controls (parameter sliders, buttons, graphs, etc.):

- Incorporate temperature and time of year so that parameters will be affected accordingly
- Give the user the ability to release a certain amount of water from the reservoir

3. Integrate more GIS layers

- Include a GIS layer with vegetation information
- Integrate a GIS layer with infiltration rates based on areas around the watershed
- Integrate a census population GIS layer
- Incorporate the City, Buckman, and private well GIS layers into the model.
- Make these layers interact with the groundwater and provide a source of water for the city and its citizens

4. Make water relationships (both with the city and nature) more realistic

- Make the model reflect the relationship between city consumption and water within various sources more accurately
- Make evaporation more realistic according to fluid dynamic laws
- Have the model calculate and display the depth to the water table in important locations around the watershed

- Create the connection between surface water and groundwater
- Make water infiltrate and recharge groundwater according to the GIS vegetation layer and infiltration layers

5. Fix Netlogo specific issues

- Find a way to work the unit system without the model being overwhelmed by the evaporation or precipitation variables so that it is visually pleasing and accurate.

The implementation of all of these recommendations will make the Watershed Model accurate and precise enough to give officials the confidence to take into consideration the simulation results when making their water management decisions.

5.3 Smart Phone Application

There are many recommendations for the future of our phone application. The first and most important recommendation is that the application is developed. As of right now the application is only a series of images linked together with HTML coding. Having a fully functional and downloadable application is the final step that is needed to make this part of the project a success. If the application is not developed then this section of the project serves no purpose. The application should also be produced on both the iPhone and Android platforms to reach a wider audience.

The other main recommendation is to find an organization that can financially support the production of the application and also provide the necessary rewards. The best choices for this would be any group that supports clean flowing water or needs water to survive. The application mockup can be used as a framework for developing the application in the future. We hope that the Santa Fe Watershed Association will look into the creation and distribution of this application.

5.4 Conclusion

By accomplishing these four objectives the Team has made an effort to encourage the community to participate in and restore the Santa Fe Watershed. Encouraging community involvement will have lasting benefits to our sponsor, the Santa Fe Watershed Association, and the community. The sharing platform created can allow easy maintenance and access of the information on the Santa Fe watershed. The watershed model can help with future predictions of watershed conditions. The phone application can provide a photographic library of the River's condition along with involving the community with the restoration efforts and increase the sense of stewardship over the Santa Fe River. These objectives will aid the Santa Fe

Watershed Association in involving the community in river restoration efforts and ultimately can establish a foundation of powerful technology that improves the current information-sharing and education efforts.

6. WORKS CITED

Borchert, Claudia and Amanda King. *Annual Water Report*. Santa Fe, NM: Sangre de Cristo Water Division, 2010 (accessed 2/2/2011).

Buckman Direct Diversion Project. "Buckman Direct Diversion Project." http://www.bddproject.org/index.htm (accessed February 1, 2011).

Bucknall, Julia. *Making the most of Scarcity: Accountability for Better Water Management Results in the Middle East and North Africa*. Washington, D.C.: World Bank, 2007, Table of contents only http://www.loc.gov/catdir/toc/ecip072/2006032526.htmlhttp://bibpurl.oclc.org/web/17465http://go.worldbank.org/WDPAMJ5290.

Bureau of Land Management. *New Mexico Water Rights Fact Sheet*, 2001, http://www.blm.gov/nstc/WaterLaws/newmexico.html (accessed February 15, 2011).

City of Santa Fe. *Long-Range Water Supply Plan, July 2008*. Santa Fe, New Mexico, 2008a, http://www.santafenm.gov/DocumentView.aspx?DID=3057 (accessed 2/22/2011).

Dickinson, Mary Ann. *Water Conservation in the United States: A Decade of Progress*. Sacramento, California: California Urban Water Conservation Council, 2001.

EarthWorks. "EarthWorks about Us." http://www.earthworksaction.org/about_us.cfm (accessed 2/2, 2011).

Francis, Kennith. . *Unearthing the Acequias*. Boston, MA: A Penney White Proposal, 2004 (accessed February 7, 2011).

Grant, Paige. *Santa Fe River Watershed Restoration Action Strategy*. Santa Fe, New Mexico: Santa Fe Watershed Association, 2002, http://www.nmenv.state.nm.us/swqb/Santa_Fe_WRAS-2002.pdf (accessed 2/22/2011).

Hurd, Brian H. *Who Owns Water? Water Rights in the Southwest States*. Ruidoso, New Mexico: New Mexico State University, 2003, http://srwqis.tamu.edu/media/2264/hurd.pdf (accessed 2/8/2011).

Kemp, Roger L. *Cities and Water : A Handbook for Planning*. Jefferson, N.C.: McFarland & Co., 2009.

Kenny, J. F., N. L. Barber, S. S. Hutson, K. S. Linsey, J. K. Lovelace, and M. A. and Maupin. *Estimated use of Water in the Unitied States in 2005*. Reston, Virginia: U.S. Geological Survey, 2009.

MacDonald, Glen M. "Water, Climate Change, and Sustainability in the Southwest." (2010),http://www.pnas.org/content/107/50/21256.full.pdf+html.

The Nature Conservancy. "New Mexico: Using Fire to Protect Water." http://www.nature.org/wherewework/northamerica/states/newmexico/science/art32845.html (accessed 2/15, 2011).

Office of the State Engineer. "Water use and Conservation." http://www.ose.state.nm.us/ (accessed 2/2, 2011).

Pearce, Fred. "When the Rivers Run Dry." In *When the Rivers Run Dry*, 9-11. Boston: Beacon Press, 2006.

Racked, Eglal, Eva Rathgeber, and David B. Brooks. *Water Management in Africa and the Middle East Challenges and Opportunities*. Ottawa: International Development Research Centre, 1996.

Santa Fe Watershed Association. "The Santa Fe Watershed Association." http://www.santafewatershed.org/ (accessed February 15, 2011).

U.S Census Bureau. "2000 U.S. Census." U.S. Census Bureau. quickfacts.census.gov/qfd/states/35/3570500.html (accessed 2/12, 2011).

USDA Forest Service. "Santa Fe National Forest." http://www.fs.fed.us/r3/sfe/ (accessed 2/10, 2011).

Water Footprint Network. "Waterfootprint.Org: Water Footprint and Virtual Water " http://www.waterfootprint.org/?page=files/home (accessed 3/1/2011, 2011).

WildEarth Guardians. "WildEarth Guardians about Us." http://www.wildearthguardians.org/site/PageServer?pagename=about (accessed 2/7, 2011).

World Water Council. "Water Crisis." http://www.worldwatercouncil.org/index.php?id=25 (accessed 2/20, 2011).

Younger, Paul L. *Groundwater in the Environment : An Introduction*. Malden, MA; Oxford: Blackwell Pub., 2007.

7. APPENDIX

Appendix A: Hydrology

Hydrology is the study of water movement and distribution throughout the environment. This project deals with the health of a river and its watershed, therefore it is important to know how water interacts in the environment. The following sections will explain some basic concepts that are necessary to understand Santa Fe's issues with water.

Quantifying water can be difficult when there is no defined area, which is why the concept of the watershed was created. A watershed is defined by the topography of a region. The watershed boundary, called a divide, is defined by the highest elevations surrounding the watershed. All water falling within the divide has the potential to work its way into the surface water bodies or the groundwater contained within the divide. Water outside of this divide finds its way into the adjacent watersheds.

The water cycle is a continuous process, and therefore, has no defined beginning or end. For this explanation we shall begin with evapotranspiration. This process is a combination of evaporation and transpiration. Evaporation is a process by which water is vaporized from its own surface. Heat from the sun causes the surface of the water body to rise in temperature by adding kinetic energy. Once this energy becomes great enough, surface molecules are converted to water vapor, gaseous water. A similar process occurs where water is vaporized from plant bodies, and this is called transpiration. Transpiration is similar to perspiration in animals but relates to plants. The transfer of water through evapotranspiration is shown in Figure 36, below. The concentration of water vapor in air is known as humidity.
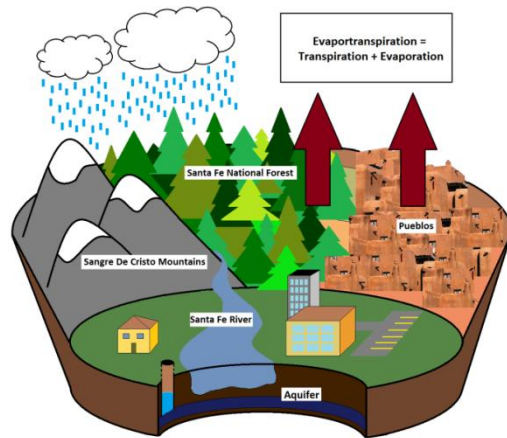
Figure 36: Water Is Converted to its Gaseous Form, Water Vapor, During Evapotranspiration

As water vapor rises in the atmosphere, it loses its kinetic energy through cooling. These molecules bond with each other, and once air becomes saturated with this vapor, the vapor condenses into clouds. When the water in these clouds (either solid or liquid) becomes heavy enough, gravity causes it to fall to the Earth's surface as shown in Figure 37.This process is known as precipitation, and includes rain, snow, and other forms of water.
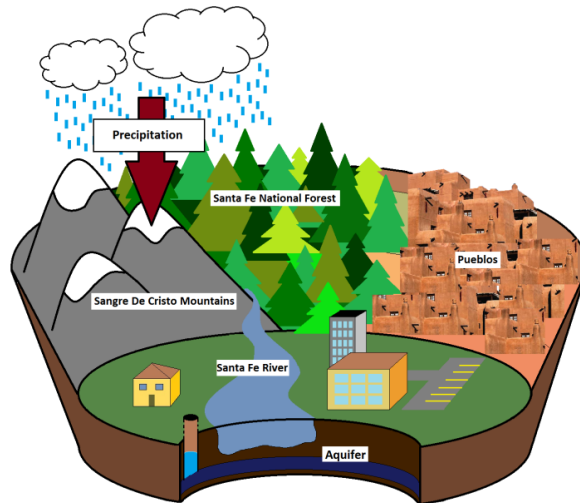
Figure 37: Gravity Causes Water to Fall from the Sky through Precipitation

When this water falls to the surface, it begins to collect and flow from higher elevation to lower elevation.Water in this stage of the cycle is referred to as overland runoff, as shown in Figure 38.
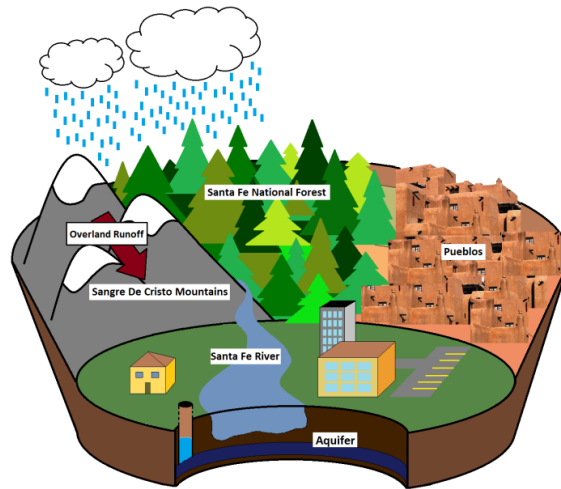
Figure 38: Overland Runoff Occurs When Water Flows Across the Surface of the Earth

When water seeps into the ground, it finds its way into a water-bearing earthen layer known as an aquifer. This is a water-permeable layer of rock that stores the groundwater of a watershed. Water drips through the spaces between soil grains and pools in an area called the saturated zone. The position of the saturated zone corresponds to the water table, which is the depth of the pooled groundwater. Wells must be drilled into the water table so the ground water can be accessed as shown in **Figure 15**. Surface water seeps through the soil via infiltration and replenishes the water that is removed from the aquifer. This is a process called aquifer recharge because it essentially renews and restores the groundwater of an area.
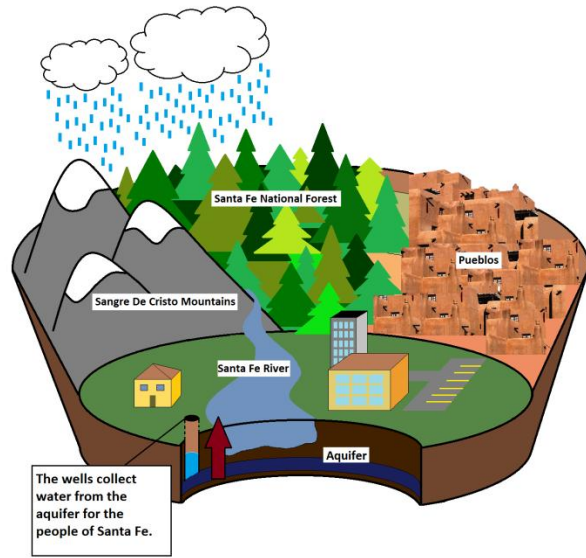
Figure 39: Groundwater is Drawn from Wells

Appendix B: Water Rights in the Southwest

The government has also handled the distribution of water in the Santa Fe region. The question of how to legally distribute water was answered with water rights. A water right is a "property claim to the use of public waters" which is used as a means for the allocation of water in a region of water scarcity[55]. Rights are used for water allocation because they provide "a measure of legal security against the uncertain actions of others"[56]. Without the order of the water rights, uncertainty and conflict would deter "investment, economic development, and stable settlement" within communities[57]. So, it is in the best interests of the citizens and businesses within southwestern states to use water rights as a means of legal distribution of water in their water management plans.

Water rights are distributed based on prior appropriation or "first in time, first in right", under the stipulation that the water be used beneficially by the holder. Prior appropriation applies seniority to water rights, meaning whoever has been legally using water at a location for the longest time has rights that trumps the rights of all other. To determine who can and cannot have water rights, courts and state officials rely on the concept that "beneficial use shall be the basis, the measure and limit of the right to use water"[58]. To first acquire a water right, a person must submit their demands to the proper official, in New Mexico this is the State Engineer. If the water need is deemed legitimate and their proposed water use determined to be favorable, they will eventually receive a court decree entitling them to a designated portion of the water supply as well as the time and place from which it will be drawn. In the water rights system there are various levels of jurisdiction including, from order of highest to lowest priority, international treaties, federal water rights, state agreements (usually court decisions), and finally the state.

At the topmost tier of the water rights hierarchy in the southwestern United States sits the international treaties made with Mexico. The most recent treaty, the Treaty of 1944, divides the waters of the Colorado River, its major tributaries, and the lower Rio Grande giving Mexico 1.5 million acre-feet/year (af/yr) and the U.S. approximately 350,000 af/yr. As of 2003, Mexico has breached the Treaty and has accrued a total water debt of approximately 1.5 million acre-feet of water to the U.S.[59]

The next level of the hierarchy includes any water designated for use by the Federal government. Water needed to satisfy the demands of federal lands, including Indian reservations, military operations, and national

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[55]Brian H. Hurd, *Who Owns Water? Water Rights in the Southwest States.* (Ruidoso, New Mexico: New Mexico State University,[2003]), http://srwqis.tamu.edu/media/2264/hurd.pdf (accessed 2/8/2011).

[56] Ibid.

[57] Ibid.

[58] Ibid.

[59] Ibid.

parks, takes priority over all other water rights other than obligations to Mexico. These rights reserve the amount of water necessary to fulfill the federal purpose and cannot be lost due to non-use as water rights based on prior appropriation can. To determine specific water amounts necessary for the governmental purpose, the Federal agency holding the right must submit to the adjudication process of the state in which the water right will take effect. For New Mexico, this means that the Federal agency would negotiate with the State Engineer. Upon reaching an understanding, both parties sign an agreement which would subsequently pass through the New Mexico legislature for acceptance[60].

The next level of water right complexity is derived from interstate policies. Waters shared by states often leads to disputes, especially so between New Mexico, Arizona, Utah, Colorado, California, and Nevada. These issues can be resolved through one of several different avenues, the US Supreme Court, Congress, and/or interstate agreements. Preference has been given for interstate agreements because this is the least costly and most amiable path. Also, to go through the Supreme Court requires costly legislative fees, undermining the purpose of the desired agreement. When Supreme Court involvement is necessary to resolve disputes, though, decisions are made based on the original intent of the involved parties and the basis of equitable apportionment[61].

Specific to New Mexico and the Santa Fe area is another layer of water rights, those of the acequias. They are communal irrigation systems that currently support thousands of families in New Mexico. The acequias infrastructure includes the physical irrigation network as well as an organization meant for its maintenance, led by the elected Mayadormo[62]. Acequias date back hundreds of years and only exist in northern New Mexico as well as some southern areas of Colorado. They trace their beginnings from several different societies but mainly were formed by the Pueblo Indians. Up until the late 17th century, the Spanish colonized the region and in the process integrated the old Pueblo acequias with newer networks using techniques taught to them by the Moors hundreds of years prior. Historically, these local governments have been the sole organizations in charge of the distribution and use of water to the community. Acequias have the power to borrow money and enter contractual agreements to maintain their water source. However, funding beyond those methods for maintenance or improvement must come from the individuals who utilize the irrigation system because the acequias do not have the right to tax. The prior appropriation doctrine followed by New

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[60]Bureau of Land Management, *New Mexico Water Rights Fact Sheet*,[2001]),
http://www.blm.gov/nstc/WaterLaws/newmexico.html (accessed February 15, 2011).
[61]Hurd, *Who Owns Water? Water Rights in the Southwest States.*
[62]Kennith Francis, *Unearthing the Acequias* (Boston, MA: A Penney White Proposal, 2004)

Mexico inherently suggests that acequias are senior to all other water rights in New Mexico (except Federal Water Rights) due to their being formed earlier than all rights in the region[63].
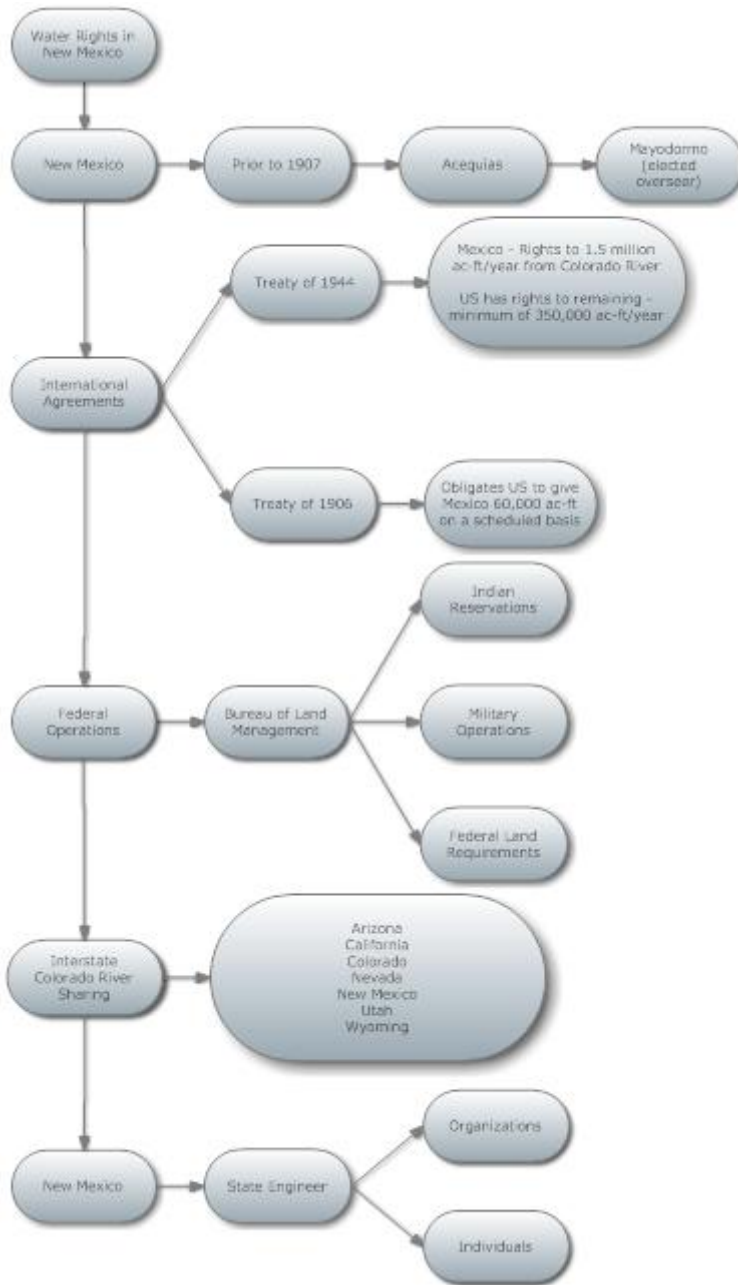
Figure 40: Water Rights Hierarchy

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[63]Office of the State Engineer, "Water use and Conservation," http://www.ose.state.nm.us/ (accessed 2/2, 2011).

Appendix C: List of Contacts in Organizations

Santa Fe's Organizations	Contact Name	Title	Contact Email	Contact Number
Water Conservation Department, City of Santa Fe	Claudia Borchert	Water Resource Coordinator	dsransom@santafenm.gov	505-955-4221
Santa Fe County	Amanda Hargis	G.I.S. Coordinator	ahargis@santafecounty.orf	505-995-2732
Santa Fe Watershed Association	Felicity Broennan	Executive Director	felicity@santafewatershed.org	505-820-1696

Appendix D: Directions to Maintain Google Maps

Directions to Maintain the Buckman Wells Google Map

1. Sign into your Gmail account at www.gmail.com
2. Click on "Documents" on the top
3. When the list of documents appear, click on "Water-Level Trends for Buckman Monitoring Program area wells"
4. This will bring you to the spreadsheet that is formatted like the one you used to have on your computer, you may change numbers and dates manually or cut and paste columns of data into the spreadsheet
5. Remember: Do not change the titles of the columns because the code uses these titles to know where to pull the data from
6. After you change the data you wish to change (while remaining on the spreadsheet view) click on the dropdown menu (▼) button next to the button that says **Share** in the upper right corner, above the spreadsheet.
7. There should be an option "Publish as a Web Page", click on this.
8. A screen will open up, click on the button that says **Republish Now***

*This will ensure that the spreadsheet is up to date and publicized, but it is set to automatically republish every few minutes so this step is just to ensure that the spreadsheet will be published.

Directions to Maintain the Domestic Wells Map

1. Sign into your Gmail account at www.gmail.com
2. Click on "Documents" on the top
3. When the list of documents appear, click on "Watershed Wells"
4. You may add entries to this spreadsheet by adding rows. Make sure there is a longitude and latitude location entered in decimal format or else the map will not load correctly
5. You may change the contents of the columns that contain the title of the well or the elevation.
6. As the depth of the wells are collected, you may record them in this spreadsheet in the empty column titled "Depths", when the depth is entered, it will appear on the information window on the map
7. After you change the data you wish to change (while remaining on the spreadsheet view) click on the dropdown menu (▼) button next to the button that says **Share** in the upper right corner, above the spreadsheet.
8. There should be an option "Publish as a Web Page", click on this.
9. A screen will open up, click on the button that says **Republish Now**
10. Remember: do not change the names of the columns, because the code uses these titles to take the correct data from each column

*This spreadsheet just contains domestic wells that are located within the watershed boundary, domestic wells maybe be removed or added to best fit your needs.

Directions to Maintain the Stream Flow Map

This map is based off of the Google Document titled "Stream Flow Gauges". The data entered in these sheets of the spreadsheet is fake data that is acting as a place holder. You may enter the correct data and it will update the graph that is present in the information windows.

1. After you change the data you wish to change (while remaining on the spreadsheet view) click on the dropdown menu (▼) button next to the button that says **Share** in the upper right corner, above the spreadsheet.
2. There should be an option "Publish as a Web Page", click on this.
3. A screen will open up, click on the button that says **Republish Now**
4. Remember: do not change the names of the columns, because the code uses these titles to take the correct data from each column

If you have any problems with the maps or spreadsheets, feel free to email me at oliviarichards@wpi.edu or oliviaannerichards@gmail.com with the problem and I will try to fix it.

Appendix E: Importing Elevation Information into Netlogo

To begin the process for getting the desired elevation layer into Netlogo we must first start by downloading the initial layer as an ArcView Image File from the USGS website. Go to their site and pick which file you would like to download from the options on the right hand site. With the selector and zooming tools, zoom in to the location where you would like the elevation file. Then use the desired method from the left hand toolbar to select the necessary download area. The area selected will include all of the layers selected from the right hand side. Once the download area is selected make sure to select the option tab that allows you to change the format of the file. Find the files that you checked off and select the ArcView Image File from the dropdown tab next to them. Then hit the save and return to download summary tab and download the file. Once downloaded, save the file to your computer in an easy to find location.

Next, we will use ArcGIS software to convert the downloaded ArcView Image file to the raster file used in Netlogo, as a ASCII Text file. If ArcGIS is not located on your computer, go to their website and download the 30 day free trial. The file is around 3.8 GB so give yourself some time to download it completely. Once it is fully downloaded, install it and we are ready to continue. Once opening ArcGIS, open a new map unless you have one already in the works. Upload your .bil raster elevation file into your map by dragging it from its location to your map (make sure its name is less than nine characters or this will not work properly, you will also have to rename all related GIS files to the same header). Once the file has been successfully loaded into ArcGIS, click on the window tab on the menu bar at the top. Open the ArcGIS Toolbox where you will find the converter tool. Click on the raster to ASCII converter option and choose your .bil file from the dropdown tab. Before confirming the conversion, manually change the .txt extension at the end of the file to .asc. This ensures that you are converting to the proper format. This completes the steps needed to find and convert your elevation layer to the proper format. Upon completing these steps all you need to do is go into Netlogo and tell it where to find your file within the Netlogo folder with quotes, e.g. "data/yourelevationfilehere.asc".

Appendix F: Watershed Model Code

Note: All capitalized letters must be commented out for the code to run properly (meaning putting a semicolon in front of the line)

MODEL ASSUMPTIONS:
1 tick = 1 hour
1 turtle = 1 acre-inch = 27,154 gallons

UNIT CONVERSION INFORMATION:
1 acre-foot = 325,851 gallons
1 acre = 4046.85642 m^2
1 acre-inch = 27,154.2857 gallons, 1 gallon = 2.55740273 × 10-7 acre-inches = .000000255740273

CALCULATING THE TOTAL ELEVATION LAYER:
observer>show gis:world-envelope
observer: [1608432.2176377126 1788064.7388532055 1634009.078667639 1745466.4607451672]
observer> show item 1 gis:world-envelope - item 0 gis:world-envelope
observer: 179632.52121549286
observer> show (item 1 gis:world-envelope - item 0 gis:world-envelope) / world-width
observer: 224.2603261117264
observer> show (item 3 gis:world-envelope - item 2 gis:world-envelope) / world-height
observer: 224.2603261117267
A/patch = (224.2603261117267)^2 m^2 * 1 acre/4046.85642 m^2 = 12.4275953
Total Area = 12.4275953*398097 patches = 4,947,388 acres

CALCULATIONS:
Converting 1 inch/year and 1 month/year to turtles/tick or turtles/tick*patch
 On a per acre basis (entire elevation layer):
  1 in/year * 4,947,388 acres = 4,947,388 acre-inch/year
  4,947,388 acre-inch/year * 1 year/8760 hours * 1 hour/1 tick * 1 turtle/acre-inch = 565 turtles/tick
  4,947,388 acre-inch/month * 1 month/720 hours * 1 hour/1 tick * 1 turtle/acre-inch = 13752 turtles/tick

On a per patch basis:
  area per patch = 12.43 acres
  1 in/year * 12.43 acres/patch = 12.43 acre-inch/patch*year
  12.43 acre-inch/patch*year * 1 year/ 8760 hours * 1 hour/1 tick * 1 turtle/acre-inch = .00141895 turtles/patch*tick or 705 tick*patch/turtle
  12.43 acre-inch/patch*month * 1 year/ 720 hours * 1 hour/1 tick * 1 turtle/acre-inch = 0.017263 turtles/patch*tick or 57 tick*patch/turtle

 Converting acre-feet/year to turtles/tick
  1 acre-foot/year * 12 acre-inch/1 acre-foot * 1 turtle/1 acre-inch * 1 year/8760 hours * 1 hour/1 tick = 0.00136986301 turtles/tick
  1/0.00136986301 turtles/tick = 730.000002 ticks/turtle

```
MODEL CODE:
extensions [gis]

globals [sfwatershed-dataset
  sfcounty-dataset
  nmhydrology-dataset
  riogrande-dataset
  sfreservoir-dataset
  sfriver-dataset
  sfhydrology-dataset
  sfcboundary-dataset
  upperwatershed-dataset
  color-min
  color-max
  elevation-dataset
  border
  water-height
  elevation
  slope
  aspect
  waters-rate
  sfpopulation-dataset
  gallonsperwateragent
  evaporation
  sfreservoir
  sfcity
  patcheselevation
  acre-foot acre-feet
  acre-inch acre-inches
  gallon gallons
  hour
  day
  month
  year
  mPointsX mPointsY mouseState cursor]

breed [waters
     water]

patches-own [pwatershed
         pAspect
         priver
         pcity
         phidden
         pelevation
         preservoir]

to setup
  clear-turtles
```

```
clear-all-plots
reset-ticks
clear-drawing
clear-patches


LOAD ALL DATASETS:
  set elevation-dataset gis:load-dataset "data/elevation1.asc"
  set sfwatershed-dataset gis:load-dataset "Data/SantaFeWatershedBoundary.shp"
  set sfreservoir-dataset gis:load-dataset "Data/SantaFeReservoirs.shp"
  set sfriver-dataset gis:load-dataset "Data/SantaFeRiverLine.shp"
  set sfcboundary-dataset gis:load-dataset "Data/sfjur.shp"
  set upperwatershed-dataset gis:load-dataset "Data/wtrshd buf 1000 in.shp"
  set sfpopulation-dataset gis:load-dataset "Data/2010CensusTract.shp"
  set sfcounty-dataset gis:load-dataset "Data/fe_2007_35_county.shp"
  set riogrande-dataset gis:load-dataset "Data/Rio_Grande.shp"
  gis:set-world-envelope gis:envelope-of sfwatershed-dataset

SETUP PATCHES:
  ask patches gis:intersecting sfwatershed-dataset [set pwatershed true]
  ask patches gis:intersecting sfriver-dataset [set priver true]
  ask patches gis:intersecting sfcboundary-dataset [set pcity true]
  ask patches gis:intersecting sfreservoir-dataset [set preservoir true]
  set sfreservoir patches gis:intersecting sfreservoir-dataset
  set sfcity patches gis:intersecting sfcboundary-dataset
  set-default-shape turtles "circle"

CREATING INTERACTION BETWEEN AGENTS AND ELEVATION:
  let horizontal-gradient gis:convolve elevation-dataset 3 3 [ 1 1 1 0 0 0 -1 -1 -1 ] 1 1
  let vertical-gradient gis:convolve elevation-dataset 3 3 [ 1 0 -1 1 0 -1 1 0 -1 ] 1 1
  set slope gis:create-raster gis:width-of elevation-dataset gis:height-of elevation-dataset gis:envelope-of
elevation-dataset
  set aspect gis:create-raster gis:width-of elevation-dataset gis:height-of elevation-dataset gis:envelope-of
elevation-dataset
  let x 0
  repeat (gis:width-of slope)
  [let y 0
    repeat (gis:height-of slope)
     [let gx gis:raster-value horizontal-gradient x y
      let gy gis:raster-value vertical-gradient x y
      gis:set-raster-value slope x y sqrt ((gx * gx) + (gy * gy))
      ifelse (gx != 0) or (gy != 0)
      [ gis:set-raster-value aspect x y atan gy gx]
      [ gis:set-raster-value aspect x y 0 ]
      set y y + 1]
    set x x + 1]
  gis:set-sampling-method aspect "bicubic_2"
  set gallonsperwateragent 1
  display-elevation
```

```
CREATING INTACTION WITH THE SAND TABLE
  set mPointsX n-values 20 [0]  set mPointsY n-values 20 [0]
  set mouseState "up"
  ct
  crt 1 [set shape "circle" set cursor self set color green ht]
end

to display-elevation
gis:apply-raster elevation-dataset pelevation
  let mine gis:minimum-of elevation-dataset
  let maxe gis:maximum-of elevation-dataset
  let scale 200 / (maxe - mine)   ; lop off top 45 in hue space
  ask patches
    [if  (pelevation <= 0) or (pelevation >= 0)  ; avoids "NaN"
    [set pcolor hsb ((maxe - pelevation) * scale)  210 200]]
end

to restart
  ask waters [die]
  clear-turtles
  clear-all-plots
end


to go
TURTLE MOVEMENT:
 ask turtles with [preservoir != true]
   [if abs xcor > max-pxcor * .98 or abs ycor > max-pycor * .98 [die]
    forward random-normal .8 .8
    let h gis:raster-sample aspect self
    ifelse h >= -360
    [ set heading subtract-headings h 180]
    [ die ]]

SLIDER INTERACTIONS:
  consumewater
  evaporatewater
  infiltratewater
  precipitatewater
  BDD

PLOTS:
  plot-watershed
  plot-river
  plot-city
  tick
  check-mouse
end

to drop-water?
```

```
  if mouse-down?
  [create-waters 1
  [setxy mouse-xcor mouse-ycor
   set size 3
   set color white]]
end




SLIDER INTERACTIONS:
to consumewater
  let dailywaterconsumption ((consumption-rate * population) / (24 * 27154))
  if any? waters with [pcity = true][if count waters with [pcity = true] > dailywaterconsumption[ask n-of
(dailywaterconsumption) waters with [pcity = true] [die]]]
  if any? waters with [priver = true][if count waters with [pcity = true] < dailywaterconsumption[if count
waters with [priver = true] > dailywaterconsumption [ask n-of (dailywaterconsumption) waters with [priver =
true] [die]]]]
  if any? waters with [preservoir = true][if count waters with [priver = true] < dailywaterconsumption[if count
waters with [preservoir = true] > dailywaterconsumption[ask n-of (dailywaterconsumption) waters with
[preservoir = true] [die]]]]
end

to evaporatewater
 if any? waters [if count waters > (evaporation-rate * 565 * 12) [ask n-of (evaporation-rate * 565 * 12) waters
[die]]]
end

to infiltratewater
  if any? waters with [pcity = false][ask n-of (infiltration-rate * 573) waters [hide-turtle]]
  if any? waters with [pcity = true][ask n-of (infiltration-rate * 573 * .1) waters [hide-turtle]]
  if any? waters with [phidden = true][ask n-of (infiltration-rate * 573 * .1) waters [die]]
  ;water in the city infiltrates slower (I chose 50%) because of impermeable barriers
  ;Part of the water that does infiltrate into the city becomes available through municipal and private wells (I
chose 10% arbitrarily)
end

to precipitatewater
 create-waters (precipitation-rate * 565)
  [setxy random-xcor * .98 random-ycor * .98
   set size 3
   set color white]
end

to BDD
  create-waters (BDD-Contribution * 12) / (24 * 365)
  [move-to one-of sfcity
   set size 3
   set color white]
end
```

```
to release-reservoir
  create-waters reservoir-release
  [move-to one-of sfreservoir
   set color white
   set size 3
   forward random-normal .8 .8
   let h gis:raster-sample aspect self
   ifelse h >= -360
   [ set heading subtract-headings h 180]
   [ die ]]
end

to add-water
  create-waters 1200 ;add 100 acre-feet
  [setxy random-xcor * .98 random-ycor * .98
   set size 3
   set color white]
end
```

BUTTON INTERFACE CODE:
```
to display-sfwatershed
  gis:set-drawing-color black
  ;gis:fill sfwatershed-dataset blue
  gis:draw sfwatershed-dataset 2
end

to display-sfcounty
  gis:set-drawing-color brown
  gis:draw sfcounty-dataset 1
end

to display-riogrande
  gis:set-drawing-color black
  gis:draw riogrande-dataset 1
end

to display-sfreservoir
  gis:set-drawing-color black
  gis:draw sfreservoir-dataset 2
end

to display-sfriver
  gis:set-drawing-color black
  gis:draw sfriver-dataset 2
end

to display-sfcboundary
  gis:set-drawing-color brown
```

```
  gis:draw sfcboundary-dataset 2
end

to display-upperwatershed
  gis:set-drawing-color black
  gis:draw upperwatershed-dataset 2
end

to display-sfpopulation
  gis:set-drawing-color black
  gis:draw sfpopulation-dataset 3
end

to check-mouse
  ifelse mouse-xcor > min-pxcor and mouse-xcor < max-pxcor and mouse-ycor > min-pycor and mouse-ycor
< max-pycor
  [set mpointsX lput mouse-xcor but-first mpointsX
   set mPointsY lput mouse-ycor but-first mPointsY
   ifelse variance mPointsX != 0 [set mouseState "down"  ask cursor [setxy mouse-xcor mouse-ycor st]][set
mouseState "up" ask cursor [ht]]]
  [set mouseState "up"]
end

PLOTS:
to plot-river
  plot count waters with [pwatershed = true] / 12
  set-current-plot "City Availability"
end

to plot-watershed
  plot count waters with [priver = true] / 12
  set-current-plot "Watershed Availability"
end

to plot-city
  plot count waters with [pcity = true] / 12
  set-current-plot "River Availability"
end
```

Appendix G: Watershed Model Tutorial

This tutorial provides a thorough step by step description of how to open the Watershed Model onto any given computer.

1. Open the Water Knowledge compact disc to access the files within.
2. Within the compact disc, open the folder named Watershed Model.
3. Install Netlogo by opening the Netlogo 4.1.3 application file within the Netlogo folder.
4. After Netlogo installation is complete, go back into the Water Knowledge CD and open the Watershed Model.nlogo file.

Appendix H: Watershed Model Analysis Tutorial

To begin the BehaviorSpace analysis as described in the methodology, open the Watershed Model within Netlogo. Open the BehaviorSpace tool via the tools tab. When the experiments window opens, click on new to begin creating your own experiment. Rename your experiment as appropriate. The window shows all of the sliders inherent within the model and allows you to set minimum and maximum values along with an increment value. These values mean that the model will run multiple times and will increase the sliders from the minimum value to the maximum value according to the increment amount. If you would like to set the model to run the same variable values more than once then set the repetitions value to reflect how many times you would like it to repeat each run. To make the model record information to be compared to historical information, input the proper code into the section that says "measure runs using these reporters". An example of this would be to have the model count the number of agents total with "count turtles". Next, input your specific setup and go commands (typically "setup" and "go"). Also input any specific stop or final commands. Finally, set the time limit for the model (the amount of ticks which will be completed before moving on to the next run). After your experiment is setup as desired, click ok. Then click on the just created experiment and hit run. A window appears where you can then select what format the model will report the information as. To make the model report the information generated as a Microsoft Excel spreadsheet, select "Table Output" and uncheck "Spreadsheet Output". Finally, click ok on this screen and the model will run your experiment and produce spreadsheets of information. This type of analysis would help to produce information that could be compared with the corresponding historical information by creating graphical representations of the model spreadsheets and combining them with historical graphs.

Appendix I: Sample Phone App Source Code

```
<!DOCTYPE html PUBLIC "-//W3C//DTD HTML 4.01//EN"
"http://www.w3.org/TR/html4/strict.dtd">
<html>
<head>
  <meta content="text/html; charset=ISO-8859-1"
 http-equiv="content-type">
  <title>AppCollectPhoto</title>
</head>
<body>
<img style="width: 394px; height: 355px;"
 alt="Collect Photo Top"
 src="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/AppCollectPhotoTop.jpg"><br>
<img
 style="width: 394px; height: 526px; position: absolute; top: 363px; left: 8px;"
 alt="Collect Photo Bottom"
 src="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/AppCollectPhotoBottom.jpg"><b
r>
<br>
<a
href="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Test%29AppCollectPhoto
Upload.html"><img
 style="border: 0px solid ; position: absolute; top: 559px; left: 67px; width: 279px; height: 45px;"
 alt="Upload Data"
 src="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Upload%20Data%29.jpg">
</a><br>
<a
href="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Test%29AppCollectPhoto
OtherObs.html"><img
 style="border: 0px solid ; position: absolute; top: 491px; left: 58px; width: 304px; height: 44px;"
 alt="Other Observations"
 src="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Other%20Observations%2
9.jpg"></a><br>
<a
href="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Test%29AppCollectPhotoL
abels2.html"><img
 style="border: 0px solid ; position: absolute; top: 446px; left: 58px; width: 302px; height: 45px;"
 alt="Water Level"
 src="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Water%20Level%29.jpg"><
/a><br>
<a
href="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Test%29AppCollectPhotoL
abels.html"><img
 style="border: 0px solid ; position: absolute; top: 402px; left: 58px; width: 303px; height: 44px;"
 alt="Trash"
 src="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Trash%29.jpg"></a><br>
```

```
<a
href="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Test%29AppPicturePostM
ove.html"><img
 style="border: 0px solid ; position: absolute; top: 303px; left: 70px; width: 279px; height: 46px;"
 alt="Capture Image"
src="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Capture%20Image%29.jpg"
></a><br>
<a
href="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Test%29AppMap.html"><i
mg
 style="border: 0px solid ; position: absolute; top: 262px; left: 312px; width: 50px; height: 29px;"
 alt="Map"
src="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Map%29.jpg"></a><br>
<a
href="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Test%29AppOptions.html"
><img
 style="border: 0px solid ; width: 102px; height: 41px; left: 259px; top: 216px; position: absolute;"
 alt="Options"
src="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Options%29.jpg"></a><br>
<a
href="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Test%29AppMyInfo.html">
<img
 style="border: 0px solid ; width: 102px; height: 41px; left: 157px; top: 216px; position: absolute;"
 alt="My Info"
src="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28My%20Info%29.jpg"></a>
</body>
</html>
```

Collect Photo Menu Page

```
<!DOCTYPE html PUBLIC "-//W3C//DTD HTML 4.01//EN"
"http://www.w3.org/TR/html4/strict.dtd">
<html>
<head>
  <meta content="text/html; charset=ISO-8859-1"
 http-equiv="content-type">
  <title>AppMyInfo</title>
</head>
<body>
<img style="width: 394px; height: 423px;" alt="My Info Top"
 src="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/AppMyInfoTop.jpg"><br>
<img
 style="width: 394px; height: 458px; position: absolute; top: 431px; left: 8px;"
 alt="My Info Bottom"
src="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/AppMyInfoBottom.jpg"><br>
<a
href="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Test%29AppMyInfoViewAl
l.html"><img
 style="border: 0px solid ; position: absolute; top: 568px; left: 67px; width: 279px; height: 45px;"
```

```
 alt="View All"
src="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28View%20All%29.jpg"></a>
<br>
<a
href="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Test%29AppMyInfoMyRe
wards.html"><img
 style="border: 0px solid ; position: absolute; top: 386px; left: 56px; width: 303px; height: 45px;"
 alt="My Rewards"
src="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28My%20Rewards%29.jpg">
</a><br>
<a
href="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Test%29AppOptions.html"
><img
 style="border: 0px solid ; position: absolute; top: 216px; left: 259px; width: 102px; height: 41px;"
 alt="Options"
src="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Options%29.jpg"></a><br>
<a
href="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Test%29AppCollectPhoto.
html"><img
 style="border: 0px solid ; position: absolute; top: 215px; left: 58px; width: 102px; height: 43px;"
 alt="Collect"
src="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Collect%29.jpg"></a>
</body>
</html>
```

My Info Menu Page

```
<!DOCTYPE html PUBLIC "-//W3C//DTD HTML 4.01//EN"
"http://www.w3.org/TR/html4/strict.dtd">
<html>
<head>
  <meta content="text/html; charset=ISO-8859-1"
 http-equiv="content-type">
  <title>AppOptions</title>
</head>
<body>
<img style="width: 394px; height: 407px;" alt="Options Top"
 src="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/AppOptionsTop.jpg"><br>
<img
 style="width: 394px; height: 474px; position: absolute; top: 414px; left: 8px;"
 alt="Options Bottom"
src="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/AppOptionsBottom.jpg"><br>
<a
href="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Test%29AppMyInfo.html">
<img
 style="border: 0px solid ; position: absolute; top: 216px; left: 155px; width: 102px; height: 41px;"
 alt="My Info"
src="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28My%20Info%29.jpg"></a><
br>
```

```
<a
href="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Test%29AppCollectPhoto.
html"><img
 style="border: 0px solid ; position: absolute; top: 215px; left: 55px; width: 102px; height: 43px;"
 alt="Collect"
src="http://dl.dropbox.com/u/22380279/PC%20VERSION%202/%28Collect%29.jpg"></a>
</body>
</html>
```

Options Menu