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DOI: https://doi.org/10.31979/etd.298a-drbs
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The South Bay Water Recycling Program: An Evaluation of Water Recycling Outcomes in Comparison to Selected Cities and Countries

by

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A Thesis Quality Research Paper
Submitted in Partial Fulfillment of the
Requirements for the
Masters Degree
in

PUBLIC ADMINISTRATION

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San José State University

May 2019

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INTRODUCTION

Statement of Problem

California's water infrastructure has been in a very precarious state. The once water-abundant state endured six years of record-setting drought beginning in December 2011 and ending in March 2017. According to the Public Policy Institute of California (PPIC), not only have the droughts negatively affected agricultural and urban water users, but they have also disrupted the river and wetland ecosystems, along with the fish and wildlife that are dependent on them. Drought crises of this magnitude were severe enough to trigger the state legislature's actions for assessing the strengths and weaknesses of all operations and policies currently implemented (PPIC, 2018). California's water management system needed to set clear goals for the environment and public health to successfully prepare for and respond to future water scarcity, flood, and preservation challenges.

In the last few years, the state has experienced one of the most variable rainfall occurrences in the nation, with randomly heavy storms making a difference between the dry and wet years (Mount et al., 2015). Although the higher than average temperatures have reduced snowpack in the Sierra Nevada Mountains – the state's vital source of stored water – there is not enough definitive research to attribute the droughts to what many are defining as climate change (Mount et al., 2015). In this era of rising average temperatures, California's water management must take into account all emerging environmental concerns and balance it with human water use. Improved water management systems are necessary to overcome future challenges that the state may face.

California's vast water infrastructure is interconnected by a complex system that intricately stores and conveys water year-round. Water availability comes from movement and storage of water in surface reservoirs and groundwater basins, precipitation patterns, imported water, and artificial and natural water reuse (Hanak et al., 2011). Of all the water resources, the state's main supply comes from precipitation that fluctuates each year. Freshwater is not an unending supply on earth; therefore, it is crucial to use this natural resource wisely. In order to achieve overall higher water conservation, water-recycling programs have been implemented throughout California, the U.S., and worldwide.

Research Question

Is the South Bay Water Recycling (SBWR) program achieving its planned recycled water outcomes? This research will compare the SBWR program's 2018 recycled water data with other water reuse programs in Las Vegas, Orange County, Singapore, and Australia. The purpose of the research is to determine whether the SBWR program is achieving its goals for conserving fresh water for beneficial reuse, and how the outcomes compare with selected cities and countries.

BACKGROUND

Established in 1996, the South Bay Water Recycling (SBWR) Program is under management by the San José-Santa Clara Regional Wastewater Facility (RWF). RWF is one of the most extensive treatment facilities in California, with wastewater passing through the facility for tertiary treatment before being discharged to the southern end of San Francisco Bay. After tertiary treatment at the RWF, 13% of the treated water is transferred to SBWR for recycling (City of San José, 2016a). The RWF is jointly owned by the cities of San José and Santa Clara, and managed by the City of San José's Department of Environmental Services. It serves the waste water disposal needs of 1.4 million people in San José, Santa Clara and Milpitas, Cupertino Sanitation District (Cupertino), West Valley Sanitation District (Campbell, Los Gatos, Monte Sereno and Saratoga), and three county sanitation districts. (City of San José, n.d.)

The SBWR program was created to comply with the need to decrease the discharge of fresh water to the southern end of San Francisco Bay to protect "the salt marsh harvest mouse and the clapper rail." (BAWSCA, 2017). In 2014, an Advanced Treatment Facility (ATF), called the Silicon Valley Advanced Water Purification Center (SVAWPC), was added to the recycling system as a joint project with the Santa Clara Valley Water District (SCVWD), to create higher quality recycled water to attract more recycled water users (BAWSCA, 2017). The SVAWPC water is blended with the recycled water (Erickson, 2016). All the recycled water is sold to water retailers under permits. SBWR is a regional permit holder for recycled water in San José, Milpitas, and Santa Clara (City of San José, n.d.). The program is a recycled water wholesaler to four retailers: San José Municipal Water, San José Water Company, City of Santa Clara, and City of Milpitas (City of San José, n.d.)

The Santa Clara Valley Water District (SCVWD) is a special purpose district created by the state legislature to serve Santa Clara County as its flood control district, water conversation agency and drinking water wholesaler. (Valley Water, 2019a) There are fifteen cities in the county, as well as unincorporated areas, with a population of 1.9 million (US Census, 2018). Most of the county's potable drinking water comes from groundwater wells, reservoirs, streams, rivers, and lakes (City of San José, 2016a). The water district gets the drinking water from ground water in the county and water it imports from the State Water Project to the Penitencia Water Treatment Plant (SCVWD, 2019a) and the Federal Bureau of Reclamation's Central Valley Project through the South Bay Pipeline (SCVWD, 2019b). This water is then sold to retailers, such as San José Municipal Water, San José Water Company, Great Oaks Water, and California Water Service.

The RWF follows a standard process for water treatment up to tertiary level, which includes removing all harmful materials. According to the RWF website (2018), after wastewater enters the treatment facility, it undergoes a rigorous three-step treatment process to remove solids, harmful pathogens, and pollutants. Heavy machinery and strong gravity force solids to separate from the wastewater. Next, naturally-occurring anaerobic bacteria called "digesters" are added to digest sludge, removing pollutants from the wastewater before it enters an advanced filtration process. RWF's treatment process produces water that is 99% purified before discharging it into the South San Francisco Bay (RWF Fact Sheet, 2016).

In the Santa Clara County, a complex network of creeks, reservoirs, and specialized ponds replenishes the groundwater basin. A similar system is used to transport imported water so that it can be used to replenish the aquifers. The network of water distribution works so well that "managed" recharge has actually exceeded natural recharge in the past years (Valley Water, 2018). Farmers, water retailers, and private well owners primarily use the water pumped through wells from groundwater basins (Valley Water, 2018)

Another ground water protection and sustainment resource is having sufficient imported water availability. Roughly 55% of the county's water supply comes first as rain or snow in the Sierra Nevada range of northern and eastern California, then as water in rivers that flow through the Sacramento-San Joaquin River Delta (Valley Water, 2019b). This imported water is brought into the Santa Clara County through the complex infrastructure of the Central Valley Project (CVP), State Water Project (SWP), and San Francisco's Hetch Hetchy system. Imported water delivered by the CVP and SWP is sent to the SCVWD's three potable water treatment plants used to supplement groundwater recharge, or stored in state and local reservoirs for use in subsequent years (Valley Water, 2018).

In March 2014, RWF began supplying secondary-treated wastewater to the SVAWPC for further cleaning by microfiltration, reverse osmosis, and ultra-violet disinfection. SVAWPC uses this advanced technological process to thoroughly purify the water before blending it with SBWR recycled water to reduce overall salt content and create the highest quality of reclaimed nonpotable water for their customers (RWF Fact Sheet, 2016).

SBWR customers purchase recycled water from the retailer in their location. SBWR's recycled water system consists of over 150 miles of purple pipelines, ten million gallons of water storage in reservoirs, and five pump stations (City of San José, 2016a). Since October 2014, the State Water Resources Control Board (SWRCB) and Division of Drinking Water (DDW) authorized SBWR to use a Truck Fill Program, implementing truck fill stations for commercial and nonpotable uses, such as street sweeping, sewer clean out, and dust control (SBWR Annual

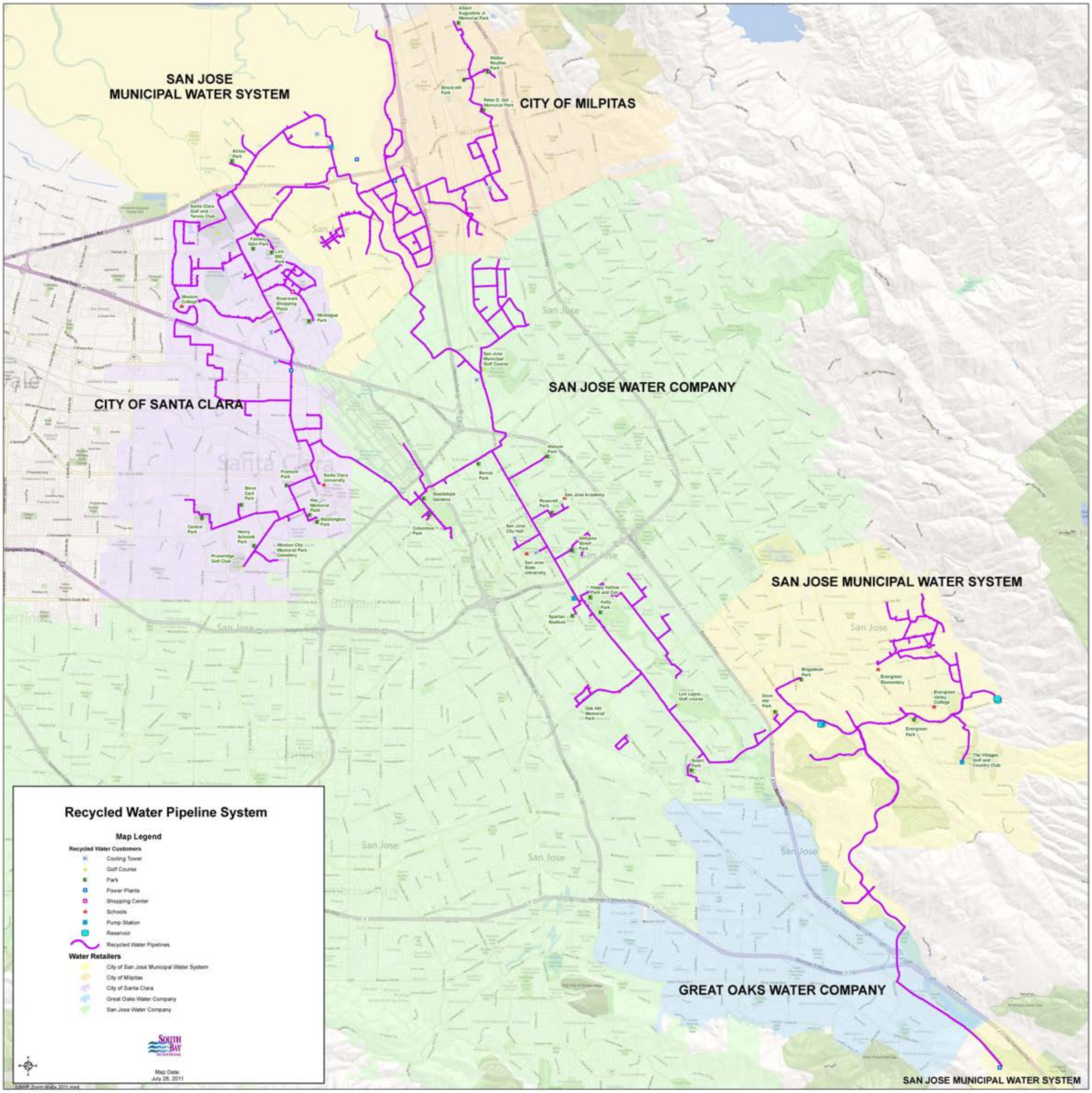
State Report, 2018). All of SBWR's local retail agencies have been approved for truck fill stations through individualized implementation plans (SBWR Annual State Report, 2018).

Purple Pipes Indicate Recycled Water

Purple pipes are used to distinguish nonpotable water distribution systems to help prevent cross-connections with potable drinking water. Irvine Ranch Water District (IRWD) in Orange County, California chose the distinctive color of this pipe and called it "Irvine Purple". IRWD was one of the early pioneers of recycled water, and the district dates back to as early as 1961 (Peterson, 2014). The City of Irvine was the first water district in the state to get a permit to use recycled water for any acceptable use other than agriculture (Peterson, 2014).

SBWR's purple pipeline system consists of a north to south artery across San José and an east to west artery from mid-Milpitas down through the eastern side of Santa Clara. These main arteries transfer recycled water through the pipeline extensions to various customers (SBWR Fact Sheet, 2016). The program delivers anywhere between four to six billion gallons of recycled water, approximately 11 million gallons per day (MGD), to more than 850 customers annually (SBWR Fact Sheet, 2016). Purple pipes are all clearly labeled "Recycled Water – Do Not Drink" and were built in response to a flow cap placed by the National Pollutant Discharge Elimination System (NPDES) discharge permit under the Federal Clean Water Act. The permit went into effect to prevent an overabundance of discharged treated wastewater into the South San Francisco Bay. High amounts of treated wastewater can destroy the salt marshland environment, along with the lives of a few endangered species inhabiting it (SBWR Strategic & Master Plan Report, 2014).

Figure 1: SBWR Recycled Water Pipeline System Map



Source: City of San José. From the South Bay Water Recycling Program (2012).

History and Technological Advancements of Recycled Water Use

California has been using recycled water as a non-potable water supply for more than a century. Farmers were among the first to use wastewater to grow crops and irrigate landscaping in the late 1800s (Department of Water Resources, 2004). Early water recycling programs and projects were first developed to control pollution. However, with California experiencing severe droughts in the last five to six years, fresh water has become scarcer, causing a shift to cultivating higher quality recycled water, even as potable drinking water, to the communities and environment. San Francisco was the first city in California to begin exploring the possibilities of water reuse and reclamation in 1932. The city instituted a small system using partially treated groundwater in the Golden Gate Park to irrigate natural areas within the park (Watermark, 2016).

There are various technologies and techniques implemented to recycle water. Reverse osmosis (RO) recycles wastewater by reducing total dissolved solids (TDS). RO relies on pressure differential to force water through a membrane that retains the solute on one side and allows the pure solvent to pass through to the other side (Koch & von Gottberg, 2009). RO membranes have been shown to significantly reduce total dissolved solids, heavy metals, organic pollutants, viruses, bacteria, and other dissolved contaminants (Bartels, 2006). RO membrane technology has been proven to treat wastewater successfully, and plays an increasingly important role in the reclamation of municipal wastewater.

Ultraviolet (UV) disinfection, or UV water purification, is another method used to disinfect bacteria from water (Oram, n.d.). UV rays penetrate harmful pathogens in water and destroy illness-causing microorganisms by attacking their DNA; so this process is extremely efficient in eliminating the microorganisms' ability to reproduce (APEC Water, 2017). Chlorine was previously used for disinfection of drinking water, but due to health and safety concerns associated with the chemicals in chlorination, the UV purification method has experienced increased acceptance in both household and municipal systems (APEC Water, 2017).

Gray water reclamation is another recycled water technique primarily used in domestic households (Lamb, 2008). Gray water is water that has been gently used from bathroom sinks, showers, tubs, and washing machines (Greywater Action, n.d.). This type of water may contain traces of dirt, food grease, hair, and certain household cleaning products but has never come in contact with feces or urine. Gray water is not to be reused as drinking water but as a beneficial source of irrigation water in yards (Lamb, 2008). This method is a conservative approach to saving water by reusing it in an existing drip irrigation system. However, gray water reclamation systems vary significantly, depending on geographic location, size of household, intended reuse, and the level of commitment users will devote to making the most of their wastewater and protecting the environment (Lamb, 2008).

Recycling Methods

In the United States, there are two main types of water reuse projects: potable reuse and nonpotable reuse. Potable reuse projects use highly treated reclaimed wastewater to enhance water supply that is used for drinking (NAS - Water Reuse, 2015). Nonpotable reuse projects treat wastewater for specific purposes other than consumption, such as agriculture, landscape irrigation, and industrial uses. Nonpotable reuse could also use reclaimed water to build or replenish wetlands that support wildlife (NAS – Water Reuse, 2015).

In some communities, residents may already be reusing wastewater without even realizing it – this recycled water method is called De Facto Reuse. De facto reuse occurs when a community draws water from a reservoir or river that includes wastewater from upstream communities (NAS – Water Reuse, 2015). Although it has not been systematically analyzed in the U.S. in more than three decades, this method is quite commonly used. Since its last assessment, de facto reuse has likely increased, as expanding cities discharge more treated wastewater into water sources used by downstream communities (NAS – Water Reuse, 2015). Several California counties, such as Santa Clara and Orange County, are attempting to implement an effective "toilet to tap" program that allows water, which has been flushed or washed down the drain, to be reclaimed and safely used for potable consumption (Bansal, 2017).

A 2016 poll revealed that 83% of Californians are "ready to use" recycled water in their everyday lives (Bansal, 2017). The SVAWPC goes above and beyond to remove the tiniest of harmful micropollutants and pathogens in recycled water. Since 2014, the plant has produced about eight to ten million gallons of potable water every day (Bansal, 2017). SVAWPC uses a process called microfiltration to get rid of harmful pathogens by pumping partially cleaned water from the nearby San José-Santa Clara Regional Wastewater Facility through thousands of tiny tubes. Next, the water flows through reverse osmosis membranes to remove salts, and lastly gets blasted with UV light to break down remaining pathogens or chemicals (Bansal 2017). However, before it becomes potable drinking water for public consumption, it goes through one final cleaning phase: being blitzed with hydrogen peroxide (Bansal, 2017).

Beneficial Reuse of Recycled Water

The Santa Clara Valley Water District (SCVWD), now known as Valley Water, is another entity that provides safe, clean water, along with flood protection and stewardship of streams (SCVWD, 2019b). SCVWD understood the threat of an unreliable water infrastructure and worked to develop a reliable and sustainable water supply. The county's current water source is mainly dependent on groundwater, rainfall, and imported water from the State Water Project and Central Valley Project that is transferred through the Sacramento-San Joaquin Delta. However, these traditional water sources are continuously affected by environmental regulations, an increasing population trend, and climate change, creating an ambiguous future for Santa Clara County's water supply needs. Consequently, the SCVWD took a proactive approach to expand the county's water supply with local sources to increase reliability (SCVWD Recycled Water Fact Sheet, 2012).

The development of Silicon Valley Advanced Water Purification Center (SCVAWP) in 2014 created a system that thoroughly purifies secondary-treated wastewater from the RWF, and can produce up to 10 million gallons/day (MGD) for potable use. This advanced water purification technology has already been developed and successfully implemented in Orange County (GWRS) and Los Angeles (SCVWD Recycled Water Fact Sheet, 2012). The secondary-treated wastewater will undergo a three-step purification process:

- Microfiltration: The removal of particles down to 0.1 micron in size, including all bacteria;
- Reverse Osmosis: A method adapted from natural processes used by living cells to separate water from contaminants on a molecular level;
- Ultra-Violet (UV) Disinfection: Water passes through ultraviolet light to ensure that any remaining organisms are eradicated. This technique is often used to sterilize food, medicine, and fruit juices without the use of harsh chemicals.

Reusing water provides immense environmental and economic benefits by reducing energy consumption for water treatment, and pollution from wastewater discharge. Recycled water saves a significant amount of money because reclaimed water for industrial, commercial, and landscape irrigation requires less treatment than recycled water for drinking **(**SCVWD, 2016**).**

Santa Clara County's recycled water currently makes up about 4% of total water use, but has the potential to account for more (SCVWD, 2016).

In a case study done by the UCLA Fielding School of Public Health (2014), researchers discovered environmental benefits from using recycled water. When comparing two conservation efforts, such as expanding the use of recycled water and banning landscape irrigation, increasing use of recycled water had the most significant potential to reduce energy use, water consumption, and lower greenhouse gas (GHG) emissions. The "increased use of local groundwater extraction, desalination, and expanded recycled water use have all been suggested as ways to help meet California's urban water needs and shift reliance away from the use of imported water. Shifting to alternative water sources has the potential to lower GHG emissions and have a positive impact on human health" (Sokolow et al., 2016). The study identified a cause of the positive impact on human health as decreasing air pollution, because it reduces the occurrence of respiratory disease (Sokolow et al., 2016).

In SBWR's Annual State Report (2018), a total of 3,828.7 MGD were distributed for irrigation, agriculture, cooling towers, and other industrial use. Irrigation use (parks, golf courses, commercial campuses, and schools) accounted for the most at 2,465.8 MGD, 64% of total reuse flow, and agriculture use (vineyards) accounted the least at 0.4 MGD. The cooling towers accounted for 1,116.4 MGD, 29% of total reuse flow, and other industrial use accounted for 246.1 MGD, 6% of total reuse flow. San José State University (SJSU) used about 37 million gallons (MG) of recycled water, principally for irrigation, and the SJSU Student Union used about 2 MG in its restrooms for the calendar year 2018.

California currently faces the problem of ground subsidence. Ground or land subsidence is the loss of surface elevation due to the removal of subsurface support (USGS, 2017). Ground subsidence is the result of excessive groundwater pumping. "The compaction of susceptible aquifer systems caused by excessive groundwater pumping is the single largest cause of subsidence in California" (USGS, 2017). Compaction occurs when groundwater is excessively removed from the basin, causing the land to sink. "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" (Fulcher, 2017, p.6). The SCVWD continues to implement its Groundwater Monitoring and Mitigation Program (GMMP) in order to monitor groundwater quality and elevation. GMMP identifies potential threats that can lead to land subsidence and take appropriate actions to prevent any adverse groundwater occurrences (SCVWD, 2019c). The District actively monitors groundwater elevations to assess groundwater storage, optimize recharge efforts, and support groundwater management (SCVWD, 2019c).

T.J. Rodgers, an inventor of semiconductor technologies, also an early investor in solar technology company SunPower, believes that with the right water conservation technologies, California can drastically cut the amount of water used, while improving agricultural outputs. Rodgers currently serves as an executive chair of WaterBit - a “San José-based startup that is using technology such as sensors and miniature solar panels so that farmers can better control the amount of water their crops need based on factors such as the crop itself, the type of soil involved and a plant's stage in its life" (Crum, 2018). Rodgers and WaterBit plan to reduce and conserve water by making wine. He determined that grapes were a great start to testing out the water technology because it is not a high water-consuming crop (Rodgers, 2018). Rodgers is using his vineyard as testing grounds for the WaterBit technology and believes the experiment will both reduce the amount of water used and improve the quality of grapes produced (Crum, 2018). Every gallon of water that gets recycled minimizes the dependency on imported water purchased from the State Water Project. More importantly, it will preserve drinking water supplied for both current and future generations to come.

Analysis of Successful Recycling Programs

Orange County – Groundwater Replenishment System (GWRS)

The Orange County (California) Water District (OCWD) houses the world's largest indirect potable water reuse system (OCWD GWRS, n.d.a). The system takes highly treated wastewater that would have previously been discharged into the Pacific Ocean and purifies it using a three-step advanced treatment process (OCWD GWRS, n.d.b). Approximately 35 MGD is pumped into injection wells to create a seawater intrusion barrier. Another 65 MG are pumped daily to OCWD's percolation basins in Anaheim, where the GWRS water naturally filters through sand and gravel to the deep aquifers of the groundwater basin to increase the local drinking water supply (OCWD GWRS, n.d.c). On average, GWRS converts about 100 MGD of wastewater to recycled water and aims to eventually grow to a capacity of 130 MGD (Mellen, 2018). Maximizing the production of recycled water dramatically reduces the need for costly imported water, and uses less energy than desalinated or imported water (Mellen, 2018). Greg Sebourn, chairman of the board for the Orange County Sanitation District, declares that GWRS water purity levels far exceed the state and national drinking water standards. Sebourn states the water is so pure; it is near-distilled in quality, and has minerals added back for taste.

Las Vegas Valley Water District (LVVWD)

About 90% of Las Vegas' water comes from Lake Mead, the nation's largest man-made reservoir, created on the Colorado River by Hoover Dam. Las Vegas is legally allowed to access about 300,000 acre-feet (about 4% of Lake Mead) per year; that is about 98 billion gallons of water. The water allocation law is fixed, which means despite the population tripling over the last decade, Las Vegas is not allowed any more access to water than the established 4%, even with their new residents. The city was falling deeper into a crippling state of extreme water scarcity and desperately needed a recovery plan. Patricia Mulroy, general manager of the Las Vegas Valley Water Authority (LVVWA) and Southern Nevada Water Authority (SNWA), implemented a plan to raise water rates by reducing the monthly fixed charge and increasing rates based on volume (Fishman, 2011). Nevada's unusual water rights system left nearly 865,000 acre-feet of unclaimed groundwater. After conducting an investigation and filing roughly 146 applications to the state capital for unused water rights, Mulroy planned to secure permission for the use of water from Lake Mead. Over two decades, she plans to build a big underground pipeline that will bring water three hundred miles south.

Las Vegas is one of the driest cities in the United States – "Of the 280 cities in the United States with at least 100,000 people, Las Vegas is No. 280 in precipitation and number of days each year that it rains" (Fishman, 2011, p.54). Las Vegas wastefully uses water year-round in order to keep visitor numbers high. Mulroy decided to implement a "Cash for Grass" program that paid out Nevada residents between $1-$1.50 for every square foot of grass removed and replaced with desert landscaping (Fishman, 2011). The SNWA identified that Las Vegas homeowners account for nearly half of the overall water use in Las Vegas. About 70% of water used in homes was used outdoors for lawn and garden watering, washing cars, and/or filling swimming pools (Fishman, 2011). SNWA calculated that every square foot of grass removed saves about 55 gallons of lawn watering every year. The program will save Las Vegas roughly 7.7 billion gallons of water per year (Fishman, 2011).

Other Countries with Recycled Water Programs

Water recycling has become a norm in several other countries experiencing similar water shortages. Australia experienced severe droughts in the early 2000s and has since then implemented several recycling programs and methods to use reclaimed water. In the Goulburn Valley, wastewater is recycled and returned to the Goulburn River where it is eventually harvested and processed for drinking (Steen, 2018). In Queensland, the Western Corridor Recycled Water Scheme is the largest in the country; the water is currently used for industrial purposes, but can be used for agriculture as well as to conserve drinking water supplies in the event of another drought (Steen, 2018). The Groundwater Replenishment Scheme located in western Australia returns recycled water to natural groundwater storage (aquifers) for later extraction as drinking water (Steen, 2018). Generally speaking, indirect potable reuse in Australia involves getting effluent (treated wastewater) further treated at existing treatment plants before reaching the recycling plants. The recycled water is then mixed with the natural water supply. Australia's water recycling process is very similar to the U.S. After going through microfilters the treated water undergoes reverse osmosis, then oxidation and disinfection using hydrogen peroxide and intense UV light. The recycled water is transferred to a reservoir or groundwater aquifer, where it can be stored and mixed with the standard water supply (Steen, 2018).

Singapore has one of the most successful water recycling programs in the world. Roughly 30% of Singapore's total water supply is imported from Malaysia (Duerr, 2013). The launch of NEWater project gained international recognition for being the most efficient at recycling wastewater (PUB, 2018c). Currently, four purification plants are producing roughly 430 million liters of NEWater a day (PUB, 2018a). The majority of this water is consumed by industries or large cooling facilities, while the rest is combined with nutrient-rich reservoir water, purified again and bottled up, but not for consumption or sale (Duerr, 2013). The bottles are used for educational purposes at major events to raise awareness about the NEWater project. Today, about 5% of tap water in Singapore comes from NEWater, and officials say the project has provided immense relief for the country during their dry months (PUB, 2018b).

LITERATURE REVIEW

In Las Vegas, a study was done on whether water scarcity was the product of flawed water policies or other exogenous changes from 1996 to 2007 (Brelsford & Abbott, 2017). “Many municipalities implement multiple water-focused policies simultaneously – while still subject to other exogenous drivers – so it is important to pair policy evaluations with approaches that examine multiple drivers of water use” (Brelsford & Abbott, 2017, p.99). The research determined that the largest measurable factor driving water conservation in Las Vegas was overall lower consumption in new homes, while in established neighborhoods, the factor was a "declining vegetation area." The study provided indirect evidence that a decline in water consumption coincides with increased water waste enforcement and raising drought awareness. Policy responses played an essential role in Las Vegas's water conservation. An array of different approaches focused on behavior and infrastructure can effectively reduce water consumption (Brelsford & Abbott, 2017).

Every day, approximately 100 million gallons of raw sewage is treated by the Clark County Water Reclamation District (CCWRD), with roughly 90 million gallons of reclaimed water released daily into the Las Vegas Wash, replenishing Lake Mead with billions of gallons of water every year (Whitaker, 2014). It is a six-hour process to purify sewage water before it is put back into Lake Mead, where it will be stored and pumped back out for final treatment before entering all Las Vegas residence taps. The purification process starts with flushed water from homes and businesses streamed to nearby treatment facilities. Pre-treatment sifting then occurs by removing sludge and trapping trash using a mechanical rake. Next occurs the primary treatment using rotating metal arms to skim surface scum into troughs, this is vacuumed out weekly, and scrape bottom sludge into hoppers that lead to underground pits, where it will be pumped out and dried. An aeration process is then activated to remove phosphorus; next a secondary treatment is applied; third, the filtration of water through sand and anthracite to remove tiny solids and any remaining phosphorus; and lastly, the disinfection of water to remove all harmful pathogens, before being released back into the Las Vegas Wash for potable use (Whitaker, 2014). The SNWA extracts this water out of Lake Mead to serve two million residents and nearly 40 million visitors a year.

Another study was done in four major U.S. cities to determine the importance of public values and perception of considering alternative water sources (Ishii et al., 2015). The methodology used was an online survey distribution to residents in four major metropolitan areas located in Georgia, Texas, California, and Florida. Primarily, the study was conducted to find out whether residents were on board with drinking water considered going from "toilet to tap to potable drinking use." In this study, "purified water" was defined as "municipal wastewater that has undergone advanced water treatment processes, thus resulting in water quality that, at a minimum, complies with drinking water regulations" (Ishii et al., 2015, p.559). Findings concluded that 50-60% of respondents were in support of using purified water as potable water. Respondents had the highest concerns about the levels of contaminants in the smell, taste, and microbial load of both current tap and purified water. The survey results highlighted the importance of addressing certain areas when communicating about direct potable reuse (DPR) to the general public, such as barriers against microbial contamination, trustworthiness of utilities, potential improvements over the status quo, and community-specific drivers that necessitate the use of purified water in a given setting (Ishii et al., 2017).

Using a case study of California’s water supply, a study was conducted to determine whether ocean desalination and water recycling capacities could substitute for groundwater depletion in the state (Badiuzzaman et al. 2017). This research hopes to shed new light on water sustainability to decrease the rate of groundwater depletion. The volume of groundwater depletion was used as a proxy for unsustainable water consumption, and was defined by combining existing research estimates into the low, medium, and high depletion baselines (Badiuzzaman et al. 2017). The data was compared against projected water supply increases from ocean desalination and water recycling by the year 2035 to determine whether new drought-proof water resources can substitute for California's unsustainable groundwater consumption.

The research methodology used for this study sought to "operationalize the theoretical concept of resource substitutability by constructing a case study that compares the production capacities of two advanced water supply sources with groundwater depletion… the analysis synthesizes the results of three key studies in groundwater storage change in the Central Valley…" (Badiuzzaman et al. 2017, p.125). The data is compared against current supply predictions found in government policy studies, reports, and any relevant literature on water supply. The results of this study showed that the maximum projected new water supply produced about 2.47 million acre-feet per year (MAF/yr). The new water supply was sufficient in meeting low depletion estimates of 2.02 MAF/yr but failed to meet high depletion estimate of 3.44 MAF/yr.

The researchers of this study felt that the results do not necessarily indicate physical limitations of substitutability, but more so socioeconomic limitations influenced by high comparative costs. "The results agree with existing evaluations which stress the need for a portfolio of water strategies, rather than one silver bullet solution, to balance California's water household." (Badiuzzaman et al. 2017, p. 131). Moreover, the results of this research strongly advised investment in institutional and social capital as an essential factor for enhancing water substitutability and other natural resources for greater water conservation in the long run.

Due to severe prolonged droughts since 2002, Australia has successfully developed and implemented several recycled water projects throughout the entire continent and its counties. One of Australia's first water recycling projects is the dual reticulation water recycling system. This system provided recycled water for urban housing gardens, toilet flushing, and car washing in Rouse Hill, New South Wales (Radcliffe, 2010). "At Newington, water from the Sydney Olympic Park wastewater plant and harvested stormwater are treated with the UV disinfection/microfiltration (MF)/reverse osmosis (RO)/chlorination train… Sydney Water is aiming to have 25 more water recycling schemes in place by 2015, supplying 12% of Sydney's water needs" (Radcliffe, 2010, p.796). Plans for the future development of dual reticulation water systems, coupled with new subdivision developments, will be located in Melbourne, Adelaide, and Sydney.

The next water-recycling project implemented used indirect potable water. Brisbane installed three large Advanced Water Treatment Plants designed to transfer indirect potable recycled water to Brisbane's principal water reservoir, the Wivenhoe Dam. Several other water-recycling projects have been implemented for agricultural and industrial use, such as an experimental managed aquifer recharge combined with wetland-treated stormwater in Adelaide, and RO treated wastewater in Perth. Desalination plants have been constructed in Melbourne, Adelaide, and Perth, in addition to newly operational plants in South-East Queensland and Sydney. However, despite multiple examples of unplanned potable recycling, Australia's government remains reluctant about moving towards a planned potable recycling system – "The Commission concluded that while urban water planning is now based on a more diverse portfolio of supply and demand options, a number of government policy decisions continue to constrain certain water supply options" (Radcliffe, 2010, p.801). The study states that although there is evidence of specific policy bans still being managed by governments, the National Water Commission continues to reinforce the necessity of impartially objective considerations of all water supply options.

To assess the Santa Clara County's current groundwater and land subsidence levels, research was done to determine whether there were sustainable groundwater practices implemented by Groundwater Sustainable Agencies (GSA). Fulcher (2017) distributed three surveys to groundwater management professionals at four California GSAs. In determining whether the current GSA practices and programs met the mandated requirements of the Sustainable Groundwater Management Act of 2014, water conservation and marketing efforts have proven successful, according to Fulcher's results. The groundwater professionals at SCVWD have developed new water recycling infrastructure that will provide other pathways to clean and safe drinking water while ensuring proper management and conservation of local groundwater (Fulcher, 2017). The recycled water is being pumped back into percolation ponds and recharge wells to continue supporting the groundwater supply. Additionally, active community engagement and awareness will play a vital role in effectively diminishing the occurrence of land subsidence by reducing water consumption in business, agriculture, and homes (Fulcher, 2017).

METHODOLOGY

Research Design: Outcome Evaluation

The methodology used to evaluate this research will be an outcome evaluation considering program goals, functions, indicators, measures and outcomes (Sylvia & Sylvia, 2012). This research design will determine whether the South Bay Water Recycling program was effective at achieving its planned water recycling outcomes, and how it compares with the recycling goals of the other programs. The theoretical goal (legislative intent) of the program is to increase water-recycling efforts and protect the salt marsh habitat in the South Bay. Three SBWR program goals are measured: (1) increase industrial, landscape, and commercial recycled water usage in the South Bay; (2) increase the production and distribution of recycled water; and (3) minimize effluent water discharge into the San Francisco Bay during the driest three consecutive months.

The first program goal was measured by comparing the number of recycled water permits issued along with total gallons of water recycled, distributed, and reused by the four water retailers participating in the program. The second goal evaluated whether the program increased its recycled water production and distribution efforts by showing monthly average water flow rates from 2014 to 2018. The third program goal was measured by comparing the total gallons of effluent water discharged annually from calendar years 2014 to 2018. The third goal was the main driver for the creation of the SBWR program. The Environmental Protection Agency (EPA) and SWRCB discovered how severely the South Bay marsh environments were negatively impacted from large amounts of fresh water being discharged into the San Francisco Bay during dry seasons. Many birds and fish, such as the salt marsh harvest mouse, clapper rail, stripers, black bass, and salmon, were gradually becoming extinct in the area due to the overwhelming freshwater discharge into the estuary (SBWR Strategic & Master Plan Report, 2014).

Freshwater is defined as treated wastewater that has undergone an advanced three-step treatment process to remove pollutants, solids, and harmful bacteria (City of San José, n.d.). After wastewater enters the third (tertiary) and final process, the water is considered 99% pure and meets both state and federal water quality regulations for South San Francisco Bay's sensitive ecosystem (City of San José, n.d.). The SWRCB enacted the NPDES discharge permit requirement, allowing no more than 120 MGD of effluent flow to be discharged annually for the primary purpose of protecting marshlands and natural habitats of local plants and wildlife.

Figure 2: Outcome Evaluation of South Bay Water Recycling

PROGRAM	THEORETICAL GOAL	PROGRAM GOALS	PROXIMATE INDICATORS	PROGRAM MEASURES	OUTCOME VALENCE
South Bay Water Recycling Program	T_1: To increase water-recycling efforts and protect the salt marsh habitat in the South Bay	G_1: Increase industrial, landscape, and commercial recycled water usage (T_1) G_2: Increase the production and distribution of recycled water (T_1) G_3: Minimize freshwater discharge into San Francisco Bay during three driest consecutive months (T_1)	I_1: Total MGD and AF of recycled water is used (G_1-G_2) I_2: Number of permits issued (G_1) I_3: Average flow in MGD/AF of recycled water used per permit in 2018 (G_1) I_4: Average recycled water used by South Bay cities (G_2) I_5: Total MGD of effluent water discharged into SF Bay (G_3)	M_1: Compare permit issue per city (I_1-I_4) M_2: Compare all programs average water recycle use and Influent flow rates (I_1) M_3: Compare annual change in permits issued with average recycled water usage in 2018 (I_3) M_4: Compare annual change in total MGD effluent water discharged in the last five years (I_5)	±

FINDINGS

This section of the research provides tables and figures assessing raw data collected by the SBWR program analyzing the number of recycled water permits issued in comparison to how much water is being used and produced in the Santa Clara County. SBWR distributes recycled water for use at industrial, landscape, and commercial sites. Each customer requires a reclaimed water permit to ensure that their site complies with State regulations for recycled water use and quality maintenance (City of San José, 2016b). In this research, a recycled water permit is defined as a customer and the data collected only analyzes new permit holders added onto the water distribution system each year. There are certain regulations and rules for a new customer to obtain an on-site recycled water permit. Each local water retailer holds the responsibility to implement and enforce program rules and policies (City of San José, 2016b). The procedures for obtaining recycled water services vary slightly depending on whether the service is for an existing facility or a new facility. Each water retailer enforces different on-site water system requirements (City of San José, 2016b). The data will further examine the amount of effluent (freshwater) discharge into the SF Bay from 2014 to 2018, the monthly influent water flow into the program from 2016 to 2018, and water recycling values of four other water reuse programs in comparison to SBWR. The findings will determine whether the SBWR program is achieving its planned water recycling outcomes for 2018.

Data Sources

This research used data acquired from the City of San José's online public document center. SBWR gathered and recorded information on an annual basis to identify water recycling outcomes and monitor water quality through Annual State Reports from 2014 to 2018. Data for LVVWD, Singapore NEWater, and Sydney Water Recycling programs were collected from each program’s online resource database through annual or comprehensive reports and publications. The SBWR program reported data collected on:

1. Water quality and process monitoring;
2. List of customers using recycled water;
3. Customer self-monitoring reports;
4. Test results from the groundwater monitoring program;
5. System Diversion and Demand Update report;
6. System Expansion and Program Update report;
7. Summary of recycled water usage

Graphs, tables, and figures were used to calculate how many recycled water permits were issued historically, how many customers the program served, how much water was produced and distributed by each water retailer, the average monthly flow rate from 2014-2018, the average monthly influent flow rate from 2016-2018, and the ADEWF flow rate discharge from 2014-2018. The descriptive statistical analysis summarized the comparison of SBWR water recycling values from the four other programs.

There are four main water distribution retailers in the SBWR Program: San José Municipal Water System (SJ Municipal Water) and San José Water Company (both within the City of San José), the City of Santa Clara, and the City of Milpitas. Recycled water from SBWR is for commercial sites only. Commercial customers may be eligible to receive water if the water retailer in that location has availability. Potential customers will need to contact the water retailer to determine availability and whether the site is feasible, based on the proximity to the recycled water pipeline (City of San José, n.d.).

Figure 3 illustrates the total number of water permits issued by water retailer for the calendar year 2018. In 2018, there were 928 permits issued (customers served) by SBWR's four water retailers. The retailer that issued the most permits was the City of Santa Clara at 267 permits. The City of Santa Clara currently holds the most permits issued because the city has been issuing recycled water permits since 1989, prior to the implementation of SBWR program in 1996 (SBWR Annual State Report, 2018). The city of Milpitas issued the lowest number of permits (205) because the city is smaller in comparison to the Cities of Santa Clara and San José.

Figure 3: Total Number of New Recycled Water Permits Issued by SBWR Retailers 2018

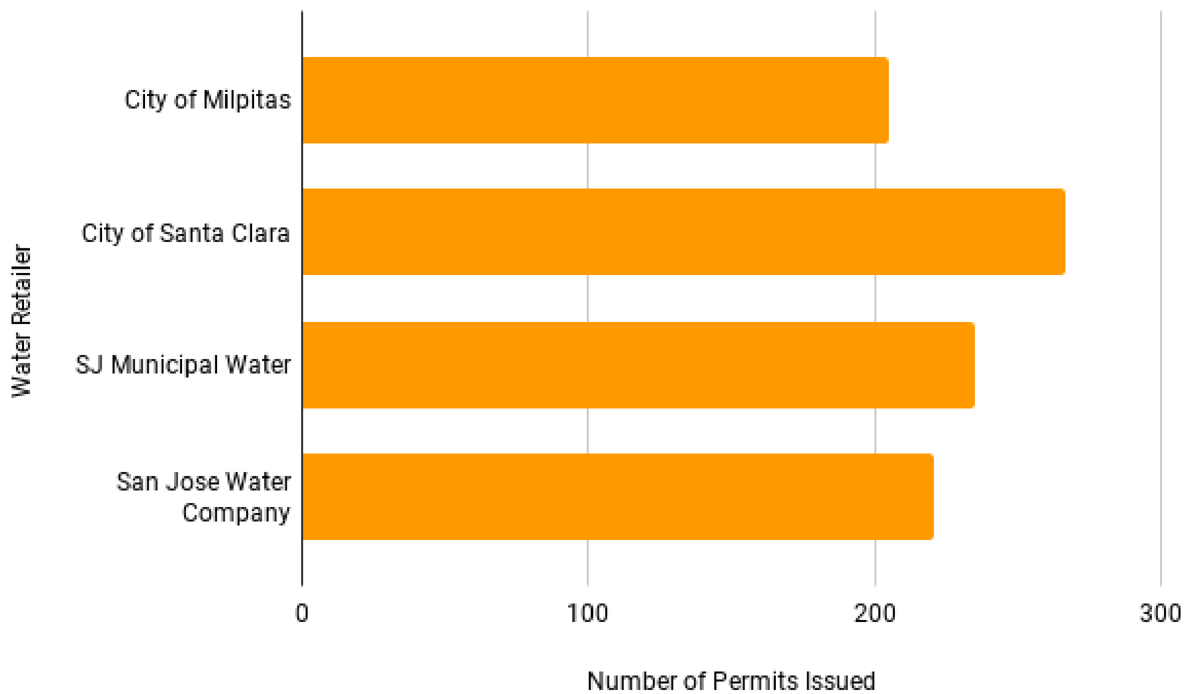


Figure 4 shows the historical trend in the total number of new water recycling permits issued annually by water retailer from 1989 to 2018. The City of Santa Clara was the only water retailer issuing recycled water permits from 1989 to 1996 because they are a co-owner of the RWF and received approval to use recycled water prior to the implementation of the SBWR program in 1996. There was a big push for the program to add large-scale irrigation customers upon establishing the SBWR program in 1996, and this was the reason for the high surge in recycled water permits issued. From 1996 to 2007, there was gradual drop in new permits issued across all four water retailers because most of the large-scale commercial customers had already registered for a permit, and there was not enough piping built during that time frame to add more customers onto the irrigation sector (Young, 2019a).

There was a period in 2002 to 2005 when San José Water Company did not issue any recycled water permits because they were not allowed to add any more recycled water customers. This is because San José Water Company is a for profit water company and requires an approved authorization from the San Francisco Public Utilities Commission (SFPUC) for additional piping in order to accrue more customers, once they have accepted the maximum allowed on their distribution system (Young, 2019a). Notably, San José Water Company significantly increased water permits issued from 2007 to 2012 because they were able to obtain approval from SFPUC to build a larger piping extension for their future customers (Young, 2019a). Figure 4 shows a gradual increase in permits distribution starting from 2008 to 2018, and this is likely attributed to SBWR introducing a cooling tower project that allowed for construction of on-site cooling towers for industrial use. With the introduction of industrial combined with irrigation water use, the program was able to gradually increase water permits issued across all four water retailers.

Figure 4: Number of Recycled Water Permits Issued by SBWR 1989-2018

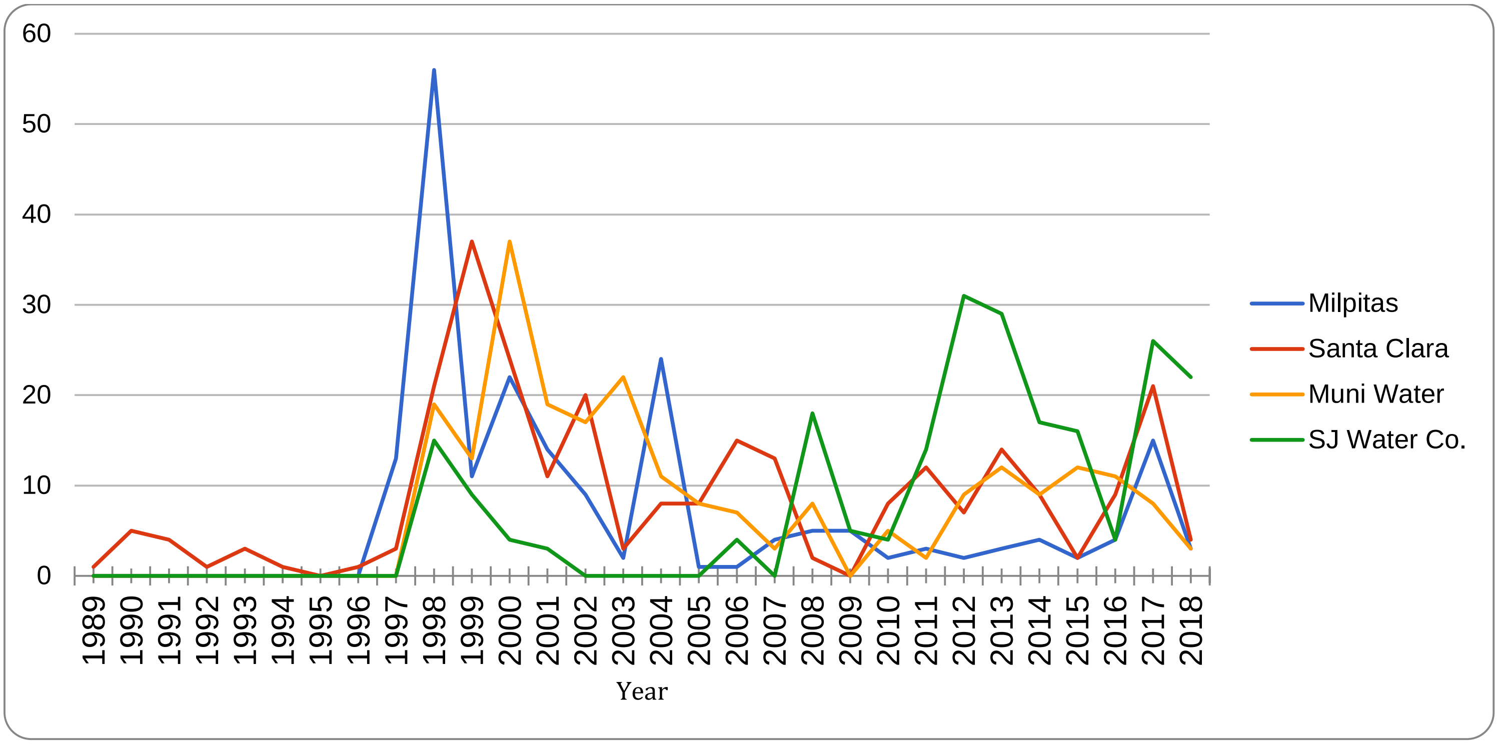


Table 1 shows the total number of customers served annually from 2014-2018, along with the overall amount of water distributed in acre-feet (AF), and percentage change in water distributed from the prior year. There are various reasons why a number of prior year customers may have stopped using recycled water services. One common reason is that on-site construction may shut down one service and develop a new water recycling system as the site is being rebuilt. Even if the system is generally rebuilt as it was before, SBWR will update the permit number in order to reflect new plans, testing, and inspections (Young, 2019b). Several other reasons can be: the site is in between transition to a new owner, certain areas of landscape removed for parking and buildings, or a customer (new owner) decides to switch to potable water – this reason is very uncommon but it has occurred before (Young, 2019b). Table 1 shows a decrease of 529 AF (10,892 - 10,363 = 529) of water distributed from 2014 to 2015, with a continued decline through to 2017. The decrease in water distribution from 2015 to 2017 was a result of the county entering another drought and experiencing subsequent drier years. The reduction in water delivery was attributed to decreased internal use at the RWF and continued drought response including water conservation mandates (SWBR Annual State Report, 2017). The drought ended in 2017, indicating an increase of 1,992 AF (11,752 - 9,760 = 1,992) of total water distributed from 2017 to 2018.

Table 1: SBWR Number of Customers Served and Total Water Distributed (AF) 2014-18

Year	Total Number of Customers	Number of Prior Year Customers Who Did Not Use Recycled Water	Total AF Distributed	% Change From Prior Year
2014	785	10	10,892	3%
2015	818	16	10,363	-14%
2016	831	16	10,298	-9%
2017	880	19	9,760	-6%
2018	928	23	11,752	7%

Figure 5 illustrates the total amount of water (AF) distributed by water retailers in 2018. The City of Santa Clara distributed the most water at 4,211 AF. The City of Santa Clara distributing the most water is expected because it directly correlates with Figure 3, showing Santa Clara having the most recycled water permit customers. Among the four water retailers, the City of Milpitas distributed the least amount of recycled water at 1,252 AF - This is 2,959 AF

(4,211 - 1,252 = 2,959) less than the City of Santa Clara. Similar to data shown in Figure 3, Milpitas distributed less water overall because the city has the least amount of recycled water customers and is relatively smaller in size compared to the City of Santa Clara and San José.

Figure 5: SBWR Total Recycled Water Distributed by Retailer in 2018

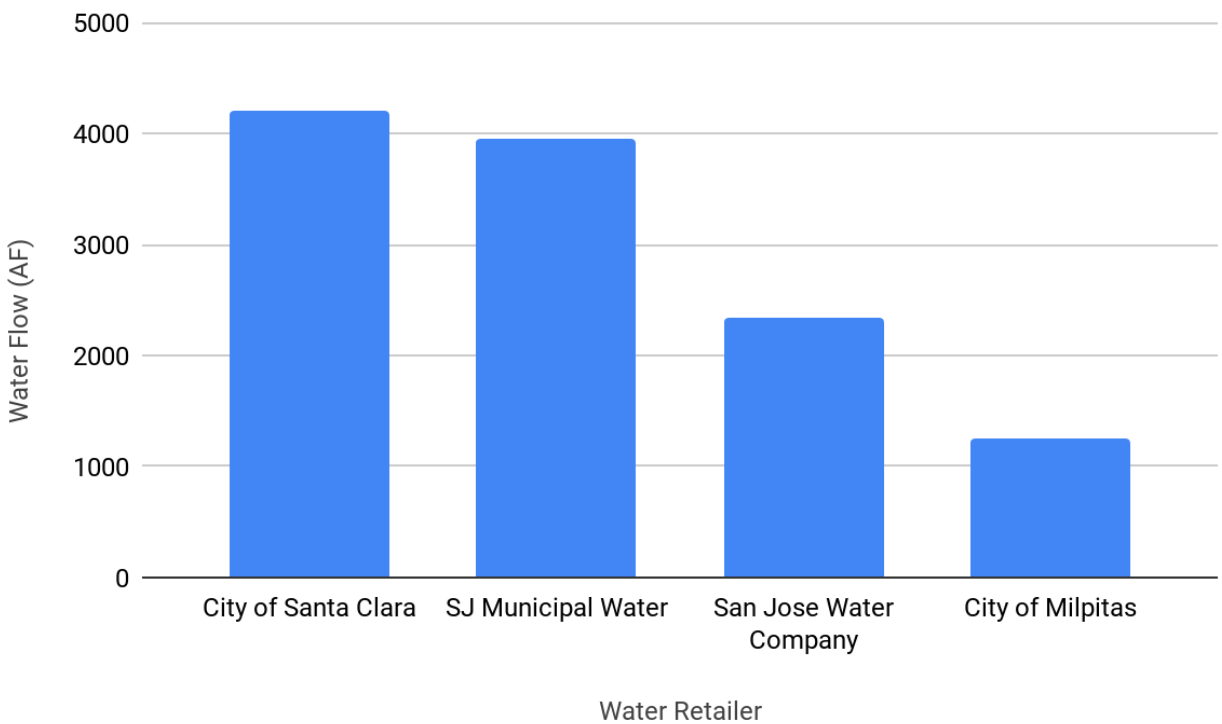


Figure 6 breaks down the total percentage of water distributed by SBWR's four water retailers in 2018. Comparable to the results shown in Figure 5 above, this pie chart shows the City of Santa Clara distributing the most water to their customers at 35.8%; SJ Municipal Water came in close at distributing 33.6%; then San José Water Company at 19.9%; and lastly, the City of Milpitas distributed the least amount of recycled water at 10.7%.

Figure 6: SBWR Percentage of Recycled Water Distributed by Retailer in 2018

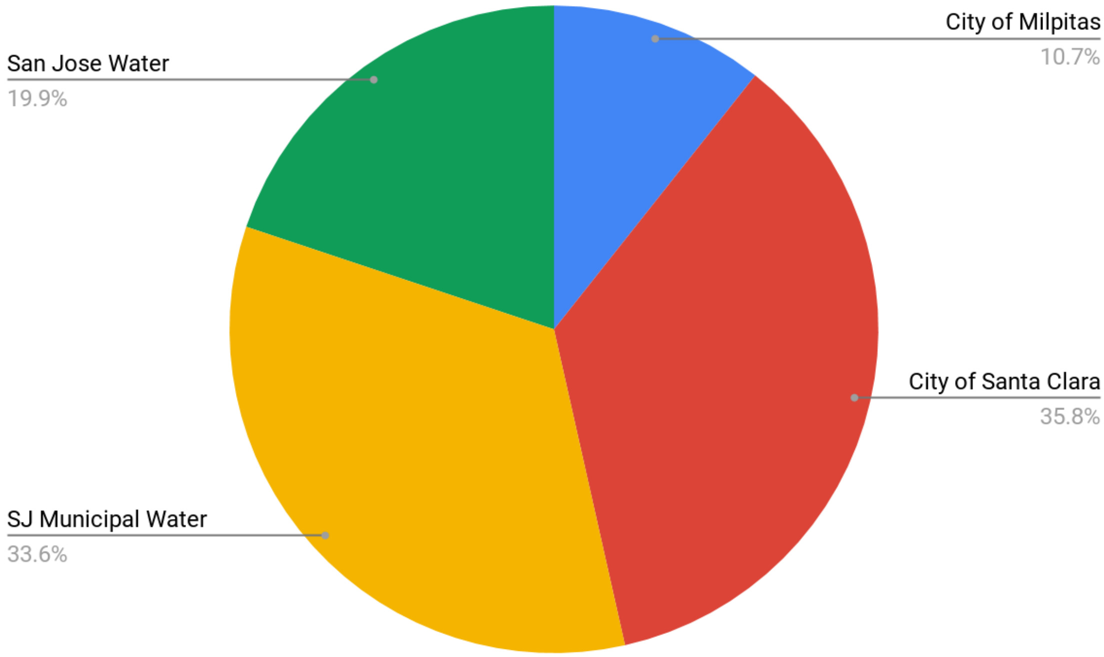
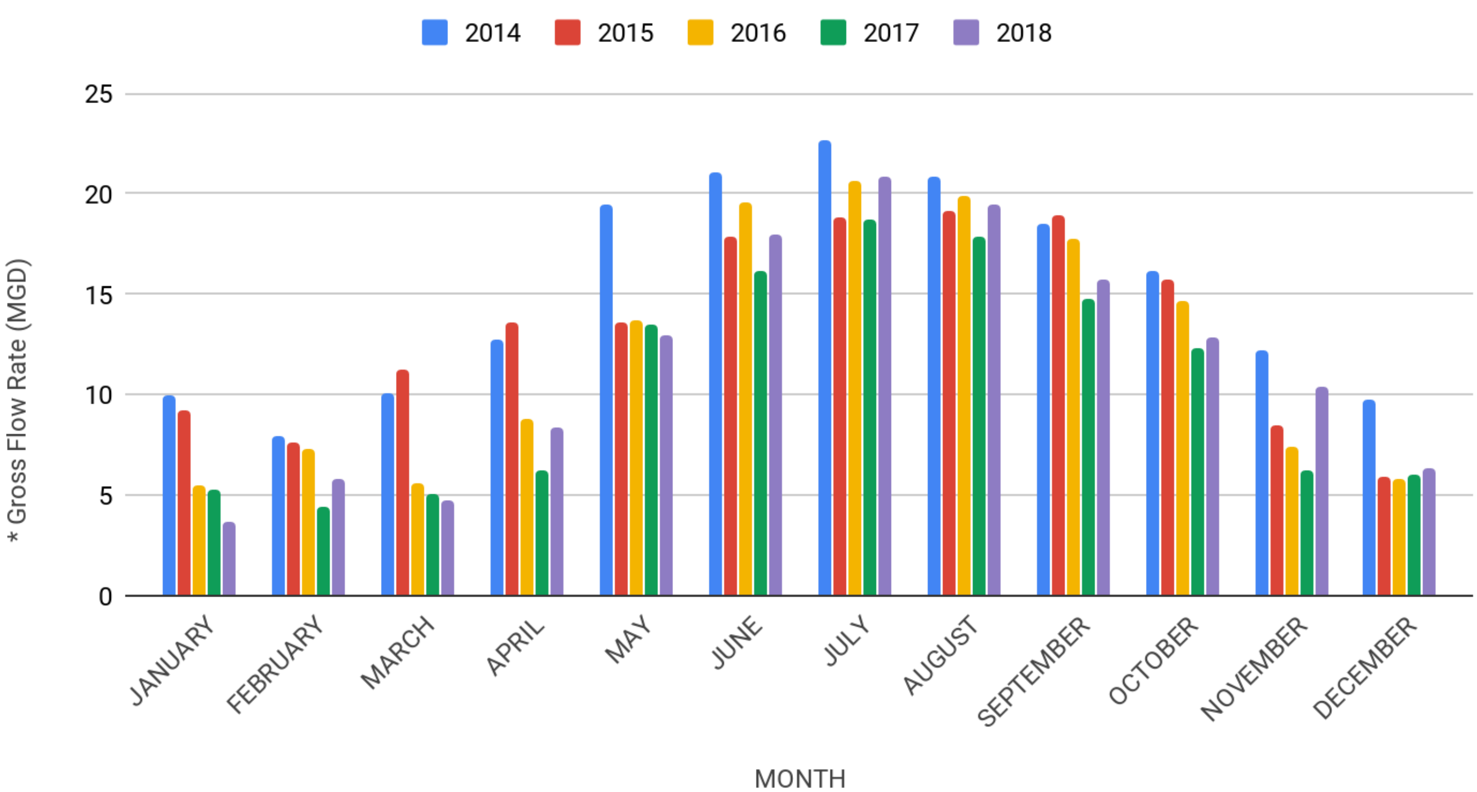


Figure 7 illustrates the monthly average flow rate (MGD) of recycled water from 2014-2018. The gross average flow rate is how much recycled water (MGD) is being produced each month before being transferred to SBWR's transmission pump stations (TPS) for distribution by the program's four water retailers. The figure shows a similar trend throughout five years, with less water produced and distributed in the cooler months of January, February and March, then gradually increasing in the warmer months from April to August, before steadily dropping again in September to December. In the warmer months, there is a higher production of recycled water because of a higher demand to irrigate agriculture and power cooling towers on industrial sites.

When comparing all five years, there is a noticeable difference with higher water production in the warmer months of 2014, and this is likely due to the implementation of the

Silicon Valley Advanced Water Purification Center (SAWPC) project. SVAWPC additionally produces up to 8 MGD of purified water and blends with SBWR's existing tertiary treated recycled water. The figure illustrates a similar declining trend in water production for the years 2015, 2016 and 2017 in comparison to 2014 in response to the county entering a drought, and enacting water use restrictions. With the drought ending in 2017, the figure shows a general trend in SBWR's water production and distribution increasing in 2018.

Figure 7: SBWR Monthly Average Flow Rates 2014-18



*Gross flow rate is total plant recycled water pumped to Transmission Pump Station (TPS)

According to the SBWR Strategic and Master Plan (2014), ADWEF is the measurement the wastewater facility uses to meet the NPDES Discharge Permit requirements. It accurately captures sewer usage, and stormwater run-off as well. SBWR calculates dry weather flow as any three consecutive months from May 1 to October 31 of each calendar year. Effluent is defined as wastewater that has been converted into freshwater before being discharged into the bay. In Table 2, the column labeled "Percentage Distributed During ADWEF Period" shows the approximate percentage of recycled water distributed to customers during the ADWEF period, and ranges from 35% in 2014 to 41% in 2018. From 2014-2018, the months of July and August have been consistently recorded as two of the three driest weather flow months each year. Average recycled water usage was the highest in 2014, then gradually declined through to 2017during the drought-caused restrictions, before increasing again in 2018. Under the column labeled "Total Water Discharged into the Bay (MGD)", the data shows all five years efficaciously meeting the discharge permit requirement of not releasing more than 120 MGD of effluent water into the South SF bay.

Table 2: SBWR Average Dry Weather Effluent Flow (ADWEF) Rates 2014-18

Year	Total Water Discharged into the Bay (MGD)	Percentage Distributed During ADWEF Period	Three Consecutive Months Recorded	Average Recycled Water Usage (MGD)
2014	76.0	35%	July, August, September	19.6
2015	68.9	36%	July, August, September	17.4
2016	73.0	41%	July, August, September	18.1
2017	77.8	41%	July, August, September	16.9
2018	79.4	41%	June, July, August	18.9

Figure 8 shows the total monthly influent water flow rates recorded in the last three years (2016-2018). The monthly influent flow data was calculated as the daily average (MGD) for each month (Young, 2019c). Influent is the untreated wastewater or raw sewage coming into the RWF treatment plant. RWF treats on average 110 MGD with a maximum capacity to treat up to 167 MGD (RWF, 2018). Roughly 80-87% of the tertiary-treated wastewater from RWF is discharged to the outfall channel and the remaining 13-20% gets transferred to SBWR (Young, 2019c). The tertiary-treated wastewater flows to Artesian Slough, through Coyote Creek, and eventually ending in the South San Francisco Bay (City of San José, n.d.). Influent flows into the San José-Santa Clara RWF before roughly 13% of the tertiary-treated wastewater gets transferred to the SBWR program for distribution to water retailers (SBWR Fact Sheet, 2016).

Figure 8 shows a similar trend across all three years, with the exception of a higher spike in flow rate for the months of January, February and March of 2017. Consistent with all the findings in this section, the influent flow growth in 2017 and 2018 was likely due to the county pulling out of a drought experienced in 2015-2017. Both 2017 and 2018 influent flow rates notably increased in comparison to 2016. With the exception of December 2017, influent flow rates in both 2017 and 2018 were at least 100 MGD every month. The average daily flow rate for 2016 to 2018 was 103 MGD.

Figure 8: SJ-SC RWF Monthly Influent Flow Rates (MGD) 2016-18

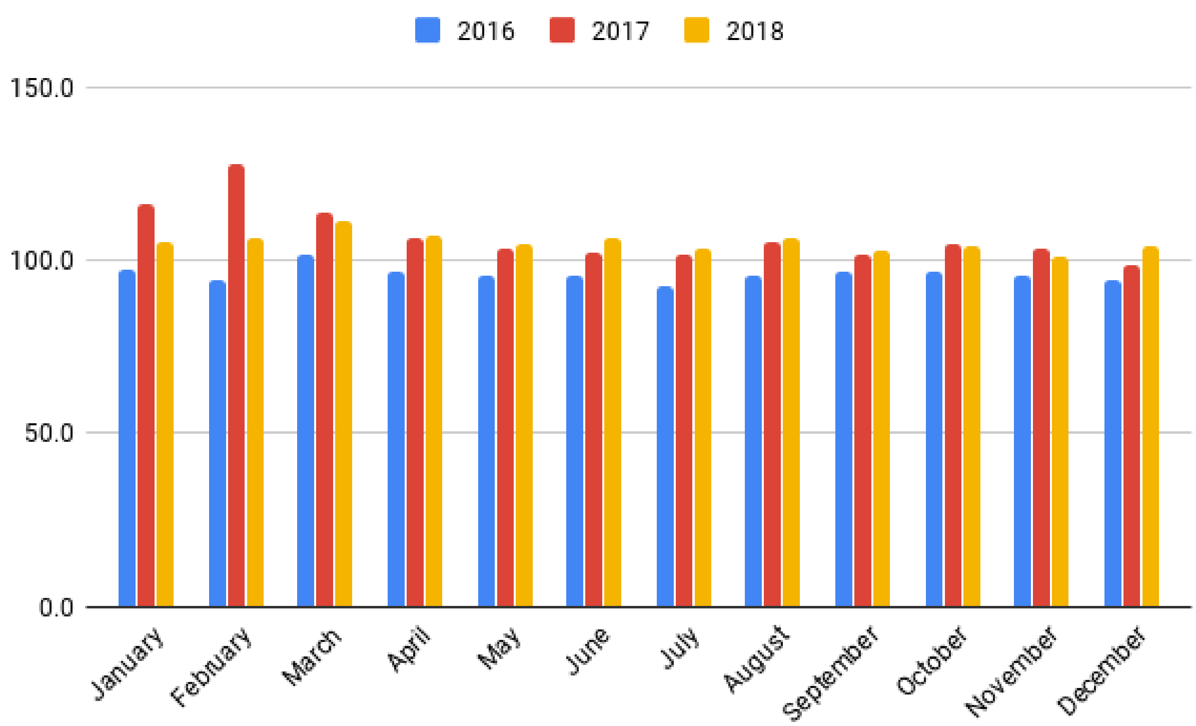


Table 3 shows a 2018 comparative analysis of recycling water outcomes of SBWR and four other water recycling programs located in Orange County (OC GWRS), Las Vegas (LVVWD), Singapore (NEWater), and Sydney, Australia (Sydney). SBWR's total water delivered and daily average water use was much lower in comparison to OC GWRS, LVVWD, and Sydney. This is likely because the SBWR program is running on a comparatively smaller scale than the four other programs. SBWR's maximum storage capacity was also the smallest, holding 9.5 MG, compared to LVVWD holding about 1 billion gallons in Lake Mead. Overall, LVVWD's water outcomes far surpass the four other water reuse programs. Although the program has the same amount of recycling water plants (2) as OC GWRS and SBWR, the total number of storage reservoirs exceeds both programs by 76 (SBWR) and 75 (OC GWRS) allowing the program to store and recycle more water at greater magnitudes.

Some values were missing from both Singapore's NEWater and Sydney's Water Recycling analysis. Singapore's NEWater program did not publish data on total water delivered (MG) and maximum storage capacity. However, available data showed that Singapore's NEWater program's daily average water usage was higher than SBWR (175 MGD), with five recycling water plants, and 17 reservoirs. Sydney's Water Recycling program did not publish data on daily average water use (MGD) and maximum storage capacity. Instead, Sydney provided data on the total water delivered, showing a higher number than SBWR (11,315 MG), with 14 recycling water plants and nine storage reservoirs. When comparing both NEWater's and Sydney's recycling water outcomes, it is logical to assume NEWater's total water delivered (MG) and Sydney's daily average water use (MGD) is likely higher than SBWR when comparing the available data.

Table 3: Recycled Water Comparative Analysis 2018

Program	Total Water Delivered (MG)	Daily Average Water Use (MGD)	Total Number of Recycling Water Plants	Total Number of Storage Reservoirs	Maximum Storage Capacity (Gallons)
SBWR	3,829	14	2	3	9.5 Million
*OC GWRS	32,703	89.6	2	4	560 Million
*LVVWD	93,671	309	2	79	1 Billion
NEWater	-	175	5	17	-
Sydney	11,315	-	14	9	-

*Values and data were provided by most recent year reported by the program (2017)

ANALYSIS

The primary purpose of this research was to identify whether the SBWR program achieved its planned recycled water outcomes, and how they compare to four other water reuse programs.

The first program goal was to increase industrial, landscape, and commercial recycled water usage. The program achieved this planned outcome, with research findings that showed SBWR distributing more recycled water to more customers by 2018. The data retrieved from the SBWR program only analyzes new customers obtaining a recycled water permit each year. Although the findings displayed a historic erratic trend in permits issued by each water retailer, SBWR was successful in amassing new customers every year with the extension of recycled water services for industrial and commercial use since implementation of the program (1996). The results showed that the total number of new recycled water permits increased each year from 728 customers in 2014 to 928 customers in 2018. The increase in new customers was likely attributed to a positive growth in economy, industry, and expansion of the recycled water mainline. Although there was a steady decline in recycled water use in years 2015-2017 due to a severe drought response limit on outdoor irrigation and nonpotable uses, water use gradually increased to 11,752 AF by 2018; an overall 4% increase from 2014. The increase in 2018's overall flow rate was due to heavier rainfall and the drought gradually ending in 2017.

The second program goal was to increase the production and distribution of recycled water. The program reached this goal outlined in the monthly average flow rate from 2014-2018 and total water distributed in 2018. With the exception of a decrease in total water distributed in years 2015-2017, possibly due to water conservation efforts as a drought response measure, total water distribution steadily increased in 2018. The findings analyze the amount of recycled water produced and distributed each month, showing the daily average flow rate lower in 2018 than

2014. This expresses a positive recycling outcome for the program because the reduction in 2018 monthly average flow rate, along with the increase in customers using recycling water when compared to 2014, is likely indicative of the South Bay practicing water conservation efforts and reducing the amount of water used every day. Additionally, the findings for influent water flow rates show a positive outcome, with an increase in wastewater entering the RWF facility from 2016 to 2018 for treatment before being pumped to SBWR for distribution. The recycled water is initially pumped into the RWF for treatment before a portion of it is transferred to SVAWPC for purification and disinfection, and then finally blending with SBWR recycled water before nonpotable distribution to customers.

The third program goal was to minimize freshwater discharge into the SF Bay during the three driest consecutive months. The findings display the Average Dry Weather Effluent Flow (ADWEF) rates from 2014-2018. According to the NPDES discharge permit, as set by SWRCB and EPA, SBWR achieved another planned recycling outcome of continuing to protect and preserve the salt marsh habitat, its wildlife, and local plant life by not discharging more than 120 MGD of freshwater into the San Francisco Bay. The most freshwater discharged within the five years was 79.4 MGD in 2018, showing notable improvement from an average of 130 MGD before implementation of the NPDES discharge permit (SBWR Strategic Plan, 2014).

Although some values and data were missing when comparing SBWR with other water reclamation programs in Orange County, Las Vegas, Singapore and Australia, the overall findings brought into perspective how much water was produced, the daily average water usage, and the different water distribution structures of SBWR in comparison to four other programs in 2018. All five programs use the same water recycling and treatment systems before distribution: microfiltration, reverse osmosis, and UV disinfection, as well as mainly distribute recycled water for industrial, landscape, and commercial use. The total water delivered (MG) value of Singapore's NEWater was not provided in public data. Instead, NEWater provided data on the percentage of water supplied and how it correlates with the country's water demands. NEWater's daily average water use is 175 MGD and is currently supplying 40% of Singapore's water demands. NEWater plans to increase supply to 50% by 2030, and 55% by 2060 (PUB NEWater, 2018c). Sydney Water Recycling Program did not provide daily average water use value, but instead published the total amount of water delivered to their customers, 11,315 MG in 2018. Sydney hopes to increase recycled water use and optimize the way they manage their water supply systems by 2020 to meet the growing needs of their population for a sustainable, drought-proof future (Sydney Metro Water Plan, 2017).

There was a significant limitation in the research when attempting to find comparable water recycling data and values for the other programs to analyze with SBWR. While, the four other water reclamation programs published different values that did not precisely align with SBWR program's data, the different values provided beneficial information on how each program implemented successful water recycling programs. The next limitation is that the values recorded for the five programs are not all from the same year. The most current year for which data was provided for Orange County and Las Vegas was 2017, while the most current year for SBWR, Singapore, and Sydney was 2018.

Another limitation of the program is the lack of water recycling piping in some regions of Santa Clara County. The city set specific regulations and requirements allowing implementation for water reuse piping in areas where the city is certain customers will purchase, such as major industries and campuses, but not residential areas, because residences are not plumbed for a separate water recycling system (SBWR Rules & Regulations, 2016). Sites may purchase and use recycled water approved by the State Department of Health Services (DHS) with a permit (SBWR Rules & Regulations, 2016). The state regulates recycled water use under Title 22 of California's Water Recycling Criteria. Title 22 outlines how water is treated and discharged, as well as requires the DHS to develop and enforce bacteriological treatment standards for water reuse (Water Education Foundation, 2019).

Figure 9: Outcome Evaluation of South Bay Water Recycling – Final Outcome Valence

PROGRAM	THEORETICAL GOAL	PROGRAM GOALS	PROXIMATE INDICATORS	PROGRAM MEASURES	OUTCOME VALENCE
South Bay Water Recycling Program	T_1: To increase water-recycling efforts and protect the salt marsh habitat in the South Bay	G_1: Increase industrial, landscape, and commercial recycled water usage (T_1) G_2: Increase the production and distribution of recycled water (T_1) G_3: Minimize freshwater discharge into San Francisco Bay during three driest consecutive months (T_1)	I_1: Total MGD and AF of recycled water is used (G_1-G_2) I_2: Number of permits issued (G_1) I_3: Average flow in MGD/AF of recycled water used per permit in 2018 (G_1) I_4: Average recycled water used by South Bay cities (G_2) I_5: Total MGD of effluent water discharged into SF Bay (G_3)	M_1: Compare permit issue per city (I_1-I_4) M_2: Compare all programs average water recycle use and Influent flow rates (MGD/AF) (I_1) M_3: Compare annual change in permits issued with average recycled water usage in 2018 (I_3) M_4: Compare annual change in total MGD effluent water discharged in the last five years (I_5)	+ + + +

CONCLUSION

The SBWR program must continue to work in collaboration with the RWF and SCVWD to effectively provide their customers with recycled water for nonpotable use in landscape irrigation, industrial cooling towers, power plants, plumbing in commercial sites, and for management of wildlife habitat preservation. Comprehensive data and analyses determined the Findings of this research, proving that the SBWR program achieved its planned water recycling outcomes in 2018. SBWR's strategy to increase recycled water usage, production, and distribution will maximize preservation of the city's drinking water supply; continue to preserve saltwater marshland habitats by diverting wastewater discharge away from the San Francisco Bay estuary; and create a more reliable water infrastructure for the South Bay, especially during drought years.

When analyzing data from the other water reuse programs and assessing it with SBWR, it is recognized that each program serves cities of different physical size and population using varying water sources. The Findings show that the diverse geographical make-up and industry of all five water-recycling programs may or may not be comparable, and thus their varying approaches offer examples rather than direct comparisons. All five programs have been shown to successfully implement sustainable water reuse programs, and continue to coordinate strategies and plans for improvements outlined in their annual reports.

Reclaimed and purified water is a significant and growing source of water. Recycled water is primarily used for agriculture, industry, and irrigation. The wastewater is treated to meet strict regulations and standards set by the SWRCB. Although SBWR recycled water is not used to recharge percolation ponds or for any groundwater sustainment activities, using recycled water helps conserve drinking water supplies by providing a drought-proof, reliable, and locallycontrolled water source. It reduces the community's dependency on imported water and groundwater, preserves the saltwater habitat by reducing freshwater discharge into the South San Francisco Bay, and minimizes treated wastewater discharge to the Pajaro River in the south county (Valley Water, 2018). Natural rainfall currently replenishes and recharges the county's groundwater basins, injection wells and percolation ponds. To reduce groundwater pumping and prevent land subsidence, SCVWD uses imported and local surface water to replenish groundwater and recharge ponds (Valley Water, 2019b). Water recycling, treated water deliveries, and water conservation indirectly preserves the county's groundwater basins by reducing demands on the groundwater supply. A recommendation for the SBWR program is possibly implementing a plan to use a portion of the recycled water to recharge the county's percolation ponds and groundwater subbasins.

California's lengthy droughts in recent years have made a tremendous impact in the South Bay's ability to import water from the Central Valley Project and State Water Project, placing a high value on recycled water as a critical water resource. SBWR continues to work towards expanding their water systems, and plans to double recycled water use by 2030 (SBWR Strategic Plan, 2014). The program's continued efforts to implement public and media outreach about water conservation emphasizes the importance of saving water for a sustainable future.

REFERENCES

APEC Water (2017). *Complete guide to home water filtration*. Retrieved from: https://www.freedrinkingwater.com/whole-house/water-filter-knowledge-base/how-does-ultraviolet-water-purification-work.htm

Australian Water Association (n.d.). *Water Recycling Fact Sheet*. Retrieved from: http://www.awa.asn.au/AWA_MBRR/Publications/Fact_Sheets/Water_Recycling_Fact_Sheet/AWA_MBRR/Publications/Fact_Sheets/Water_Recycling_Fact_Sheet.aspx?hkey=54c6e74b-0985-4d34-8422-fc3f7523aa1d

Badiuzzaman, P., Mclaughlin, E., & Mccauley, D. (2017). Substituting freshwater: Can ocean desalination and water recycling capacities substitute for groundwater depletion in California? *Journal of Environmental Management*, *203*, 123-135. doi:10.1016/j.jenvman.2017.06.051

Bansal, D. G. (2017, July 05). Toilet to tap? Some in drought-prone California say it's time. Retrieved from: https://www.mercurynews.com/2017/07/05/toilet-to-tap-some-in-drought-prone-california-say-its-time/

Bay Area Water Supply and Conservation Agency (BAWSCA). (2017, July). Water Recycling and Potable Water Reuse. Retrieved from: http://bawsca.org/uploads/userfiles/files/WATER%20RECYCLING%20AND%20POTABLE%20REUSE_Final_7_12_17.pdf

Brelsford, C., & Abbott, J. K. (2017). Growing into water conservation? Decomposing the drivers of reduced water consumption in Las Vegas, NV. *Ecological Economics*, *133*, 99-110. doi:10.1016/j.ecolecon.2016.10.012

City of San José. (n.d.). San José-Santa Clara Wastewater Facility. Retrieved from: http://www.sanjoseca.gov/index.aspx?NID=1663

City of San José. (2016a) South Bay Water Recycling Program: *Media fact sheet.* Retrieved from: https://www.sanjoseca.gov/DocumentCenter/View/34673

City of San José. (2016b) South Bay Water Recycling Program: *Rules and regulations.* Retrieved from: https://www.sanjoseca.gov/DocumentCenter/View/8603

Crum, R. (2018, October 28). Making wine to help save water: TJ Rodgers' latest venture. *San José Mercury News*. Retrieved from: https://www.mercurynews.com/2018/10/18/t-j-rodgers-svchat/

Deutsche Welle. (n.d.). Singapore's 'toilet to tap' concept | DW | 25.06.2013. Retrieved from: https://www.dw.com/en/singapores-toilet-to-tap-concept/a-16904636

Environmental Protection Agency (2018). Maintaining Potable Water Reuse in the United States: Strategies for leveling the playing field. Retrieved from: https://www.epa.gov/sites/production/files/2018-04/documents/mainstreaming_potable_water_reuse_april_2018_final_for_web.pdf

Erickson, S. (2016). Response to the 2016 Audit of the South Bay Water Recycling. City of San José. http://www.sanjoseca.gov/documentcenter/view/55499

Fishman, C. (2011). *The Big Thirst: The Secret Life And Turbulent Future Of Water*. New York, NY: Free Press.

Fulcher, P. (2017, December). Protecting and Maintaining Silicon Valley's Liquid Gold. Retrieved from: https://scholarworks.sjsu.edu/cgi/viewcontent.cgi?article=1555&context=etd_projects

Greywater Action (n.d.). *About greywater reuse.* Retrieved from: https://greywateraction.org/greywater-reuse/

Hanak, E., Lund, J., Dinar, A., Gray, B., Howitt, R., Mount, J. (2011). *Managing California's Water From Conflict To Reconciliation*. San Francisco, CA: Public Policy Institute of California.

Ishii, S. K. L., Boyer, T. H., Cornwell, D. A., & Via, S. H. (2015). Public perceptions of direct potable reuse in four US cities. *Journal - American Water Works Association, 107*(11), E559-E570. doi:10.5942/jawwa.2015.107.0132

Koch, J., & von Gottberg, A. (2009, November 16). Reverse Osmosis For Wastewater Recycling. Retrieved from: https://www.manufacturing.net/news/2009/11/reverse-osmosis-wastewater-recycling

Lamb, R. (2018, June 28). How Gray Water Reclamation Works. Retrieved from: https://science.howstuffworks.com/environmental/green-science/gray-water-reclamation.htm

Las Vegas Valley Water District. (2018, June 30). Comprehensive Annual Financial Report. Retrieved from: https://www.lvvwd.com/assets/pdf/comprehensive-annual-financial-report.pdf

Las Vegas Valley Water District. (2019, June 30). Operating and Capital Budget. Retrieved from: https://www.lvvwd.com/assets/pdf/financial-budget.pdf

Las Vegas Valley Water District. (n.d.). Water recycling. Retrieved from: https://www.lvvwd.com/water-system/water-recycling/index.html

Mellen, G. (2018, February 20). From waste to taste: Orange County sets Guinness record for recycled water. Retrieved from: https://www.ocregister.com/2018/02/18/from-waste-to-taste-orange-county-sets-guinness-record-for-recycled-water/

Monks, K. (2015, November 17). From toilet to tap: Drinking recycled waste water. Retrieved from: https://www.cnn.com/2014/05/01/world/from-toilet-to-tap-water/index.html

Mount, J., Hanak, E., Chappelle, C., Gray, B., Moyle, P., Thompson, B., & Lund, J. (2015). Policy Priorities for Managing Drought. Retrieved from: http://www.ppic.org/publication/policy-priorities-for-managing-drought/

M.W. Watermark (2016, July 19). *Overview of the history of water reuse.* Retrieved from: http://www.mwwatermark.com/en_US/overview-of-the-history-of-water-reuse-2/

National Academies of Sciences, Engineering and Medicines (2015). Understanding Water Reuse: Potential for Expanding the Nation's Water Supply Through Reuse of Municipal Waste Water. *Types of water reuse.* Retrieved from: http://nas-sites.org/waterreuse/what-is-water-reuse/types-of-water-reuse/

Oram, B. (n.d.). Water Research Center: *UV disinfection drinking water*. Retrieved from: https://www.water-research.net/index.php/water-treatment/water-disinfection/uv-disinfection

Orange County Water District. (2018, June 18). Groundwater Replenishment System: 2017 Annual Report. Retrieved From: https://www.ocwd.com/media/6822/2017-gwrs-annual-report.pdf

Orange County Water District. (n.d.a). Groundwater Replenishment System: Technical Brochure. Retrieved from: https://www.ocwd.com/media/4267/gwrs-technical-brochure-r.pdf

Orange County Water District. (n.d.b). Groundwater Replenishment System. *About us.* Retrieved from: https://www.ocwd.com/gwrs/about-gwrs/

Orange County Water District. (n.d.c). Groundwater Replenishment System. *The process.* Retrieved from: https://www.ocwd.com/gwrs/about-gwrs/

Public Utilities Board (2018a). Annual Report 2017-2018. Retrieved from: https://www.pub.gov.sg/Documents/annualreport2018.pdf

Public Utilities Board (2018b). Innovation in Water Singapore. Retrieved from: https://www.pub.gov.sg/Documents/Innovation_in_Water_Singapore_Vol10.pdf

Public Utilities Board (2018c). Our Water, Our Future. Retrieved from: https://www.pub.gov.sg/Documents/PUBOurWaterOurFuture.pdf

Public Utilities Board (2017): Corporate Brochure. Retrieved from: https://www.pub.gov.sg/Documents/PUBcorporatebrochure2017.pdf

Radcliffe, J. C. (2010). Evolution of water recycling in Australian cities since 2003. *Water Science and Technology: A Journal of the International Association on Water Pollution Research, 62*(4), 792. doi:10.2166/wst.2010.362

RWF [San José-Santa Clara Regional Wastewater Facility]. (2018) Treatment Process. Retrieved from: https://sanjoseca.gov/index.aspx?NID=1672

Santa Clara Valley Water District. (2019a). About the Water District: How we operate. Retrieved from: https://www.valleywater.org/how-we-operate/about-the-water-district

Santa Clara Valley Water District. (2019b). Central Valley Project. Retrieved from https://www.valleywater.org/your-water/where-your-water-comes-from/imported-water/central-valley-project

Santa Clara Valley Water District. (2019c). Your Water: Groundwater monitoring. Retrieved from: https://www.valleywater.org/your-water/where-your-water-comes-from/groundwater/groundwater-monitoring

Santa Clara Valley Water District. (2014, December). South Bay Water Recycling Strategic and Master Planning Report: Volume 1. Retrieved from: https://www.valleywater.org/sites/default/files/335%20P3%20Related%20Reports%20SBWR%20Stratigic%20and%20Master%20Plan%20-%20Report%20%28Vol.1%29%20%281%29.pdf

Shreeves, R. (2018, May 31). How 'toilet to tap' water is made. Retrieved from: https://www.mnn.com/lifestyle/recycling/blogs/taste-recycled-waste-water

Southern California Public Radio. (2014, March 14). Purple pipe means recycled water. But why purple? Retrieved from: https://www.scpr.org/blogs/environment/2014/03/10/16035/purple-pipe-means-recycled-water-why-purple/

Steen, M. (2018, March 14). Recycled drinking water - is it safe to drink treated effluent? Retrieved from: https://www.choice.com.au/food-and-drink/drinks/water/articles/recycled-drinking-water

Sydney Water Corporation. (n.d.). Sydney Water Annual Report 2017-18. Retrieved from: http://www.sydneywater.com.au/web/groups/publicwebcontent/documents/document/zgrf/mtk4/~edisp/dd_198655.pdf

Sydney Water Corporation. (n.d.). How We Managed Sydney’s Water: Recycled Water Network. Retrieved from: http://www.sydneywater.com.au/SW/water-the-environment/how-we-manage-sydney-s-water/recycled-water-network/index.htm

Sydney Water Corporation. (2017). Metropolitan Water Plan. Retrieved from: https://www.planning.nsw.gov.au/-/media/Files/DPE/Other/About-us/Metropolitan-Water/2017-Metropolitan-Water-Plan.pdf

Sylvia, R. & Sylvia, K. (2012). Program Planning & Evaluation for the Public Manager, Waveland Press, ISBN 1-57766- 778-6. 2012.

U.S. Census Bureau. (2018). Santa Clara County Population. Retrieved from: https://www.census.gov/search-results.html?q=santa+clara+county+population&page=1&stateGeo=none&searchtype=web&cssp=SERP&_charset_=UTF-8

U.S. Geological Survey. (2017, October 16). Land Subsidence in California. Retrieved from: https://ca.water.usgs.gov/land_subsidence/index.html

Valley Water. (2018) District Act. Santa Clara Valley Water District. Retrieved from: https://www.valleywater.org/sites/default/files/2018-02/2018%20PAWS%20Report%20-%20022118-1721-AM.pdf

Valley Water. (2019a) District Act. Santa Clara Valley Water District. Retrieved from: https://www.valleywater.org/how-we-operate/about-the-water-district/district-act

Valley Water. (2019b) District Act. Santa Clara Valley Water District. Retrieved from: https://www.valleywater.org/where-your-water-comes-from

Water Education Foundation. (2019). Water Recycling and Title 22. Retrieved from: https://www.watereducation.org/aquapedia/water-recycling-and-title-22

Whitaker, I. (2014, August 24). How our water goes from the toilet to the tap. Retrieved from: https://lasvegassun.com/news/2014/aug/24/how-our-water-goes-toilet-tap/

Young, M. (2019a). Personal Communication. San José, CA: City of San José.

Young, M. (2019b) South Bay Water Recycling: Annual State Reports 2014-2018. San José, CA: City of San José.

Young, M. (2019c). San José-Santa Clara Regional Wastewater Facility Influent Flow Data. San José, CA: City of San José.