Fall 12-2017

Protecting and Maintaining Silicon Valley's Liquid Gold

Paul Mark Fulcher
San Jose State University

Protecting and Maintaining Silicon Valley's Liquid Gold

by

Paul Mark Fulcher

A Thesis Quality Research Paper
Submitted in Partial Fulfillment of the
Requirements for the
Master's Degree
in

PUBLIC ADMINISTRATION

Professor Frances Edwards, Ph.D.
Adviser

The Graduate School

San Jose State University

December 2017

TABLE OF CONTENTS

LIST OF TABLES

(*Survey & Interview Question Results)*

LIST OF APPENDICES

INTRODUCTION

In 2015, many California residents felt the pain caused by the State's extreme drought conditions (McCullough, 2015). In response, California Governor Jerry Brown issued a mandate requiring all state water agencies to implement a mandatory reduction in urban water use by twenty-five percent (McCullough, 2015). This mandate had a direct impact on the residents of the state.

Woods Hole Oceanographic Institution researchers commented that "Evidence suggests California's drought is the worst in 1,200 years" (McCullough, 2015). In 2015, these extreme drought conditions demonstrated the need for California water agencies to implement new rules that would facilitate successful water management, particularly during times of extreme drought conditions.

California's water use and environmental protection laws are very complex. Nearly half of all the water in California is being used for environmental purposes (McCullough, 2015). Public sector leaders and decision makers in the California water industry have learned from previous severe drought conditions that to sustain water supplies during extremely dry seasons, there is a substantial need for behavioral changes associated with water conservation efforts among the businesses and residents of the community to maintain an adequate water supply. The intent of this study is to compare four California water agencies that have been designated as sustainable groundwater agencies (GSA), and determine what current programs and/or practices those agencies are using to meet the mandated requirements of the Sustainable Groundwater Management Act of 2014 (Act of 2014). Under the Act of 2014, GSAs have been given authority to enforce their GSA approved groundwater

sustainability plan. This study goes on to examine some of the methods that are used by three other water districts, located outside of the state of California. This was done to determine best practices that have been implemented to address severe drought conditions, like the circumstances that Californians experienced from 2010 to 2016; a period when California experienced one of the worst droughts ever recorded in the state's history (McCullough, 2015).

BACKGROUND

One key mission of the Santa Clara Valley Water District (SCVWD) is to ensure an adequate supply of groundwater in the basins they manage. Santa Clara Valley Basin (Basin 2-9) is one of two groundwater basins located in Santa Clara County and managed by SCVWD (Allshouse, 2014). SCVWD's 2010 Urban Water Management Plan emphasizes that extreme drought conditions will present the greatest challenge to Santa Clara Valley's (Valley) groundwater supply. In 2012, SCVWD modified its 2010 Groundwater Management Plan (GWMP) highlighting objectives, strategies, and outcome measures implemented by SCVWD to effectively sustain an adequate water supply in Basin 2-9.

The GWMP describes how SCVWD will administer and maintain detailed documentation of potential negative groundwater impacts and challenges to Basin 2-9 (2012). These challenges include, but are not limited to, increased demand, regulatory changes, emerging concerns of water stakeholders, recharge limitations due to dam restrictions, reduced availability of imported water or other supplies, climate change, and intensified land development (GWMP, 2012).

The GWMP provides a historical overview of how the efforts of SCVWD's water officials have successfully protected and maintained the Valley's groundwater supply, while ensuring that the current and future inhabitants of this Valley continue to have an adequate supply of raw water (GWMP, 2012).

In the 1920s, water levels in Silicon Valley were significantly declining due to severe drought conditions. This decline in the water level caused the ground to subside by more than 13 feet in some of the Valley's basins. Since then, SCVWD has

taken proactive measures to ensure that sustainable water supply is protected and maintained for all its residents, local businesses, and visitors. By the mid-1930s, SCVWD constructed many of its existing reservoirs and dams for banking water during rainy seasons. By the mid-1940s, the District had successfully secured an adequate water supply and could meet the communal water needs during periods of limited rain (GWMP, 2012).

In 1945, after World War II had ended, many of the military veterans migrated to this valley, which was undergoing major population and industrial expansion. SCVWD was not fully prepared to sustain the significant growth of the valley's population in the early 1960s, which increased the industrial and environmental needs beyond the water supply that was accessible at the time, which consisted only of banked surface water from the rainy seasons and groundwater resources. To sustain the community water needs, on November 20, 1961 SCVWD signed its State Water Project water supply contract with the State of California Department of Water Resources. By the end of the 1970s, SCVWD was able to meet the demands from the population increase in the 1960s by importing State Water Project water and using that as an additional source of water for its groundwater recharge program. SCVWD entered into a water supply contract with the Bureau of Reclamation in 1977 (SCVWD, 2012).

In the mid-1980s, northern California was facing serious drought conditions and the SCVWD's existing water supply was not able to sustain the community water needs. Consequently, the valley's surface water and ground water levels were rapidly declining. As a result, there was significant damage, costing Santa Clara County hundreds of millions of dollars in infrastructure damage. This prompted California

water officials to construct an aqueduct system that delivers water from the Feather River area to areas south of the San Francisco-San Joaquin Delta (Carle, 2009).

SCVWD's involvement with the Central Valley Aqueduct Project has given them precedence to purchase imported water from the California Department of Water Resources. Having access to this imported water is essential for the businesses and residents of Silicon Valley, as the purchase of this water ensures that there is a sustainable water supply in the valley's groundwater basin to avoid compaction. In addition to the rights of the water from the State Water Project, SCVWD also produces and procures a small amount of recycled water. It also purchases imported water in the spot market (SCVWD, 2012).

Presently, SCVWD generally obtains Santa Clara County water supplies by tapping into several sources. These sources include local surface and groundwater, imported state water, and imported federal water (2012). However, due to the population and economic growth, environmental mandates and the worst California drought on record, SCVWD is once again dealing with circumstances requiring it to address inadequate water resources in the valley (Lindsey, 2014).

The California Legislature passed the Sustainable Groundwater Management Act in 2014 (ACT 2014). The purpose of ACT 2014 is for California water agencies to create groundwater management plans for the medium to high priority groundwater basins they are responsible for managing.

Under ACT 2014, all California water agencies managing medium to high priority groundwater basins must be designated by the Department of Water Resources (DWR) as a groundwater sustainable agency (GSA). ACT 2014 stipulates

that all designated GSAs must develop and adopt a Groundwater Sustainability Plan (Plan) to protect California's groundwater basins (basins).

Basins are massive pockets of water that develop over thousands of years and form underground. Iacurci (2015) stated that these basins consist of dissolving sediment that include gravel, debris, and sand buildup. The Nature World News' website explained how water goes through an extensive natural filtration process and eventually settles in basins by percolating through the various layers of the earth's surfaces (Iacurci, 2015). Groundwater that ends up in basins is an ideal source of water that offers many communities a sustainable supply during times of extreme drought conditions, when surface water is scarce. However, excess water draw-downs from basins during times when surface water is scarce can lower the groundwater level, causing the land above the basins to subside (Iacurci, 2015). Subsidence is a major concern for water agency officials who manage groundwater basins. Inadequate groundwater levels will trigger land subsidence which can potentially create costly major surface and subsurface infrastructure damage.

Compaction is a concern for water managers as well. Compaction occurs when water is drawn from a groundwater basin to the point where it causes the land to subside. Land subsidence can cause the groundwater basin to compact, meaning that the land collapses into the space left empty by the withdrawal of water, thereby making way for minerals and sediment to compact in the empty space. When compaction occurs, areas that used to store water are permanently lost.

If compaction takes place in a basin area, not only will the water storage capacity for that area decrease, the surrounding land will eventually subside, and the water storage capacity will be lost forever (GWMP, 2012) "With the ongoing drought

in the western United States, particularly California, residents have been relying more heavily on groundwater for their water needs. And yet, even though groundwater is disappearing, there is little to no accurate data about how much water remains in them, so we don't know when we'll run out" (Iacurci, 2015).

LITERATURE REVIEW

Borchers and Carpenter (2014) determined that California government officials have spent billions of dollars repairing infrastructure damage caused by land subsidence. This report further explains that during severe drought conditions, many water agencies that manage groundwater basins depend on their groundwater supply to sustain them. The report presents useful information a) on the necessity for water agencies to maintain an adequate supply of groundwater in their basins, b) on the importance of these water agencies implementing a groundwater sustainability plan that will effectively preserve an adequate water supply to protect the basins against complications related to compaction, and c) on providing the water agencies with a strategy to sustain the community and environmental water needs during extreme drought conditions (Borchers and Carpenter, 2014).

Some regions in California have already experienced subsidence and have taken measures to prevent, or at a minimum limit, this issue in the future. According to Hanak, et al. (2014), Coachella Valley Water District (CVWD) is proactively building a sustainable water supply for the community. The authors explain that CVWD has learned from experience and is currently working to manage the water supply resources better. One of the methods CVWD has incorporated is to produce surface water allocations to recharge groundwater banking more efficiently (Hanak et al., 2014).

Eneva, Adams, Falorni, & Morgan (2012) stated that Imperial Valley, which is in the southeastern part of California, is currently using Interferometry Synthetic Aperture Radar (InSAR) to detect deterioration of the ground water basin that they manage. InSAR is an imaging technique that measures the deterioration of

the Earth and how it's formation and surfaces have changed over time. Water officials at Imperial Valley used InSAR technology to scan the surface of the basins in that region. The InSAR scanned image of Imperial Valley's surface showed a significant amount of deterioration. The deterioration of the basin surface at Imperial Valley is attributed to over-pumping water from the basins in that region (Eneva et al., 2012). According to a 2014 article written in the USGS Scientific Investigation Report, most of the groundwater pumping into Antelope Valley is from the groundwater basin (Siade et al., 2014). Today, the groundwater level has declined by nearly 300 feet in some of the area's basin. Due to this significant decline, Antelope Valley has increased the length of the pumps to draw down water at greater depths in their groundwater basins. This draw down of water has reduced the efficiency of the wells in the valley (Siade et al., 2014), and has had an unfavorable impact, causing the land in that region to subside more than six feet in some areas (Siade et al., 2014).

In 2008, Orange County Water District (OCWD) established the largest Indirect Potable Reuse (IPR) project in the world. (Schwabe and Connor, 2012). IPR is a recycled water treatment process that ensures that treated wastewater meets all regulated drinking water standards. Schwabe and Connor (2012) explained that the recycled wastewater facility in Orange County has successfully produced high quality water that exceeds all regulatory drinking water standards. This study also explained that OCWD can pump water that is treated at their IPR facility into the ground to effectively recharge the groundwater basins, also providing healthy drinking water to OCWD customers (Schwabe and Connor, 2012). This study also provides other water districts, including SCVWD, with a blueprint for the operations and maintenance

involved with running a recycled wastewater facility.

Ferris (2014) asserts that the Arizona Groundwater Management Act (AGMA) is recognized as the United States' most progressive groundwater management law. The implementation of AGMA is a major contributing factor in Arizona's ability to maintain adequate groundwater levels. A significant directive under the AGMA calls for a reduction of groundwater consumption despite rapid population growth (Ferris, 2014). Ferris (2014) goes on to describe strategies that Arizona water officials have considered to reduce relentless mining of groundwater. "We should increase limits on where new wells may be drilled. We should curb groundwater use for new residential subdivisions. We should promote smart growth on land with access to surface water and other renewable supplies" (Ferris, 2014).

Tillman and Leake (2010) describe how gravel, sediment, and sand that have accumulated over many years form irregularly shaped basins in the valleys of Arizona, some of which are more than three miles deep. Much of these basin surfaces are uneven, rigid, and close to mountain fronts near the centers. This raises a concern that mountains typically block the ability to recharge groundwater basins (Tillman and Leake, 2010). The groundwater in Tucson, Arizona has been an essential water supply for their community (Kim, Jiao, and Shum, 2015). This study further discussed the effects of land subsidence potentially leading to compaction of the groundwater basins in this region (Kim, Jiao, and Shum, 2015). The overall rate of groundwater pumping more than the rate of natural recharge was a major cause of aquifer-system compaction and associated land subsidence in the Tucson area (Pool and Anderson, 2008). Since Arizona's 1980 Groundwater Management Act, the temporal variations

of groundwater table, soil compaction, and land subsidence have all been closely monitored. Some of the monitoring efforts include consistently watching gauges in wells, borehole extensometers, and annual GPS surveys at multiple stations (Carruth et al., 2007 and Pool and Anderson, 2008, cited in Kim, Jiao, and Shum, 2015).

According to Fishman (2009), Las Vegas has a robust program for limiting water use inside and outside. Resort owners in the city have constructed water recycling plants onsite, while also sending out their laundry to a central facility that has 100% water recycling. Such extreme conservation measures are essential due to persistent drought conditions in the region, where most of its water comes from an allocation of the ever-dwindling Colorado River. Fishman (2009) notes that tourists go to Las Vegas for the luxurious accommodations and the resort owners do not have to limit the occupants' use of water because of the rigorous conservation measures. This is mainly attributed to the resort owners building a recycling water system on campus. Another conservation effort in Las Vegas is the use of recycled irrigation water on the golf courses and water fountains throughout the city (Fishman, 2009).

. Like other water districts in the western United States, Las Vegas experiences land subsidence that "is directly associated with pumping excess groundwater during drought conditions" (Bell, 2002 in Zhang et al., 2012). Deformation and surface faults can cause many other adverse geographical effects, including cracking of the earth terrain (Holder 1984b in (Galloway and Burbey, 2011). Zhang (2012) notes that destructive cracks in the earth's surface can allow dangerous toxins to enter the basins' groundwater supply (2012).

METHODOLOGY

Research Design

A mixed method approach was used to determine whether there are sustainable groundwater practices that are applied by Groundwater Sustainable Agencies (GSA) which currently add value to water districts operating in areas prone to compaction. The data gathered for this research was obtained from the technical experts at the agencies identified in this study. The tools used to get feedback from these experts included surveys, interview questions, and benchmarking.

Surveys for this study were created using Survs, an online survey application. Survs allowed for distribution of the three surveys that were used for this study by email to the groundwater management professionals at each of the four California GSAs examined in this study. In addition to the three surveys, 16 standard interview questions were also sent to the GSAs. The same three surveys and interview questions were correspondingly sent to the three other water agencies that are outside of California, located in Arizona and Nevada.

Responses to three surveys offered good qualitative and quantitative data. This data provided enough detail to demonstrate the opinions, plans, and practices of GSAs. The surveys were useful tools to obtain pertinent information from the water agencies identified for this study. The surveys were also useful in understanding conservation efforts and practices used by GSAs to address conservation/marketing, monitoring, and management of their groundwater basin(s) that they manage. The three surveys are in the appendices section of this study.

Selected California Groundwater Sustainable Agencies

Coachella Valley Water District

The Coachella Valley Water District (CVWD) has learned from experience the importance of a secure and adequate supply of groundwater during times of drought. Located in southern California, Coachella Valley is a region, like Santa Clara Valley, that is facing threats of inadequate groundwater levels. Between 1936 and 1967, Coachella Valley's groundwater draw-downs resulted in significant land subsidence (Tyley, as cited in Hanak et al., 2014).

The Imperial Irrigation District

In late 2008, the Imperial Irrigation District's (IID) Board directed staff to establish an Integrated Regional Water Management Plan (IRWMP, 2015). One of the key objectives of the IRWMP was to identify relevant local laws and/or stipulations, to ensure that methods they intended to use to augment water supplies were appropriate (IRWMP, 2015). Some of the proposed methods of securing adequate water supplies included banking rain water, recycling wastewater, and desalination of sea water (2015). The IRWMP will be a good source for studying various cost-related impacts of innovative water supply strategies, including recycled water and water desalination, environmental impacts of certain approaches, and outcomes of the innovative techniques that have been implemented, particularly with water desalination.

Antelope Valley-East Kern Water Agency (AVEK)

AVEK Water Agency is located fifty miles northeast of Los Angeles. AVEK operates and manages a groundwater basin that is approximately 940 square miles. By 1972, AVEK pumped more than 90% of its total water supply from the groundwater basin

(Siade et al., 2014). The Antelope foothills are up to 3,500 feet above sea-level. IAVEK provided very helpful feedback on the sixteen interview questions. It was also helpful to get feedback on implementation of groundwater management operations best practices.

Orange County Water District

The Orange County Water District, located in Southern California, uses hydrograph technology to measure their groundwater levels. A lack of surface water has led to a program that recycles 100% of their processed water to sustain the groundwater assets (Schwabe and Connor, 2012). Their GWMP serves as a useful benchmark.

Selected Groundwater Management Agencies in Nevada and Arizona

The research method used to gather qualitative data included direct questions that were sent to groundwater experts that manage groundwater basins in Las Vegas, Nevada and Tucson, Arizona. The water districts in these western United States regions already have groundwater management strategies and plans in place, as these organizations have learned from experience that it is essential to ensure that there are protective programs in place to effectively manage and sustain groundwater levels. Thus, the three water agencies in these regions offer programmatic information and strategies to help California water agencies better manage and sustain adequate groundwater levels.

Arizona Department of Water Resources

By the 1970s, it was observed that historical groundwater pumping in Arizona had caused land subsidence up to six meters in some areas (Tillman and Leake, 2010).

In 1980 groundwater in Maricopa County, Arizona [Phoenix metropolitan area] was being pumped from the groundwater basin at thirty times the rate it was being replenished through rain and snow each year (Ferris, 2014). In June of 1980, the Arizona Groundwater Management Act (AGMA) was passed, identifying the state's most heavily populated areas as Active Management Areas (AMAs). Under AGMA, these areas were restricted from excess water draw downs, despite the growth in population (Ferris, 2014).

Metropolitan Water District in Tucson, Arizona

As a desert community, Tucson relies on ground water to supply its population. Limited rain fall has resulted in the need to conserve water in the groundwater basin. Tucson uses sophisticated technology for monitoring and maintaining its basin (Kim, Jiao, and Shum, 2015), which might be worthwhile for SCVWD to adopt as part of its GWMP.

Las Vegas Valley Water District, Nevada

Like many California water agencies, Las Vegas Valley Water District (LVVWD) has been using InSAR technology to understand the formation of the basins they manage in that region (Zhang, et al., 2012). Since 1993 the land in Las Vegas has subsided by more than 1.5 meters because of excessive water draw downs. This report recognizes many strategies that LVVWD is using to manage their groundwater supply (Zhang, et al., 2012), some of which might be beneficial to developing the SCVWD's GWMP.

Other Research Design

Sixteen interview questions **(**Appendix B**)** were developed after meeting with key SCVWD groundwater management staff, who are responsible for mapping out the business processes of groundwater management. Based on these preliminary discussions, important elements associated with groundwater management were identified, as well as potential gaps that SCVWD has concerning some of the mandates under the Sustainable Groundwater Management Act of 2014. The responses to the interview questions are useful in understanding what water agencies that have dealt with severe drought conditions are doing to ensure that they meet the needs of the community that they serve.

Groundwater Management Process Overview - Figure 1:

Inputs	Outputs		Outputs – Impact	
	Activities	*Participation*	*Short*	*Long*
Ground Water Management	Water level Modeling	Water Monitoring policies	Compare what other water districts are doing to Implement a program / policy / process to sustain safe groundwater levels in the basins	Have a process in place to continuously pump a portion of recycled water into the groundwater basin to recharge the basins
Water supply	Imported State water (Delta) Imported Federal Water (Central Valley Project)	Water districts to encourage Retailers to use alternatives to ground water draw-downs	Sell treated water to retailers at a discounted rate (slightly less than cost to pump water) to stop water draw-downs from groundwater basins	Secure a supply of potable water to sustain the basins during extreme drought conditions
Establish programs/policies to effectively address inadequate groundwater levels	Research what other water districts that manage basins are doing to ensure adequate ground water levels	Get buy in from focus group/decision makers; Implement appropriate changes to the current programs/policies	Incorporate regulatory compliance to address low groundwater level; reduce the percentage of water that can draw down from basins	Establish a recycled water treatment facility for golf courses irrigation and re-charge basins during times of extreme drought conditions

Assumptcions to keep in mind:

- If groundwater levels are not as adequate as other water districts, SCVWD is not doing a good job managing their basins.

- If groundwater levels are dropping more rapidly than other water districts SCVWD programs are not as effective as programs at other water agencies.

External Factors to consider:

- Are other water districts doing anything more effective to address inadequate groundwater levels?
- Are other water districts doing anything less effective to address groundwater levels?
- Are other water districts doing what SCVWD is doing to address inadequate groundwater levels?

FINDINGS

Survey & Interview Question Results

Interviews using sixteen questions, and three topical surveys, were sent to all California water agencies identified in this study. Not all agencies responded to every question. The responses from the surveys and the questions formed the basis for the research Findings, and recommendations to SCVWD on further developing its Groundwater Management Plan that the California Department of Water Resources required from all Groundwater Sustainable Agencies (GSA).

The surveys and questions were also sent to the three water agencies identified in this study that are outside of the California boarder, but within the Western United States. LVWD is the only one of the three water agencies outside the state of California that provided responses to the surveys and questions. LVWD, like many other water agencies in the Western United States, was also impacted by the recent severe drought conditions that lasted from 2010 to 2016. LVWD's responses to the surveys and questions offer a great insight on water conservation efforts that adhere to rigid regulatory requirements, like those included California GSAs that are held to via the Act of 2014. LVWD has historically experienced difficult drought conditions, and has since implemented many practices that have prevented subsidence of the basins in that region. A few of the practices include recycling water, obtainig water from alternative sources, and conducting water conservation marketing/campaigning efforts for the local community. The practices incorporated by LVWD allowed them to successfully sustain an adequate water level in their basins because of the proactive approach they have taken to effectively educate and inform the local community of potential risks of over-use of water which could cause the basins in that region to compact.

The feedback that was provided from three of the four GSAs identified in this study demonstrated that the typical level of education required in the groundwater profession was at an advanced level, with ample experience and expertise. Orange County Water District (OCWD) are pioneers of advanced recycled water treatment in the state of California. The Santa Clara Valley Water District (SCVWD) also operates and maintains an advanced recycle water treatment plant. These two California GSAs also employ groundwater professionals who are highly educated, and experienced, and are considered renown among water officials in the United States, and even around the world, as both the SCVWD and OCWD practice innovative water reuse - recycling methods successfully. The other California GSA that responded provided details of their experience of significant water shortages due to excessive pumping of water out of their aquifer, because of extreme drought conditions.

There was an interesting observation among the four GSAs is their response to interview question number 13: *Do you believe that the groundwater supply in the basin(s) managed by your agency is in danger of causing subsidence/compaction?* The responses provided by three GSAs revealed the importance of effectively managing groundwater basins to prevent or limit the possibility of subsidence, which can lead to compaction. Additionally, GSAs have a good understanding of how important it is to implement alternative water uses, particularly during times of severe drought conditions.

According to Hutchinson (2016), OCWD has successfully operated and maintained their advanced recycle water treatment plant system. Interestingly, according to Hutchinson, the recent California five-year drought did not have an impact on the use, or cost, of clean and safe drinking water for Orange County businesses, and residents. (Hutchinson, 2016).

There is room for debate about whether establishing a recycled water treatment plant adds value for the community or has a diminished return to the rate payers, as the financial burden may not be feasible for some of the businesses and/or residents of Silicon Valley. Responses provided by Hutchinson demonstrate the value added of operating and maintaining a recycled water treatment plant, particularly during severe drought conditions.

Interview question number five asks, *How has the community reacted to the water cutbacks?* Of the three California GSAs that responded to the interview questions, OCWD, as the region's water wholesaler, did not restrict water-use. However, according to Hutchinson's response, "*the retailers are the ones that offered incentives to the community for reduced water use"* (2016).

SCVWD has an exceptional group of employees in the groundwater management and water conservation units. These staff are dedicated to ensuring that the groundwater basins in Silicon Valley are effectively managed, preventing compaction from occurring. Additionally, SCVWD water conservation staff proactively informs the local community of all water conservation matters, including the criticality of effectively operating, managing, and maintaining adequate water levels that meet set water level targets in the basins. SCVWD's conservation team also informs the local community of how they can help meet these goals. SCVWD's water conservation program also provides the community with great incentives to address drought conditions. These incentives include water conservation related rebates, tools, and discounts to aid the residents and businesses in protecting the Santa Clara County basins from subsidence/compaction. By incorporating these water conservation efforts, in 2016, the SCVWD influenced nearly 30% reduction in water use.

CVWD's response to this question specified that the community had mixed emotions, and some of the members of the public did not support cutbacks. This raises qualitative concerns that CVWD must address with the community to ensure they come up with methods of managing water levels in the aquifer they are authorized to maintain. To do so, CVWD has delivered training to educate the community about the severe drought conditions and the potential impacts. "As a result of the drought emergency, we implemented a 36% reduced water budget for all of our urban customers and we adopted drought penalties. It is important to note that we are in the desert and therefore always in a drought. The drought did not change our situation. However, the state implemented restrictions, and we followed them" (Reyes, 2017).

LVWD implied that they did not limit water use in the community. LVWD took a strategic approach to address the necessity to reduce water use. LVWD's method of addressing the mandatory water cutbacks involved educating the community, limiting irrigation water-use, establishing applicable policies, and prohibiting development/construction.

TABLE A-1: GROUNDWATER MANAGEMENT:

No.	Question	Selected Response	Agency 1	Agency 2	Agency 3	Agency 4
1	Which other organizations does your agency partner up with to manage your basin(s)?	A.City				
		B.County				
		C.Another water agency				
		D.Multiple water agencies	X	X	X	X

No.	Question	Selected Response	Agency 1	Agency 2	Agency 3	Agency 4
2	How well does your agency maintain historical groundwter data of the basin(s) it manages?	A.Somewhat maintained				
		B.New choice				
		C.Well maintained				X
		D.Very well maintained	X	X	X	

No.	Question	Selected Response	Agency 1	Agency 2	Agency 3	Agency 4
3	3. How successful do you feel your agency's groundwater management plan has been in managing your basin?	A.Not Successful				
		B.Somewhat Successful				
		C.Successful				
		D.Very Successful	X	X	X	X

No.	Question	Selected Response	Agency 1	Agency 2	Agency 3	Agency 4
4	How well does your agency maintain the statistical data on the Groundwater levels of the basin(s) it manages?	A.Not maintained at all				
		B.Somewhat maintained				
		C.Well maintained				
		D.Very well maintained	X	X	X	X

No.	Question	Selected Response	Agency 1	Agency 2	Agency 3	Agency 4
5	Copy of How well does your agency maintain the statistical data on the Groundwater levels of the basin(s) it manages?	A.Not maintained at all				
		B.Somewhat maintained				
		C.Well maintained				
		D.Very well maintained	X	X	X	X

TABLE A-2: GROUNDWATER MONITORING:

No.	Question	Selected Response	Agency 1	Agency 2	Agency 3	Agency 4
1	How successfully has your agency managed statistical data on the land subsidence levels of the basin(s) it manages?	A. Not Successful				
		B. Somewhat Successful				
		C. Successful				
		D. Very Successful	X	X	X	X

No.	Question	Selected Response	Agency 1	Agency 2	Agency 3	Agency 4
2	How successfully has your agency managed statistical data on the projected water demands and supplies of the basin(s) it manages?	A. Not Successful				
		B. Somewhat Successful				
		C. Successful				
		D. Very Successful	X	X	X	X

No.	Question	Selected Response	Agency 1	Agency 2	Agency 3	Agency 4
3	How successfully has your agency managed statistical data on the geographical details of the groundwater basin area and boundaries of the basin(s) it manages?	A. Not Successful				
		B. Somewhat Successful				
		C. Successful				
		D. Very Successful	X	X	X	X

No.	Question	Selected Response	Agency 1	Agency 2	Agency 3	Agency 4
4	How successfully has your agency managed statistical data on the Groundwater sustainability agencies that overlie or partner up with the basin(s) you manage?	A. Not Successful				
		B. Somewhat Successful				
		C. Successful				
		D. Very Successful	X	X	X	X

No.	Question	Selected Response	Agency 1	Agency 2	Agency 3	Agency 4
5	How successfully has your agency managed statistical data on the basin(s) recharge areas of the basin(s) you manage?	A. Not Successful				
		B. Somewhat Successful				
		C. Successful				
		D. Very Successful	X	X	X	X

No.	Question	Selected Response	Agency 1	Agency 2	Agency 3	Agency 4
6	How successfully has your agency managed statistical data on the geography of all existing recharge areas that can replenish the basin(s) you manage?	A. Not Successful				
		B. Somewhat Successful				
		C. Successful				
		D. Very Successful	X	X	X	X

TABLE A - 3: GROUNDWATER MARKETING/CONSERVATION

No.	Question	Selected Response	Agency 1	Agency 2	Agency 3	Agency 4
1	How effective do you feel the amount that your agency spent on marketing was in reducing water use in your jurisdiction in 2011?	A. Did not spend any money on marketing				X
		B. Somewhat Effective				
		C. Effective				
		D. Very Effective	X	X	X	

No.	Question	Selected Response	Agency 1	Agency 2	Agency 3	Agency 4
2	How much has your agency spent on water conservation sponsorship efforts in 2011?	A. Less than $100,000	X	X	X	X
		B. $100,000 to $200,000				
		C. $200,000 to $500,000				
		D. $500,000 to $1,000,000				
		E. More than $1,000,000				

No.	Question	Selected Response	Agency 1	Agency 2	Agency 3	Agency 4
3	How much has your agency spent on promoting water conservation in 2011?	A. Less than $100,000		X	X	No Response
		B. $100,000 to $200,000				
		C. $200,000 to $500,000				
		D. $500,000 to $1,000,000				
		E. More than $1,000,000	X			

No.	Question	Selected Response	Agency 1	Agency 2	Agency 3	Agency 4
4	How effective do you feel the amount that your agency spent on marketing was in reducing water use in your jurisdiction in 2012?	A. Did not spend any money on marketing				X
		B. Somewhat Effective			X	
		C. Effective	X	X		
		D. Somewhat Effective				

No.	Question	Selected Response	Agency 1	Agency 2	Agency 3	Agency 4
5	How much has your agency spent on promoting water conservation in 2012?	A. Less than $100,000		X	X	No Response
		B. $100,000 to $200,000				
		C. $200,000 to $500,000				
		D. $500,000 to $1,000,000				
		E. More than $1,000,000	X			

No.	Question	Selected Response	Agency 1	Agency 2	Agency 3	Agency 4
6	How effective do you feel the amount that your agency spent on marketing was in reducing water use in your jurisdiction 2013?	A. Did not spend any money on marketing				No Response
		B. Somewhat Effective				
		C. Effective			X	
		D. Very Effective	X	X		

No.	Question	Selected Response	Agency 1	Agency 2	Agency 3	Agency 4
7	How much has your agency spent on promoting water conservation in 2013?	A. Did not spend any money on marketing				No Response
		B. Somewhat Effective				
		C. Effective				
		D. Very Effective	X			

No.	Question	Selected Response	Agency 1	Agency 2	Agency 3	Agency 4
8	How much has your agency spent on promoting water conservation in 2014?	A. Less than $100,000		X	X	No Response
		B. $100,000 to $200,000				
		C. $200,000 to $500,000				
		D. $500,000 to $1,000,000				
		E. More than $1,000,000	X			

No.	Question	Selected Response	Agency 1	Agency 2	Agency 3	Agency 4
9	How much has your agency spent on promoting water conservation in 2014?	A. Less than $100,000		X	X	No Response
		B. $100,000 to $200,000				
		C. $200,000 to $500,000				
		D. $500,000 to $1,000,000				
		E. More than $1,000,000	X			

ANALYSIS & CONCLUSION

The intent of this study is to compare California water agencies that have been designated as groundwater sustainable agencies (GSA), and to determine what current programs and/or practices they are using to meet the mandated requirements of the Sustainable Groundwater Management Act of 2014 (ACT, 2014) that created the GSA designation. Three other water agencies outside of the state were also contacted in this study to understand what practices water management agencies, outside of the GSA regime, have incorporated after lessons learned from past severe drought conditions in their region. Only one of these agencies responded.

Three surveys and sixteen questions were sent to the four GSAs identified in this study. Responses to the surveys and questions provided a good understanding from the perspective of public sector groundwater management and water conservation professionals, and some of the practices GSAs have implemented to address regulatory requirements stated in the ACT 2014 that GSAs must adhere to.

Based on the results of the surveys, water conservation and marketing efforts have been extremely successful and are paying off for the water districts who engage their community. The interview questions provided many clarifications on the results of the surveys. For example, budgetary amounts allocated towards conservation efforts varied significantly among the water districts identified in this study.

Another observation was the responses regarding the positive results of educating the local community on conservation efforts. This will keep water rates affordable, since Governor Jerry Brown signed an executive order that imposes a mandatory water restriction to address the severe drought conditions. The sixteen interview questions noted in Appendix B were developed to solicit information on all aspects of groundwater, including

management, monitoring and conservation matters, and required training and education for groundwater professionals.

Cost Effectiveness

Upon initial observation of the costs associated with implementing effective groundwater management practices in the nine mandated programs stated in the Sustainable Groundwater Management Act in 2014, certain factors should be considered to ensure that associated program costs are accurately reflected. To effectively evaluate costs associated with groundwater management efforts, a deep understanding of the groundwater management operations is essential.

The results of the water conservation and marketing survey appear to illustrate that water districts that allocate more than $1,000,000 dollars towards water conservation efforts do not appear to benefit in the short term more than water districts that have allocated less than $100,000 towards water conservation efforts. Responses to the sixteen interview questions revealed that water districts that have a conservation budget of more than $1,000,000 have a substantial successful rebate program that has saved that agency millions of dollars on water costs during severe drought conditions. This represents two different strategies: educating the public to use less water, which has to be repeated annually, and equipping the public with new fixtures that inherently use less water and generally represent a one-time investment. This would include low flow toilets and new shower heads.

Community Impact

Considering the technological advances currently available, groundwater basins, although essential, are not as indispensable as they once were. The Groundwater Unit Manager at one of the responding agencies stated, “Groundwater is not as substantial as it once was. Newly developed infrastructure allows for other avenues to provide clean and safe drinking water to

the community". This includes the new recycling technologies that allow for indefinite reuse of water.

Recommendation

The SCVWD has been recognized as a leader of the water industry for many years. The operational practices performed by the groundwater professionals at the SCVWD represent an innovative approach in the managing, monitoring and conserving groundwater. According to the SCVWD's Water Conservation Manager, the SCVWD has nearly 20 water conservation programs that offer a variety of incentives for consumers. Some of the incentives include rebates, one-hour consultation, free water conservation devices and installation, and site surveys. Another great program offered through the SCVWD's Water Conservation Program is the water conservation education outreach program. This program takes a proactive approach to educating the community about ways to effectively reduce water consumption in homes, businesses and even for agricultural uses.

Responses to the three surveys and the sixteen interview questions suggest that the SCVWD groundwater management staff should continue their current groundwater management, monitoring and marketing practices. The results of this research also demonstrate that the SCVWD should continue pursuing recycling water efforts to successfully sustain an adequate amount of water in their groundwater basins. The basis of this recommendation is to avoid the potential of a devastating impact to Silicon Valley's basins during seasons of severe drought conditions.

While there were no activities being conducted in the surveyed organizations that differed significantly from the current practices of SCVWD, it is essential for SCVWD staff to continue monitoring water agency best practices for basin management. SCVWD and its retailers rely heavily on water imported from both the State Water Project (SWP) and the

Central Valley Project (CVP). This makes SCVWD and its retailers vulnerable to changes in federal wildlife preservation/endangered species policy that impacts the availability of water from the CVP. It also remains vulnerable to a drop in supply to the SWP based on drought conditions in the state.

Finally, the SCVWD must continue its public education efforts even in wet years, as the basin's ground water storage is not full, and future droughts are inevitable in California. Developing an ever more robust ground water supply and a more conservation conscious public is the only way to balance supply and demand for water in Silicon Valley into the future.

APPENDIX A

APPENDIX A-1: Groundwater Management Strategies

The survey questions in this category will address the cost associated with any marketing strategies used to educate and inform the constituency of the current with the serious drought condition we are facing in California.

1. Which other organizations does your agency collaborate up with to manage your basin(s)?

A. City
B. County
C. Another water agency
D. Multiple water agencies

2. How well does your agency maintain historical groundwater data of the basin(s) it manages?

A. Somewhat maintained
B. New choice
C. Well maintained
D. Very well maintained

3. How successful do you feel your agency's groundwater management plan has been in managing your basin?

A. Not Successful
B. Somewhat Successful
C. Successful
D. Very Successful

4. How well does your agency maintain the statistical data on the Groundwater levels of the basin(s) it manages?

A. Not maintained at all
B. Somewhat maintained
C. Well maintained
D. Very well maintained

5. Copy of How well does your agency maintain the statistical data on the Groundwater levels of the basin(s) it manages?

A. Not maintained at all
B. Somewhat maintained
C. Well maintained
D. Very well maintained

APPENDIX A

APPENDIX A-2: Groundwater Monitoring Strategies

The survey questions in this category will address how groundwater basins are monitored. It is anticipated that the responses to these survey questions will provide information from standard documentation retained by sustainable groundwater agencies.

1. How successfully has your agency managed statistical data on the land subsidence levels of the basin(s) it manages?

A. Not Successful
B. Somewhat Successful
C. Successful
D. Very Successful

2. How successfully has your agency managed statistical data on the projected water demands and supplies of the basin(s) it manages?

A. Not Successful
B. Somewhat Successful
C. Successful
D. Very Successful

3. How successfully has your agency managed statistical data on the geographical details of the groundwater basin area and boundaries of the basin(s) it manages?

A. Not Successful
B. Somewhat Successful
C. Successful
D. Very Successful

4. How successfully has your agency managed statistical data on the Groundwater sustainability agencies that overlie or collaborate up with the basin(s) you manage?

A. Not Successful
B. Somewhat Successful
C. Successful
D. Very Successful

5. How successfully has your agency managed statistical data on the basin(s) recharge areas of the basin(s) you manage?

A. Not Successful
B. Somewhat Successful
C. Successful
D. Very Successful

6. How successfully has your agency managed statistical data on the geography of all existing recharge areas that can replenish the basin(s) you manage?

A. Not Successful
B. Somewhat Successful
C. Successful
D. Very Successful

APPENDIX A

APPENDIX A-3: Groundwater Conservation/Marketing Strategies

The survey questions in this category will address how groundwater basins are managed. It is anticipated that the responses to these survey questions will provide information from standard documentation retained by sustainable groundwater agencies.

1. How effective do you feel the amount that your agency spent on marketing was in reducing water use in your jurisdiction in 2011?

A. Did not spend any money on marketing
B. Somewhat Effective
C. Effective
D. Very Effective

2. How much has your agency spent on water conservation sponsorship efforts in 2011?

A. Less than $100,000
B. $100,000 to $200,000
C. $200,000 to $500,000
D. $500,000 to $1,000,000
E. More than $1,000,000

3. How much has your agency spent on promoting water conservation in 2011?

A. Less than $100,000
B. $100,000 to $200,000
C. $200,000 to $500,000
D. $500,000 to $1,000,000
E. More than $1,000,000

4. How effective do you feel the amount that your agency spent on marketing was in reducing water use in your jurisdiction in 2012?

A. Did not spend any money on marketing
B. Somewhat Effective
C. Effective
D. Somewhat Effective

5. How much has your agency spent on promoting water conservation in 2012?
A. Less than $100,000
B. $100,000 to $200,000
C. $200,000 to $500,000
D. $500,000 to $1,000,000
E. More than $1,000,000

6. How effective do you feel the amount that your agency spent on marketing was in reducing water use in your jurisdiction 2013?

A. Did not spend any money on marketing
B. Somewhat Effective
C. Effective
D. Very Effective

7. How much has your agency spent on promoting water conservation in 2013?

A. Less than $100,000
B. $100,000 to $200,000
C. $200,000 to $500,000
D. $500,000 to $1,000,000
E. More than $1,000,000

8. How effective do you feel the amount that your agency spent on marketing was in reducing water use in your jurisdiction 2014?

A. Did not spend any money on marketing
B. Somewhat Effective
C. Effective
D. Very Effective

9. How much has your agency spent on promoting water conservation in 2014?

A. Less than $100,000
B. $100,000 to $200,000
C. $200,000 to $500,000
D. $500,000 to $1,000,000
E. More than $1,000,000

APPENDIX B

APPENDIX B: Sixteen Interview Questions

1. What training and education do you have related to groundwater management?

2. What are some outreach efforts that your agency implemented to address the extreme drought conditions?

3. How have the outreach efforts been successful in sustaining adequate groundwater levels?

4. Is your agency offering any incentives/grants to assist the community with strategies to reduce water use?

5. How has the community reacted to the water cutbacks?

6. Does your agency have a groundwater management plan in place?

7. What are some of the significant problems and strategies your agency has addressed in the groundwater management plan?

8. Have any of the strategies been implemented, if so, what has the outcome been to date?

9. Does your agency work with other local public entities to address low water levels in the basin(s) your agency manages?

10. Does your agency have a recycled water facility in place? If so, how helpful has the facility been for your agency during the current extreme drought conditions?

11. How has the community reacted to the recycled water facility?

12. What do you do with the recycled water?

13. Do you believe that the groundwater supply in the basin(s) managed by your agency is in danger of causing subsidence/compaction?

14. Is your agency doing anything different then what has been done in the past to address our current drought conditions?

15. Are there any unique strategies your agency has implemented to address the current extreme drought conditions?

16. Is there any information you can recommended that I include in my study that you believe useful to other water agencies in California?

Consulted Sources

Asano, T. (Ed.). (2016). *Artificial recharge of groundwater*. E-Book. Elsevier.

Borchers, J. W., & Carpenter, M. (2014). Land Subsidence from Groundwater use in California. *California Water Foundation Full Report of Findings/April 2014, 151*

Butler, E. W., & Pick, J. B. (2012). *Geothermal Energy Development: Problems and Prospects in the Imperial Valley of California.* Springer Science & Business Media.

Cooper, D. J., Wolf, E. C., Ronayne, M. J., & Roche, J. W. (2015). Effects of Groundwater Pumping on the Sustainability of a Mountain Wetland Complex, National Yosemite National Park, California. *Journal of Hydrology*:*Regional Studies*, vol. 3, March 2015, p. 87-105. Retrieved from http://dx.doi.org/10.1016/j.ejrh.2014.10.002

Endo, T. (2015). Groundwater Management: A Search for Better Policy Combinations. *Water Policy, 17*(2), 332-348.

Eneva, M., Adams, D., Falorni, G., & Morgan, J. (2012). Surface Deformation in Imperial Valley, CA, from Satellite Radar Interferometry. *Geoth.Resour.Counc.-Trans, 36*, 1339-1344.

Evidence suggests California's drought is the worst in 1,200 years. (2014). Woods Hole Oceanographic Institute. Retrieved from https://www.whoi.edu/news-release/California-drought

Ferris, K. (2014). Groundwater management: Why it still Matters. Artizona Municipal Waters Users Association. Retrieved from https://amwua.wordpress.com/2014/06/09/groundwater-management-why-it-still-matters/

Funding sustainable groundwater management in California. (2014). California Water Blog. Retrieved from https://californiawaterblog.com/2014/04/03/funding-sustainable-groundwater-management-in-california/

Galloway, D. L., & Burbey, T. J. (2011). Review: Regional Land Subsidence Accompanying Groundwater Extraction. *Hydrogeology Journal, 19*(8), 1459-1486.

González, P. J., & Fernández, J. (2011). Drought-Driven Transient Aquifer Compaction Imaged Using Multitemporal Satellite Radar Interferometry. *Geology, 39*(6), 551-554.

Hernandez-Marin, M., & Burbey, T. J. (2010). Controls on Initiation and Propagation of Pumping-Induced Earth Fissures: Insights from Numerical Simulations. *Hydrogeology Journal, 18*(8), 1773-1785.

Iacurci, J. (2015). Earth's Biggest Groundwater Basins are in Trouble. *Nature World News.* Retrieved from http://www.natureworldnews.com/articles/15224/20150617/earths-biggest-groundwater-basins-are-in-trouble.htm

Imperial integrated regional water management plan. (2015). Imperial Irrigation District. Retrieved from http://www.iid.com/water/water-supply/water-plans/imperial-integrated-regional-water-management-plan

Kasmarek, M. C. (2012). Hydrogeology and Simulation of Groundwater Flow and Land-Surface Subsidence in the Northern Part of the Gulf Coast Aquifer System, Texas, 1891-2009. Scientific Investigations Report 2010-5154. US Geological Survey. Retrieved from https://pubs.usgs.gov/sir/2012/5154/ .

Kim, J., Lu, Z., Jia, Y., & Shum, C. K. (2015). Ground Subsidence in Tucson, Arizona, Monitored by Time-Series Analysis Using Multi-Sensor InSAR Datasets from 1993 to 2011. ISPRS Journal of Photogammetry and Remote Sensing, vol. 107, Sept. 2015, p. 126-141. Retrieved from http://dx.doi.org/10.1016/j.isprsjprs.2015.03.013

Lasserre, F. (2015). Water in Las Vegas: Coping with Scarcity, Financial and Cultural Constraints. *City, Territory and Architecture*, *2*(1), 11.

Leake, S. A., & Galloway, D. L. (2010). Use of the SUB-WT Package for MODFLOW to

Simulate Aquifer-System Compaction in Antelope Valley, California, USA. Paper presented at the Land Subsidence, Associated Hazards and the Role of Natural Resources Development: Proceedings of the Eighth International Symposium on Land Subsidence: Queretaro, Mexico, International Association of Hydraulic Sciences, 61-67.

Lindsey, R. (2014). California facing worst drought on record. NOAA, Climate.gov. Retrieved from https://www.climate.gov/news-features/event-tracker/california-facing-worst-drought-record

McCullough, M. M. S. (June 2015). The drought in California: recent history, legislation and regulation, and the effects on golf courses. Golf Course Superintendents Association of America, *Golf Course Management Magazine*. Retrieved from http://www.gcsaa.org/gcm-magazine/2015/june/the-drought-in-california

Miller, M. M., & Shirzaei, M. (2015). Spatiotemporal Characterization of Land Subsidence and Uplift in Phoenix Using InSAR Time Series and Wavelet Transforms. *Journal of Geophysical Research: Solid Earth*, *120*(8), 5822-5842.

Mount, J. & Hanak, E. (2016). Water Use in California. Public Policy Institute of California. Retrieved from http://www.ppic.org/main/publication_show.asp?i=1108

Nagourney, A. (2015). California imposes first mandatory water restrictions to deal with drought. *The New York Times*. Retrieved from http://www.pacificariptide.com/files/california-imposes-first-mandatory-water-restrictions-to-deal-with-drought.pdf

Narasimhan, T. N. (2009). Groundwater: from mystery to management. *Environmental Research Letters*, *4*(3), 035002.

Perez, R., & Ruiz, C. (2011). Groundwater: Solution to the Las Vegas water problem? University of Nevada, Las Vegas. Retrieved from http://digitalscholarship.unlv.edu/cgi/viewcontent.cgi?article=1038&context=focs_ug_research

Robinson, E. (2014). California Mandates Groundwater Regulation Through Local "Sustainability plans" starting in 2020. Kronick, Moskovitz, Teideman & Girard.

Retrieved from http://www.kmtg.com/node/3444

Scanlon, B. R., Faunt, C. C., Longuevergne, L., Reedy, R. C., Alley, W. M., McGuire, V. L., & McMahon, P. B. (2012). Groundwater Depletion and Sustainability of Irrigation in the US High Plains and Central Valley. *Proceedings of the National Academy of Sciences.* 109(24), 2320-2325. Retrieved from doi: 10.1073/pnas.1200311109

Schwabe, K. A., & Connor, J. D. (2012). Drought Issues in Semi-Arid and Arid Environments. *Choices*, 27(3)

SCVWD. (2015). Integrated Water Resources Master Plan. Retrieved from http://www.valleywater.org/uploadedFiles/Services/HealthyCreeksEcoSystems/Integrated_Water_Resources_Master_Plan/One%20Water%20Fact%20Sheets_Compiled_10-5-15.pdf?n=4259

SCVWD. (2012). Ground Water Management Plan. SCVWD (2015). Timeline of the History of Water in Santa Clara County. Retrieved from http://www.valleywater.org/Programs/TeachersStudents/TeacherMaterials/WaterHistoryTeachersGuide/SantaClaraCountyWaterHistory.aspx

SCVWD. (2010). Urban Water Management Plan. iade, A. J., Nishikawa, T., Rewis, D. L., Martin, P., & Phillips, S. P. (2014). Groundwater-Flow and Land-Subsidence Model of Antelope Valley, California.

Sneed, M. (2010). Measurement of Land Subsidence Using Interferometry, Coachella Valley, California. *Land Subsidence, Associated Hazards and the Role of Natural Resources Development* (Proceedings of EISOLS 2010, Querétaro, Mexico, 17–22 October 2010). IAHS Publ. 339, 2010, 260-263. Retrieved from http://hydrologie.org/redbooks/a339/abs_339_0260.pdf

Sustainable Groundwater Management Act of 2014. (2014). California Department of Water Resources. Retrieved from http://www.water.ca.gov/groundwater/sgm/

Teatini, P., Gambolati, G., Ferronato, M., Settari, A. T., & Walters, D. (2011). Land Uplift Due to Subsurface Fluid Injection. *Journal of Geodynamics, 51*(1), 1-16.

Tillman, F. D., & Leake, S. A. (2010). Trends in Groundwater Levels in Wells in the

Active Management Areas of Arizona, USA. *Hydrogeology Journal, 18*(6), 1515-1524.

Wentworth, C. M., Williams, R. A., Jachens, R. C., Graymer, R. W., & Stephenson, W. J. (2010). The Quaternary Silver Creek Fault Beneath the Santa Clara Valley, California. US Geological Survey, Open File Report 2010-1010. Retrieved from https://pubs.usgs.gov/of/2010/1010/

Zhang, M., Nuns, V., Burbey, T., & Borggaard, J. (2012). A new powerful parameterization tool for managing groundwater resources and predicting land subsidence in Las Vegas valley. Paper presented at the *AGU Fall Meeting Abstracts, 1* 1184. Retrieved from https://meetings.agu.org/abstract_db/