Water Supplies in the Southwest
Making a Finite Supply Sustainable for a Growing Population

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12/1/14

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Abstract

Across the world, populations continue to grow while water supplies stay fixed. In the American Southwest, water supplies are at an all time low, yet warm, favorable conditions continue to lure residents to the area. With some of the country's lowest fresh water reserves, it is imperative that changes are made to water usage trends and associated energy inefficiencies.

An analysis of water usage in Tucson was conducted to evaluate potential solutions for reducing consumption and to correspondingly shrink energy usage. Case studies were investigated, census numbers were used to roughly calculate statistics, existing knowledge on water conservation techniques were researched, and alternative water filtration as well as distribution systems were scrutinized for their viability amongst current infrastructure.

The potential to reduce water usage is greatest with the largest user of water in Tucson, the single-family residence. On average the single-family residence is capable of effectively saving nearly 25,000 gallons of water per year with efficient fixtures, another 25,000 gallons per year by reducing outdoor water use by half, and another 10,625 gallons by utilizing rainwater harvesting. Combine those savings and multiply them by the 225,000-240,000 single-family residents estimated to be in Tucson and the savings reach more than five billion gallons a year, effectively almost cutting water consumption in Tucson by a fifth. Further, to keep remaining usage impacts negligible, implementation of an indirect or direct potable water reuse system could satisfy populations for decades by reusing water that would normally be discarded as effluent.

Water consumption must be curved so that it can satisfy a growing population's needs. Amongst residents of Tucson, single-family residences have the greatest potential to reduce water and associated energy needs. Through conservation techniques, water harvesting, reducing outdoor water usage, and potable reuse, limited water supplies can satisfy future generations to come.

Introduction

As humans have reached a population of over seven billion, it has become increasingly apparent that our earth and its resources are finite. The United States has morphed into a society of consumerism, where waste of resources and lack of efficiency as a norm have given us no choice but to eventually face the consequences of our carelessness. The combustion of fossil fuels as a primary source of energy has contributed to huge environmental concerns. Global warming accompanied by overpopulation has created a worldwide climatic change with numerous consequences. This Anthropocene, or period of human induced change across the globe, has created many negative effects including mass extinction of flora and fauna (Dirzo, Young, Galetti, Ceballos, Isaac, and Collen. 2014), dwindling energy sources, unsustainable harvesting of natural resources, weather patterns becoming volatile and unpredictable, and large-scale depletion of freshwater reserves (Singh, 2008).

As these problems have become prevalent, a greater interest in the name of sustainability has evolved. Emanating from early societies who believed in conserving the limited supplies they possessed, sustainability concepts can be traced back thousands of years to numerous cultures across the globe. Sustainability is a broad concept, but essentially it encompasses human growth in physical, economical, and industrial ideals while not damaging the earth's vital systems and its resources (Adams, 2006). Even early philosophers tried to spread word of potential problems through literature such as <u>An Essay on the Principle of Population</u>, written by Thomas Malthius, criticized human nature and its eventual devastation through its own overpopulation.

During the industrial revolution in the 18th century, humans became even more dependent upon fossil fuels to power their latest technologies. An unprecedented population boom occurred due to a combination of events including the adoption of coal as a cheap and bountiful energy source, the improvement of technology and medicine, as well as the creation of modern sanitation techniques. After the Second World War, a booming economy led to urban sprawl as suburbs dotted the periphery. Finally, during the 1970's, environmental concerns started making their presence known through activists, published documents, studies, and acts such as the Safe Water Drinking Act (SWDA) and the Clean Water Act (CWA).

As the population grew in the United States, areas with the most abundant resources were inhabited first. Places near ports, rivers, natural resources, and more comfortable conditions took first priority (Maddock and Hines, 1995). After these, areas that were originally overlooked or more difficult to cultivate were next. These less desirable geographic locations included areas that faced extreme climates, were further from water sources, offered little or difficult to attain natural resources, or had other conditions that prevented easy habitation.

The arid Southwest was one of these places to be initially overlooked. Early inhabitants included Native American tribes, missionaries, and explorers. It wasn't until technologies such as railways for transportation, building improvements for comfortable living, and easily imported supplies allowed the rugged Southwest to be easily inhabited.

It became apparent as time passed, and as technology improved, that those once over-looked locations were quite habitable. A population boom due to cheap real estate, minimal building regulations, warm climate year round, and a plethora of jobs was easily recognized in the developing Southwest (Akros, 2007). As population grew though, it also became clear that these geographies weren't ideal to sustain large populations. Extreme temperatures during the summers and limited water sources were some prominent problems. These areas needed a supplemental source of water if they planned on continuing this oasis in the desert (Maddock and Hines, 1995).

In order to solve this problem, the Central Arizona Project (CAP) began construction in 1973 and was declared complete in 1993. The CAP is a 336-mile aqueduct that brings agricultural water to Maricopa, Pinal, and Pima counties and municipal water to Phoenix and Tucson from the Colorado River (Modeer, 2010). This was an adequate solution with the exception of its high-energy use and expensive construction costs. The CAP has never been the ideal situation for water in the Southwest, but its ability to get the job done and satisfy the needs of 80% of Arizonans has generally justified the means (Modeer, 2010).

As climate change progresses though, the Southwest is experiencing some of the worst droughts in history. The Colorado River is dropping year by year and reservoirs that are associated with the river are visibly dropping with it. Population continues to grow, so water demand is at an all time high (James, 2014). The combination of these things for the millions of residents that depend upon the CAP for their water creates very real problems that residents will soon have to face

If a solution is not found, water shortages for areas dependent on the CAP are very likely to occur. This paper will attempt to examine the efficiency of water transportation through the CAP, methods of water conservation, water harvesting, decentralization of water systems, and potable water reuse to offer enlightenment and try to partake in the solution to water shortages in Tucson and the general Southwest.

Literary Review

An Introduction to Water in the Southwest

Throughout the Southwest's history, it has been noted that water has been the general staple settlers were drawn when looking for a permanent settlement (Maddock and Hines, 1995). Ancient Native American civilizations originally inhabited the land, using irrigation from the area's rivers to create arable landscapes. As time passed, settlers came to the area following previous trends and inhabited places nearest bodies of water. In Phoenix it was near the Salt and Verde rivers (Maddock and Hines, 1995), and in Tucson, the Santa Cruz River drew in missionaries and soldiers. While the lands were generally arid, these modest rivers could only sustain a modest crowd. Today, the southwest area contains only 2.3% of the national supply of renewable water sources, or in other words, an extreme lack of water compared to the rest of the country (Maddock and Hines, 1995).

After the Second World War, these southwestern cities ushered in an era of prosperity and economic growth. Due to many new jobs, a mild and sunny climate, and affordable housing, Tucson and the rest of the Southwest grew at an unparalleled rate (Akros, 2007). To this day, the Southwest is one of the fastest growing parts of the country (Maddock and Hines, 1995). In areas with warm climates such as California, Nevada, Texas and Arizona, the growth rate was observed to be between 85% to 400%. This dwarfed an average rate of 50% across the rest of the country. Arizona in particular grew at a rate of 300% between 1970 and 2009 (NRC, 2012).

Even more impressive, the U.S. Census Bureau predicts population to grow by 50% between 2010 and 2060. During the unprecedented population growth between 1970 and 2009 also came unparalleled water usage to match. According to the National Research Council's 2012 report, public water use has risen from 14 billion gallons per day (BGD) to 44.2 BGD from 1950 to 2005 (NRC, 2012). In Arizona alone, the water usage report issued the latest year shows a total water usage of over 2.5 trillion gallons per year, or slightly over 7 BGD (Snyder, 2014). Throughout the country, overall water use is about 210 BGD given public, agricultural, and energy needs (NRC, 2012). Typically, the average person uses about 70 gallons per day for indoor activities such as toilet flushing, showering, cleaning dishes, etc. and between 20-60 gallons per day (or 30-60% of total domestic demand) for landscaping and irrigation (Garrison, Kloss, & Lukes, 2011). When we look at statistics, water usage in the public sector has generally risen due to landscaping needs, especially in arid areas such as the Southwest (NRC, 2012).

While water supplies in the Southwest seem to be stable, building new infrastructure to satisfy water needs of growing populations is beginning to approach its limits (NRC, 2012). Water supplies are becoming increasingly expensive and competition for water is starting to become an imminent problem (Woods, Gwendolyn, Kang, Quintanar, Curley, Davis, Lansey, & Arnold, 2013). As water reserves dwindle, the negative impacts of human civilization on stream ecology and aquatic pollution are also slowing down infrastructure development (NRC, 2012; Woods et al., 2013).

As humans evolve and their population grows, their standards of living, urbanization, industrialization, and agriculture all increase proportionally, which consumes more water (Singh, 2007). This increase coupled with humanity's newest obstacle, climate change, is beginning to create complications never witnessed before by mankind. Across the Southwest 30 weather stations have recorded an increase of 25% of days hotter than 90 degrees within the past 20 years (James, 2014). As the climate gets warmer, evapotranspiration increases, creating a greater need for water in agricultural applications, and changing weather patterns will require changes in infrastructure (NRC, 2012) while droughts are expected to intensify, extend, and become more frequent (James, 2014). Currently, the Southwest faces one of the worst droughts the Colorado Basin has experienced in 1200 years (James, 2014). Furthermore, scientific modelling predicts a 20-25% drop in precipitation in the Southwest by the end of the century even if we decrease our current climate-changing emissions immediately (NASA, 2014). Lake Powell reservoir sits at around 50% capacity (NASA, 2014), Lake Mead is at 41% capacity (Walton, 2010) and is dropping approximately a foot a week (James, 2014). In Ian James' article, Peter Gleick states, "We're past the point of 'peak water' in the western U.S. We overdraft our groundwater, we take too much from our rivers and streams, and so, even without climate change, part of the answer is changing the way we manage the system, improving especially the efficiency of our water use."

In 2006, the United Nations stated "between two and seven billion people will face water shortages by the year 2050. Even today about 80 countries, comprising 20% of the world population are suffering from serious water shortage" (Verstraete, Caveye, and Diamantis, 2009). The security and safety of water for the human population is directly related to global health, economic progress, and energy derivation (Qu, Brame, Li, & Alvarez, 2013).

Water is also needed to produce all forms of traditional energy today, which is collectively referred to as the "water-energy nexus". Water is generally consumed to spin turbines and for cooling purposes. For coal-based electricity an average of 510 gallons per megawatt hour (g/MWh) are necessary. For natural gas approximately 415 g/MWh are needed. For nuclear about 785 g/MWh are required, and the biggest consumer due to reservoir evaporation in increasingly arid climates, is hydroelectric energy with 30,078 g/MWh that are needed (Arroyo, 2010). In Arizona, Palo Verde, Redhawk and Kyrene power plants use approximately 63 million gallons per day (MGD) of water effluent for cooling purposes. (Arroyo 2010). In addition to needing water to create energy, transporting water also consumes energy. The state of Arizona estimates that three to four percent of domestic energy use is put towards electricity for drinking and wastewater solutions, with the majority of that energy consumed by transportation of the water (DOE, 2013). In the state of Arizona, the Central Arizona Project (CAP) demonstrates the water-energy nexus very clearly.

CAP

As the population of the Southwest boomed in the mid 1900's, it was apparent that the natural water systems of the area weren't enough to sustain the population according to the standards of living that were becoming normalized (Singh, 2007). The US Bureau of Reclamation was forced to find a solution to its new problem. The solution to water shortage in the Southwest, or more specifically Arizona's driest regions of Phoenix and Tucson, was to build the country's largest aqueduct.

At 336 miles long and rising almost 3000 feet, the Central Arizona Project (CAP) was the solution to water distribution to the Southwest. The CAP began construction in 1973 and brought Colorado River water from Lake Havasu to its final destination in Arizona. It was completed in 1993 and was planned to extend to New Mexico, but due to financial complications, it made its final reach to the outskirts of Tucson (Modeer, 2010; Arroyo, 2010). Today, the CAP accounts for about 80% of the water Arizonans use in cities, towns, irrigation districts, private industry, and Native American communities (Modeer, 2010; Arroyo, 2010).

The Navajo Generating Station (NGS) was built in conjunction to power the CAP and also to provide for a deficit of energy in the surrounding areas of California, Arizona, and Nevada with the growing population (Modeer, 2010). In 2009, the CAP consumed approximately 2.8 million MWh in pumping energy to deliver 1.6million acre-feet of water over the 336-mile, 3000 foot elevation gain and was deemed the single largest consumer of energy in the state of Arizona (Modeer 2010; Arroyo 2010). The NGS currently accounts for about 95% of the energy the CAP uses today (Modeer, 2010). Under contract the NGS gives about 25% of its energy (or 4.3 million MWh per year) to the CAP. The remainder of energy is sold on the energy market to help repay construction costs and pay the Indian reservations (Walton 2010).

As the largest energy consumer in Arizona, the CAP has a water intensity of about 9.8 kWh/kgal to get to Tucson. Water intensity is defined as how much energy is needed to deliver a certain amount of water (Arroyo 2010). As a comparative example, reports have shown that pumping groundwater from other locations in Arizona can range from slightly over 1 kWh/kgal to 3 kWh/kgal depending on depth of well and drilling/pumping requirements to get to water sources (Arroyo 2010). In relation to the immense energy that the CAP uses, the greenhouse emissions from energy production are also noted. A report by Garrison, Kloss & Lukes (2011) stated that 45 million tons of carbon dioxide emissions are released into the air just from the water sector in the US each year. In 2009, new requirements for clean air regulations imposed serious retrofits that could have cost anywhere from around 50 million to over a billion dollars to the NGS (Modeer, 2010; Walton, 2010; CAP, 2014). The NGS faced potentially closing, which would have implied huge energy cost jumps for CAP distributors and users. Fortunately this year, the NGS settled upon a reasonable outcome that will keep it contracted as the primary and cost efficient CAP energy provider until at least 2044 (CAP, 2014). The CAP is currently looking into renewable sources of energy, but due to limitations in energy storage for nighttime and cloudy day use, neither wind nor solar systems are at a technical point to provide adequate solutions (Modeer, 2010).

Water Conservation

It is noted that water conservation can be the cheapest and most efficient strategy to mitigate water shortages (NRC, 2012). The typical household uses around 260 gallons of potable water a day (epa.gov, 2014), with almost 80% of these needs not requiring potable water (NRC, 2012). Inside the home, the typical person uses around 70 gallons a day for activities such as showering, toilet flushing, dish cleaning, and laundry (Garrison, Kloss, & Lukes, 2011). On average in the US, around 30%, or 6 BGD (Garrison, Kloss, & Lukes, 2011) of indoor water use is for toilet flushing (epa.gov, 2014). In addition to indoor wastes of potable water, outdoor uses are the largest culprit of drinking water waste. On average, outdoor use accounts for 58% of average household use and 38% of commercial use.

Another important, underlying contributor to the over-usage of water around the country is the extreme underpricing of water at the tap. In the US, one penny can buy anywhere from 1.2 to 10.6 gallons of tap water varying with pricing in certain areas (U.S. EPA, 2004). As a result the US is the second largest waster of potable water per capita in the world next to Canada, who coincidentally, also has cheaper water prices than the US (Garrison, Kloss, & Lukes, 2011). In Tucson, water prices have a tiered rate. There is a base monthly service charge for the customer depending on their meter size, 5/8" is common for most single-family residences and has an associated charge of $11.00 per month. After that water rates are tiered by how much is used by the customer. The first tier which is from 1-10 Ccf (A Ccf is 748 gallons) has a charge of $1.38 per Ccf, the second tier which ranges from 11-15 Ccf is $3.00 per Ccf, the third is 16-30 Ccf with $7.00 per Ccf, and the final tier is anything over 30 Ccf at $11.25 per Ccf. When you do the math, for a single-family residence, the cheapest tier comes to be around a third of a penny per gallon for 7480 gallons (or 10 Ccf) of water. At the highest tier, using 31 Ccfs of water (or 23,188 gallons), the price comes to a penny and a half per gallon of water. Considering water is a scarce supply, paying a maximum of 1.5 cents per gallon of water seems counterproductive.

Consumer choices can help mitigate wasteful water use. There are a variety of things that can be done in order to use less water in the home or business. Doing simple things like not keeping the water running while shaving or brushing teeth can be an easily accomplished water and energy saver. The EPA notes that running a faucet for five minutes while you are using it consumes as much energy as using a 60-watt light bulb for 14 hours and wastes up to 8 gallons of water (epa.gov, 2014).

Taking shorter showers and avoiding baths can also save an immense amount of water and thus energy as well. Showers typically use around 5 gallons per minute (gpm) so taking a 5 minute shower as opposed to a 10 minute shower can save as much as 25 gallons of water. A full bathtub can require up to 70 gallons as well, so taking showers more often than baths and not filling bath tubs all the way to the top can be simple strategies to save water (epa.gov, 2014).

Consumers can go a step further and buy WaterSense® fixtures or ENERGYSTAR® appliances to save water and energy. Buying a more water efficient toilet can save around 2 gallons per flush. If water efficient toilets were installed across the country nearly 2 billion gallons would be saved per day. It is also estimated that investing in a high-efficiency toilet can save as much as $2,000 in water bills for a family of four over the lifetime of the toilet. It is estimated that if every household in America were fitted with these fixtures 60 billion gallons of water could be saved annually (epa.gov, 2014). Replacing faucets with high-efficiency alternatives can also reduce the flow of water by nearly 30% without any noticeable decrease in performance. High-efficiency showerheads can also be purchased for as low as $10-20 a piece and can save around 25-60% of water that would normally be used. Washing machines that are efficient can use between 35-50% less water and half as much energy as regular washers. Hot water heaters are also huge energy users. They generally account for around 13-25% of your utility bill. Switching to a solar, tankless, or heat pump water-heater can save you energy and associated water (epa.gov, 2014). Generally, all the fixtures are reasonably priced and pay for themselves in the long run. Exceptions to cheaper strategies include solar water heater systems, high-efficiency washing machines, and energy efficient dryers, however they generally pay for themselves over time while providing the satisfaction of doing one's part to conserve water and energy.

Irrigation and landscaping needs also play a large part of water use in residential and commercial settings. According to the U.S. EPA, almost 50% of dialy water consumption is used for irrigation or outdoor purposes. In hot and dry climates such as Tucson, it has been found that irrigation needs during the summer can surpass total water needs for the rest of the year for a household. Water conservation strategies can vary depending on how much water is aimed to be saved, but can have as strong an impact as completely cutting out all outdoor water needs if desired. By doing simple things such as choosing native species that don't require extensive watering, watering plants in the morning to reduce evaporation, and using drip irrigation systems, you are saving water and energy (epa.gov, 2014).

Water Harvesting

Water harvesting has great potential to help alleviate water shortage, cut down energy use, and lower greenhouse gas emissions. Rooftop water harvesting is a simple and cost effective way of supplying sustainable water to users without complicated and wasteful infrastructure requirements (Garrison, Kloss, & Lukes, 2011). Benefits of water harvesting include free on-site water, minimized energy costs associated with transporting water, reduced strain on existing, overloaded centralized systems, and reduced runoff (Garrison, Kloss, & Lukes 2011).

A study of eight different substantial cities across the US concluded that between 21 and 75 percent of necessary water for its corresponding city could be captured through rooftop water harvesting (Garrison, Kloss, & Lukes, 2011). For Tucson, using rainwater harvesting could potentially reduce residential water needs by 30 to 40 percent (Yoklic, Riley, Confer, Robinson, Lancaster, Philips, & Kroesen, 2005). In areas that have heavier rainfall, potential for water harvesting is greater depending on the amount of impermeable roof area.

In addition to rooftop rainwater harvesting that utilizes cisterns and gutter systems, passive water harvesting with infiltration basins, diversion swales, and basic dam structures can redirect storm water to vegetation and areas that can utilize the water (Garrison, Kloss, & Lukes, 2011). For example, Tucson has already been taking small steps towards widespread water harvesting techniques. A mandatory requirement passed in June 2010 requires all commercial development to utilize rainwater harvesting for at least 50% of its landscaping water needs (Garrison, Kloss, & Lukes, 2011).

Rooftop runoff is sometimes referred to as “clean runoff” since it contains minimal pollutants compared to other sources of runoff. These pollutants consist of bird droppings, roof coatings, and environmental “dust”. Furthermore, once the first rinse of the roof is accounted for, the rest of the water runs off relatively pollutant free. A simple device called a “first flush” device can be installed on any cistern or roof catchment system that allows the first rinsing of contaminants to be diverted (and contained if desired) so that catchment water is even cleaner (Garrison, Kloss, & Lukes, 2011). From that point, water can be used accordingly. Generally further treatment is recommended if potable water is desired, but for non-potable uses, the water can be distributed as the owner deems suitable-free of charge and energy requirements (granted the system is gravity fed). Traditional treatments such as chlorination, UV, ozonation, and iodine are possible if the final product is to be safely used as a potable resource (Georgia Department of Community Affairs, 2009).

Water harvesting, whether actively (cisterns) or passively (basins, swales, etc.), also helps to keep other water supplies cleaner and less polluted. Roads, sidewalks, parking lots, rooftops, and any other impermeable, man-made structures create excess runoff that carries everything on ground surfaces to be taken to final water resting areas. When storm water runoff runs across non permeable surfaces, it collects bacteria, animal wastes, pathogens, contaminants from cars, oils, metals, and any other pollutants. The pollutants are then carried to drainage systems or bodies of water where they impact natural systems and further pollute wastewaters. Rooftops consist of about 25% of total impervious surfaces and would reduce runoff considerably (Garrison, Kloss, & Lukes, 2011).

Complementing water harvesting, gray water systems can be used and are usually implemented on a residential scale if utilized. Gray water systems are simple devices that make use of disposed of water that is usually sent to sewer systems. Showers, faucets, and laundry machines can all contribute to a gray water system for use in landscaping and irrigation purposes. Tucson Water estimates that less than one in a hundred of households in Tucson utilize gray water systems even though they offer rebates for half of the cost, up to $1000 (water.tucsonaz.gov, 2014). For some, systems are very simple to set up depending on where water expelling fixtures and appliances are located. If washing machines or sinks are located outside they are prime candidates for gray water systems since gradually sloped piping can be easily and affordably be set up to direct expelled water to vegetation. However, it is more challenging to set up indoor-to-outdoor systems since plumbing is usually fixed within floor foundations as well as within the walls. In *Rainwater Harvesting for Drylands and Beyond* by Brad Lancaster, an average family of four can reuse 3,132 gallons per year from high-efficiency washing machines and 11,688 gallons per year of low-flow bathroom sink and shower water for gray water purposes. This doesn't account for kitchen faucets either. The potential for an entire city, or more than one percent, to utilize gray water should not be overlooked.

Unfortunately in the US, the water system often provides no allure for consumers to utilize rainwater harvesting for its potential. Water prices are so cheap that they provide no stimulus for users to invest in systems that can be relatively costly upfront. Stormwater fees are generally flat fees as well, and also provide no encouragement for users to divert water to cisterns or keep it on property for potential non-potable needs such as landscaping. Many water consumers that irrigate also do not realize in addition to the water prices at the tap, they are also paying a sewer fee to dispose of the potable water they are using on landscaping (Garrison, Kloss, & Lukes, 2011). As Garrison, Kloss, and Lukes so eloquently state, "rational pricing encourages rational use" and likewise, irrational pricing encourages irrational use.

Centralized Water Systems and Associated Weaknesses/Problems

Today, in developed areas of the United States, the primary method of water filtration, distribution, and disposal is accomplished through centralized water systems. Centralized systems are publicly owned, large-scale, piped water treatment plants that distribute water or collect wastewater from a large part of the municipality they are designed for. With the adoption of the Clean Water Act (CWA) and the Safe Drinking Water Act (SDWA) in the early 1970's, water treatment for both drinking and discharge purposes was now required to meet certain criteria.

Centralized systems for smaller municipalities during that time were the solution to the problem (NRC, 2012).

For drinking water the SDWA called for the United States Environmental Protection Agency (USEPA) to create standards on all public water systems serving 25 or more people, or having 15 or more water main connections. These standards included both primary and secondary standards. Primary standards included maximum contaminant levels of certain established contaminants that cannot be exceeded. Secondary standards are not enforced but recommended as guidelines and are things such as water odor and appearance (Drinan & Whiting, 2001).

For wastewater effluent the CWA was established in 1972 by the USEPA to standardize wastewater discharge. Basic standards mandated that wastewater be given secondary treatment to meet set conditions. Secondary treatments were appointed to reduce the content of suspended solids, biodegradable materials, and pathogens to acceptable levels before reinserting them back into nature (Drinan & Whiting, 2001).

Centralized systems allowed and continue to allow entire municipalities to attain and dispose of water within these new restrictions. While these central systems satisfy their purpose, they are not without their drawbacks.

Centralized infrastructure has numerous flaws. Since it encompasses extensive systems that include treatment plants, underground piping, and remote pumping stations, modifying systems can be very costly. Repairs and leaks (which can be toxic) often cost more than installing that infrastructure in the first place since often there is development over old infrastructure that must be destroyed and rebuilt to access necessary components (Rodríguez-Hernandez , Gonzalez-Viar, De Florio, & Tejero, 2012). Also as cities and towns expand, they tend to add to the periphery of the city cluster while still relying upon old centralized infrastructure (Woods et al., 2013). This makes water distribution increasingly difficult to implement because it requires new infrastructure and additional pumping stations. In Tucson, there are now communities up to 30 miles away from centralized wastewater treatment facilities that require over 50 stations just for pumping (Woods et al., 2013).

In addition to being costly to construct and maintain, extensive energy usage is utilized by these systems. The US Department of Energy (DOE) places world water related energy uses at around 7% of world total energy usage (DOE, 2013). Another report states California uses approximately 19% of its electrical and 32% of natural gas energies on water related activities (CEC, 2005; GEI Consultants/Navigant Consulting, 2010). Overall, the EPA estimates that around 4% (75 billion kWh) of US energy is consumed by water treatment and transportation per year (DOE, 2013). To be more specific, transporting water from treatment plants to users and then to wastewater plants is biggest electrical expense for US cities (Walton, 2010). Around 80% of municipal water treatment and distribution energy usage is consumed by pumping water to its destinations (DOE, 2013). To give an example, treating drinking water in Tucson only requires a fraction of a kWh for 1000 gallons while treating wastewater consumes about one kWh/kgal, but transporting the water here via CAP takes approximately 9.8 kWh/kgal (Arroyo, 2010). To contribute to this energy usage even more, wastewater related energy usage is expected to rise by nearly 50% by 2050 due to more aggressive treatment requirements. Chlorine will eventually be phased out of drinking water due to mounting evidence of its carcinogenic effects. This will lead to the adoption of even more energy intensive treatments such as Ozonation and UV treatment. On top of this massive energy consumption, the EPA reports that approximately 45 million tons of greenhouse gases are released into the air from the water sector energy each year (EPA, 2009). To get a real world grasp on these emissions, 45 million tons is equivalent to the annual emissions of 8.5 million passenger vehicles (epa.com, 2014).

Something centralized water systems are doing correctly is starting to recycle water and use it for applications that do not require as strict of regulations as drinking (or potable) water. Florida, California, Texas, and Arizona, in that respective order, are the top four users of reclaimed water (NRC, 2012), but of all the wastewater created nationally, only 1% gets reused (NRC, 2012). Urban water reuse systems generally provide reclaimed, lesser quality water to things such as agricultural and landscape irrigation, toilet and urinal flushing, car washes, decorative water features, fire protection, laundromats, street washing, and power plant cooling (NRC, 2012). Across the US and worldwide, the largest user of reclaimed water is agricultural irrigation (NRC, 2012). Reclaimed water is also being used to replenish aquifers in areas where saltwater intrusion to overdrawn freshwater aquifers is a threat.

The most difficult part of reclaimed water is the distribution system. It can be incredibly costly and requires basically all the same infrastructure as regular treatment plants such as storage facilities, pumping facilities, pipelines, valves and meters, and cross-connection control devices (NRC, 2012). It is estimated that it costs around 50% less to build new communities with reclaimed water systems than to retrofit existing infrastructure (NRC, 2012). Causing further inefficiency, in order to try and convince customers to use reclaimed water, utilities often charge a lesser price than regular water since it is considered a lesser quality of product even though reclaimed water requires significant costs, maintenance, and infrastructure to use (NRC, 2012).

While non-potable reuse of wastewater is an excellent opportunity to reuse something that has traditionally been discarded, it still needs to come a long way to have a profound impact on the water reuse industry. The necessary creation of entirely new distribution systems, the consumer cost to buy an "inferior" grade of water, and the huge costs associated with retrofitting current infrastructure all stand as barriers to its widespread use.

Decentralization & Potable Reuse

Water reuse is the practice of reusing wastewater and is ideal since effluent that is traditionally discarded is converted into water that can once again be used by people. Water reuse can diversify water supplies, create a supply of water in times of drought, and provide a solution to areas with limited water supply (NRC, 2012). As the world's population grows, effluent is the only water source that will grow with it (Arroyo, 2010). A typical American dispels approximately 150 gallons per day (GPD) as effluent in the US (NRC, 2012) and slightly less than 100 GPD in Tucson (Molina, 2010). Of this combined effluent, about 38% or 12 billion gallons per day is discharged directly into oceans or estuaries where it is lost to blend with saltwater (NRC, 2012). It is estimated that less than one percent of wastewater is reused in the US and that about a tenth of that, or .1 percent contributes to potable water supplies (NRC, 2012). In urban areas estimates place that around 80% of freshwater necessary could be obtained from effluent sources (Qin, Kekre, Tao, Oo, Wai, Lee, Viswanath, & Seah, 2006).

The majority of water reuse systems today are centralized and reclaimed, or in other words, not suited for consumption. But interestingly, many in vitro, or "petri-dish" and in vivo, or live subject, tests have been done on laboratory animals such as rats, mice, and different types of fish, which have showed that chronic exposure to 150-500x concentrates of reclaimed water had no adverse health effects. This included reproduction, development, carcinogenic effects, gender ratios, and/or toxicity (Lauer, Johns, Wolfe, Meyers, Condie, & Borzelleca, 1990; CH2M Hill, 1993; Condie, Lauer, Wolfe, Czeh, & Burns, 1994; Hemmer, Hamman, & Pickard, 1994; NRC, 1998; NEWater Expert Panel, 2002). Today, reclaimed water serves communities for non-potable applications such as irrigation in golf courses, parks, landscaping, cooling systems, cemeteries, and freeway medians (NRC, 2012).

Reclaimed water is a step in the right direction, yet it is not the fix-all solution. Reclaimed systems are difficult to install in most cities due to high costs of retrofitting. New piping must be laid out, current infrastructure, including wastewater facilities, must be updated, and new pumping stations must be built. Often times, reclaimed water costs more to implement in the end, but can only be sold more cheaply to the public than potable supplies since it is considered to be an inferior product. In new developments reclaimed systems are better suited as retrofitting is not necessary. Estimates have shown that reclaimed water systems in new developments can be as much as 50% cheaper than retrofitting current systems (SWFWMD, 2008). While it does reduce raw water needs for potable supplies while lowering discharge amounts into aquatic ecosystems (NRC, 2012), it is based off the same centralized system that typical water and wastewater systems utilize. Energy is wasted pumping water across cities from drinking water treatment plant, to the user, to the wastewater treatment plant, and finally back to the next user. A Southern California facility found that energy consumption for reclaimed water was close to that of importing water (Stokes and Horvath, 2009). Energy consumption varies though and becomes more wasteful the farther away the reclaimed water needs to be transported (NRC, 2012).

Decentralized systems have the same functions of centralized systems, yet they benefit from a number of advantages over centralized systems. Since decentralized systems are smaller scale, many of them exist instead of one and they are usually located closer to the user. Less distance for pumping water means less costs and energy associated with pumping, piping, and other infrastructure requirements. Multiple smaller systems would also improve redundancy and reliability of treated waters as well as lower the risks of a large system failure (Biggs, Ryan, Wiseman, & Larsen, 2009). Having numerous facilities instead of one would also handle heavier loads better by being able to distribute demand more evenly. Retrofitting and maintaining smaller treatment facilities is easier and more affordable as well. Centralized systems can be costly to modify when new connections or service areas need to be added (Gikas and Tchobanoglous, 2009). Around the world decentralized systems have been utilized by areas that lack centralized systems, by environmentally conscious groups trying to live more eco-friendly alternative lifestyles, and by urban greenfield development where existing infrastructure is not fully available (NRC, 2012). By and large though, most major systems are centralized.

As global population rises, efficient water usage use is becoming more crucial. Reclaimed water will likely climb in price so that it is used as efficiently as the potable sources it is meant to compliment (NRC, 2012). In some areas, water is so scarce that reclaimed water is treated to even higher standards and blended with potable supplies. Many times, communities utilize de facto reuse and do not realize it. De facto potable reuse is the term for treated wastewater effluent that released into bodies of water and eventually reused for potable water source later downstream. A study done in 1980 found that in some low-flow conditions, over 50% of the source water used for potable water supplies can come from effluent sources (Swayne, Boone, Bauer, & Lee, 1980). It is expected that this number is even higher today. In samples taken from 24 locations across the country, approximately 25% of samples had one or more prescription drugs found in drinking water intake sources (Focazio, Kolpin, Barnes, Furlong, Meyer, Zaugg, Barber, & Thurman, 2008). Voluntarily, indirect potable reuse is the most common way effluent is transformed into a potable water supply. The term "indirect" implies that there is an environmental buffer, such as a river, lake, or settling pond between sewage discharge and drinking water treatment. It is much like de facto reuse but controlled and regulated. Traditionally, environmental buffers have been used to decrease the concentration of contaminants by blending waters as well as increase time between effluent water to drinking water treatment facilities. Direct potable reuse removes the environmental buffer and replaces it with a technological or engineered process for a direct effluent to potable water product (NRC, 2012). The idea of direct potable reuse may make some people cringe, but it is being done in some places already. In Singapore wastewater is filtered to a high degree and blended with rainwater and raw water to be filtered once again and finally distributed as potable supply (NRC, 2012). In the small mountain town of Cloudcroft, New Mexico, when peak demand occurs during periods of drought, water supplies run critically low. As a solution they have created a system that blends treated and filtered wastewater with natural spring and well water to be distributed after treatment as potable supply (Livingston, 2008). In Windhoek, Namibia, the first city that has ever utilized potable reuse starting in 1968, treated effluent is blended up to 35% with potable supplies. Epidemiological studies on their population have found no relationships that exist between drinking water and adverse health effects (Isaacson, Sayed, & Hattingh, 1987; Isaacson and Sayed, 1988). When comparing risks of potable reuse to de facto reuse, the NRC determined that water quality is no worse, and perhaps better, than what the public receives today (NRC, 2012).

In fact, several treatment processes have been developed for potable reuse applications over the past 15 years and all differ from each other. This demonstrates that not only can potable water be reused safely, but there are different solutions for different situations (NRC, 2012). As technology improves it is expected that blending and retention requirements will diminish for a quicker and more efficient process. Currently artificial structures such as manmade aquifers and blending ponds can mimic natural environmental buffers (NRC, 2012), but for potable reuse to work on a decentralized scale, technology will need to be more efficient and more compact. In terms of potable reuse, decentralization also offers better conditions for recycling water due to reduced flow-rate problems such as membrane fouling and chemical requirements (Haaken, Dittmar, Schmalz, & Worch, 2014).

If an effective decentralized potable reuse system were created, problems associated with droughts, energy consumption, cost of water transportation, large distances from renewable water sources, effluent disposal costs, and a growing population's potable water needs could be essentially solved. Potable reuse combined with effective water conservation strategies could drastically reduce the amount of water and energy consumed by humans (NRC, 2012). The technology to do what needs to be done already exists, but not quite at a small or efficient enough scale, yet.

Methodology

The water-energy nexus of the Southwest is being scrutinized and dissected in this document in order to examine the potential benefits of water conservation techniques, potable reuse, and decentralization. In order to do this, it was crucial to note how much water is being consumed, where it was coming from, how far it was traveling, how much energy is needed to do it, how much energy is being wasted, how much can be saved with different techniques, and what other non-monetary benefits and drawbacks are found by creating a more efficient consumer base.

Conservation fixtures and techniques that can be utilized around the house were observed from EPA websites. Water efficient fixtures and appliances were explored as well as things such as outdoor landscaping changes and watering habits. This was done in order to understand how much water could be saved at a single-family residence scale and what impact a family can have in a broader scheme.

Water conservation and harvesting techniques and technology were studied in addition. Both monetary and environmental savings from using less water and less energy were researched and then applied to understand how they can play a role in the larger puzzle of using less water and energy in such an arid climate.

Different types of potable and reclaimed reuse water facilities were researched and noted through collective case studies. All these systems were unique and of different proportions in order to examine successes and failures, to see what has been done around the world, and also to see if there is some sort of cost analysis. Water facilities varied from size, treatment processes, geography, topography, attitudes toward water reuse, etc. The main purpose of this part was to understand what was out there, if they were economically and environmentally feasible, and if their systems were more sustainable than current systems.

A few areas of potential new direction for ideas in water reuse and filtration were examined as well. Their feasibility, potential benefits and weaknesses, availability, costs, and appropriateness for potable reuse and decentralization were among the things examined.

The main hope of this paper was to understand the technology that is behind water consumption, distribution, what can be done to minimize water usage, and then see what could be feasibly applied to real-life situations in order to reduce water usage in the Southwest. When that is discovered, instead of needing a constant supply of pumped in water and pumped out effluent, the system would more or less be independent from wasteful centralized systems. Both water and energy, some of the most crucial things to developed society can be used more efficiently when this solution is solved or at least made more efficient.

With analysis of current water systems, water conservation and harvesting, new technologies that were being tried around the world, and the experience of bright minds across the globe, it is expected that changes for the better can be made. A summary of what can be done now, how close the possibility is decentralized potable reuse is, what is necessary to solve the problem, and who needs to work together to create a solution are all things intended to be answered in this essay.

Analysis and Discussion

As people continue to migrate to the Southwest for its mellow climate, as the offspring of local residents propagate, as sources of water become less available, as current energy inefficiency trends are mended, and as greenhouse gas emissions are fought to lower current levels, it is apparent that the humans who have settled in this desert area are going to need to change their ways. Using our water wisely through efficient conservation techniques, actively as well as passively harvesting rainwater and gray water, and reusing potable water are all likely going to be components to the solution as the problem worsens.

Water conservation is actively playing its part in the Southwest. Given that single-family residential applications take up 56% of total water use in Tucson (Molina, 2010), this will be an important part of the analysis. Since 1990, an ordinance was passed that required any new and commercial development to be built with water conserving fixtures which include toilets, faucets, and showerheads. After 1990, approximately 32% (or 76,000 homes according to the 2010 Tucson city US Census) of total housing in Tucson has been built and utilizes water saving fixtures. Unfortunately that still leaves around 68% (or 164,00 houses according to 2010 census numbers) of housing in Pima County that is not equipped with these fixtures. Fortunately for these homeowners, the City of Tucson will offer rebates of up to $120 per fixture, or $200 maximum per household to replace pre-1991 toilets with High-Efficiency Toilets (HET) that use less than 1.3 gallons per flush (water.tucsonaz.gov). Given that toilets account for around 14% of total single-family residential water use (13.4 gallons per day per capita or GPCD) (Molina, 2010), an average savings of 8.8 GPCD could be saved. It is likely that a substantial amount of these fixtures have already been replaced over time, and for this report an estimate of around 50% of pre-1990 housing fixtures have been replaced, for a calculated 740 million gallons of water still being wasted due to wasteful fixtures.

This leaves faucets and showerheads for indoor uses. Unfortunately there are no rebates for these items, yet they are more affordable than toilets. Estimates for faucets and showerheads for pre-1990 built houses will assume two-thirds of these houses have not been retrofitted. That being said, single-family residences use on average 19% of total water volume for faucets and showers (Molina, 2010). 19% of the average 96 GPCD comes to 18.24 GPCD for faucet use and showers. With 40% wasted water from original, non-high-efficiency faucets and showerheads, this equates to approximately 7.3 GPCD (assuming a combined savings of 40% of 18.24 GPCD for high-efficiency faucets and showerheads would be saved) that is wasted. Apply this to three people for a single household, per year, for 108,000 houses, and 852 million gallons of water are wasted by inefficient faucets and showers in Tucson.

Another machine that utilizes a large portion of water in households is the washing machine. Molina (2010) estimates that washers account for 13% of household per-capita use. Unfortunately there are no rebates for high-efficiency washers in Tucson and they can be costly to purchase. The lowest-priced front-loading, high-efficiency washers are around $700 and up. These devices can save up to 50% water as well as 50% electricity per load (EPA.GOV, 2014). An average washer uses about 41 gallons per load, so a median savings of about 43% (EPA.GOV states between 35-50% water savings) means a saving of almost 18 gallons per load along with its electricity savings. That being said, it is difficult to say how many households in Tucson have high-efficiency washing machines in operation considering that they are expensive and no rebate is available to keep track. A quick call to the local Home Depot® at 4302 N. Oracle Road reveals that of the washers sold, 60% were high-efficiency and the average life-span of the appliances was ten years. Based on this estimate, since high efficiency washers started to become popular in the mid 1990s, an estimated 50% of the 240,000 houses, (or 120,000 single-family residences) are not using high-efficiency washers. With the remainder of 120,000 single-family residences phasing out inefficient appliances, 815 million gallons could be saved yearly (see following table).

Single -Family Residential Savings (assuming 96 GPCD, 3 people/house, and 240,000 houses in Tucson)

Fixture/ Appliance	Percent of Water Usage	Gallons Per Day	Efficient Fixture Savings per Day	Per Capita Possible Water Savings Per Year	Estimated Percent of Households Not Using High Efficiency Devices	Possible Remaining Household Savings Per Year
Toilet	14%	13.44	8.8 gallons	3212 gallons	32%	740 Million Gallons
Faucets	10%	9.66	2.9 gallons	1058 gallons	45%	343 Million Gallons
Shower	9%	8.64	4.3 gallons	1570 gallons	45%	509 Million Gallons
Washing Machine	13%	12.48	6.2 gallons	2263 gallons	50%	815 Million Gallons
				Total Possible Water Savings Per Year		2.4 Billion Gallons

Possible Potential Remaining Household Savings=Estimated Percent Not Using Device*240,000*Per Capita Possible Water savings*3

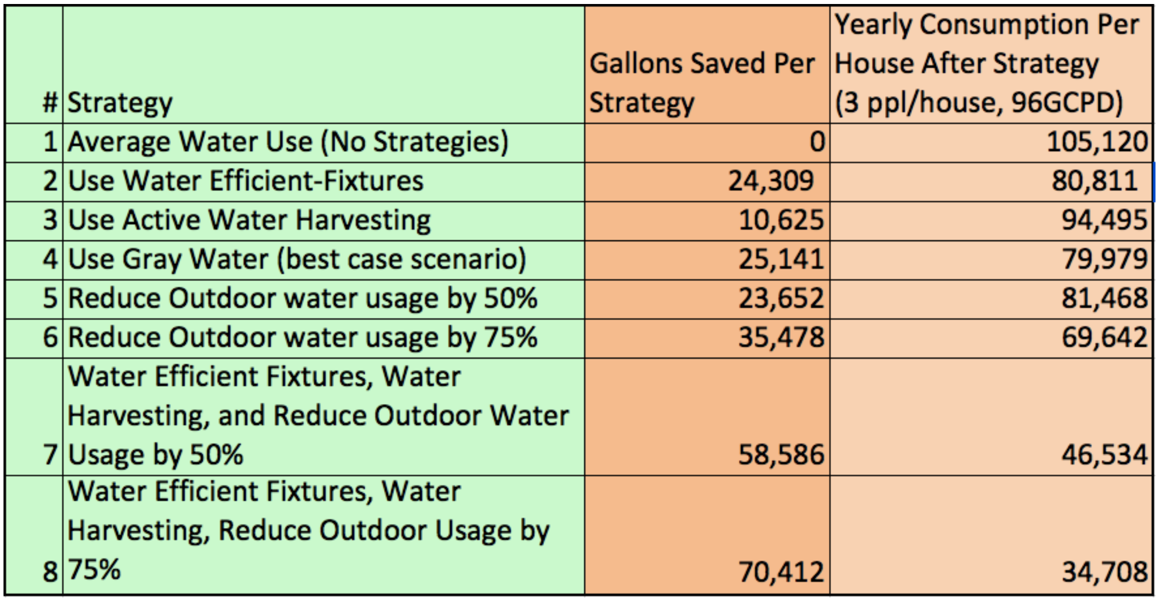
By simply replacing fixtures and your washer, the average citizen can save over eight thousand gallons per year! If you think that's amazing, think about how the entire city could be impacted if it only utilized water efficient fixtures and appliances. Referencing the table above, if the city required and enforced all citizens to use these efficient fixtures and appliances, an estimated 2.4 billion gallons of water per year could be saved, just within single-family residential housing. That is not including commercial or multi-family housing, which consists of slightly less than single-family housing units when combined.

According to Molina (2010), about 45% of water used by Tucsonans is used for outdoor purposes such as irrigation, swimming pools, or washing cars.

Remedies to reduce irrigation water usage are varied and can range from a number of things including; switching plant life to native plants that require no irrigation, manually watering plants in the morning when temperatures are coolest to minimize evapotranspiration, manually watering landscapes instead of using wasteful irrigation systems, and an abundance of other techniques. That being said, it is tough to calculate exact numbers for circumstances that vary in degree of uniqueness. For irrigation, the change with the most impact would be xeriscaping (landscaping that requires no supplemental water) by using native vegetation. Having a luscious green lawn is nice, but when precious water is needed for other things such as human survival and energy creation, lawns can be considered poor use of limited resources. For swimming pools, the best way to conserve water is to invest in a cover. Covers prevent evaporation of water, especially in hot, arid climates, and therefore the waste of water supplies on non-potable water needs. Washing cars at home can also waste a lot of water. If it must be done, use a sprayer to avoid continuous water flow. Otherwise, commercial car washes offer a quick and reasonable alternative while recycling their water afterwards. Theoretically, cutting out exterior water needs entirely could potentially save over 11.3 billion gallons of water annually if all the single-family residences stopped using water outside for irrigation, pools, car washing, and so on. Nonetheless, this is not practical because people enjoy gardening, swimming, and other outdoor activities that require water. For this reason, it is difficult to estimate the savings, but by exposing knowledge of the amount of water consumed by outdoor activities, it becomes possible to raise awareness in residents of arid climates.

Water harvesting is also another viable solution with great potential in Tucson. On average, Tucson receives around 11 inches, or 47 billion gallons, of rain per year (Phillips and Sousa, 2007). Basic techniques that can be done at home with no costs involved, aside from labor, can utilize passive water harvesting with the creation and implementation of micro basins around vegetation, diversion swales to move water to useful locations, and other earthworks. Given that nearly 50% of per capita single-family residential and 35% of commercial and industrial water is used for outdoor purposes, it would be extremely beneficial to utilize rooftop active water harvesting (gutter systems and a cistern). Since buildings vary in size, an average of 1700 square feet will be appropriated to show the potential of rooftop rain harvesting. Additionally, different roofing materials allow water to run off in lesser or greater amounts. This variable is called the runoff coefficient and is indicated by a number between 0 and 1. Runoff coefficients for porous surfaces such as gravel and soil have very low runoff coefficients, while many roofing materials such as shingles, asphalt roofing, and clay tiles have high runoff coefficients. For this model a relatively high runoff coefficient of .90 will be used to account for rooftop runoff. In a model ran by DeCook for the Office of Arid Land Studies in 1983 with the same criteria, 10,625 gallons could be harvested from a 1700 square foot roof per year. Assuming all rainwater was caught and harvested, a stipend of 29 gallons per day per household could be used with that water for non-potable purposes. A savings of 29 gallons per day for 240,000 houses equates to approximately 7 MGD saved, or 2.5 billion gallons of potable water saved per year.

Gray water systems should be considered as well. Many times they are not ideal for residents because plumbing is more-or-less fixed in walls or floors and can be very costly to implement, but in other situations where washing machines are located outdoors or plumbing is easily modified, gray water systems can be created with relative ease. Gray water systems simply make use of used water from showers, sinks, or laundry machines and instead of allowing it to go down the drain, it is guided into the yard to be utilized by landscaping. If the average three-person family utilized gray water systems from an efficient washer, showers, and bathroom faucets, a household could reuse almost 15,000 gallons per year for landscaping. Unfortunately this is a best-case scenario since most households are built with the intentions of utilizing drainage and sewer systems and plumbing that isn't easily modified, 15,000 gallons is just to raise awareness of the potential water that can still be used. Another drawback of gray water systems is that although they prevent additional potable supplies from being used for applications such as irrigation, water supplies are still lost. This means that if any type of potable reuse were to be implemented, gray water systems would deplete the supply since that water could not be used to contribute to potable supplies again.



#	Strategy	Gallons Saved Per Strategy	Yearly Consumption Per House After Strategy (3 ppl/house, 96GCPD)
1	Average Water Use (No Strategies)	0	105,120
2	Use Water Efficient-Fixtures	24,309	80,811
3	Use Active Water Harvesting	10,625	94,495
4	Use Gray Water (best case scenario)	25,141	79,979
5	Reduce Outdoor water usage by 50%	23,652	81,468
6	Reduce Outdoor water usage by 75%	35,478	69,642
7	Water Efficient Fixtures, Water Harvesting, and Reduce Outdoor Water Usage by 50%	58,586	46,534
8	Water Efficient Fixtures, Water Harvesting, Reduce Outdoor Usage by 75%	70,412	34,708

The table above demonstrates different strategies and their impacts on average household use.

Potable Reuse

In addition to water-efficient fixtures, water harvesting, and gray water systems, it is becoming more necessary to consider potable reuse solutions for future implementations. While there is not one set solution to this type of problem, different case studies that were mentioned before can be analyzed and used as models for future development. An analysis of Namibia, Singapore, and Cloudcroft's water reuse facilities will be analyzed to show the viability, benefits, and different solutions potable reuse can offer.

Case Study: Windhoek, Namibia

One of the earliest pioneers of potable reuse was across the world in Windhoek, Namibia. Windhoek is the capital of Namibia and home to over 250,000 residents. The city is a good example since it similar to Tucson in regards that it has relatively low rainfall, hot days during the summer, and relatively mild winters. Their plant began operating in 1968 and uses four distinct treatment processes to get wastewater up to drinking standards. After water is treated it is then blended with other sources of treated water before it is pumped out via the distribution system. Its current capacity is 5.5 MGD and reclaimed water represents around 35% during normal operation and 50% in times facing limited water supplies such as droughts. Extensive testing with in vitro and in vivo subjects has been done and there are no relationships to their drinking water supply and adverse health effects (NRC, 2012).

Case Study: Singapore

Singapore is probably the largest example of current potable water reuse. With a population of over 5 million, high-precipitation, and little land space to employ rainwater harvesting techniques, potable reuse plays a major role in their water supply. Today Singapore utilizes five nearly duplicate NEWater treatment plants to treat and distribute water to its citizens. The system uses microscreening, microfiltration (or ultrafiltration), reverse osmosis, and ultraviolet disinfection as well as chlorine before and after microfiltration to control biofouling of the membranes. After this process, water is either distributed for non-potable uses or expelled to surface water reservoirs where it is utilized by traditional water treatment plants that distribute it as potable water. Water quality is high and meets all EPA and World Health Organization standards. With all five plants running Singapore is capable of treating 122 MGD. Only about two percent of potable supply comes from this reclaimed source, but is expected to grow as demand rises. The rest of the reclaimed water is generally used in industrial applications such electronics and wafer creation, power generation, and air conditioning applications. Operational and maintenance costs are about $0.98/kgal, and capital costs were about $6.03/kgal/year. The city charges $2.68/kgal for the water to its citizens, which recovers all capital, production, transmission, and distribution costs (NRC, 2012).

Case Study: Cloudcroft, New Mexico

The final and smallest case study is Cloudcroft, New Mexico; a small mountain community with a permanent population of 750 people. Peak demand of the small town is about .36 MGD during holidays and weekends as the influx of tourists come to experience the winter resort the town offers. The village's geography makes importing water arduous, and recent droughts have made water acquisition problematic. As a solution, the village opened a small advanced wastewater treatment facility that has a capacity of .10 MGD and then blends up to 50% with traditional water supplies of spring and well water. Wastewater is treated by a membrane bioreactor, disinfected through use of chloramines, pushed through reverse osmosis, treated with ultraviolet radiation and hydrogen peroxide, and then combined with traditional sources in a covered reservoir where it is held for 40-60 days for retention. After that, water is treated with ultrafiltration, UV radiation, and finally granular activated carbon where it is then distributed to citizens. Operational and maintenance costs were $2.40/kgal for its first year of operation (Livingston, 2008; NRC, 2012).

Tucson Water and IPR

As of January 1st, 2017, Tucson Water predicts that Tucson will begin getting cutoff from its full allowance of the CAP. As the reservoirs where the CAP is drawn from reach levels of 1,075 feet or less by the beginning of the year, the Interior Secretary can declare a shortage and Arizona as well as Nevada will be the first to be shorted. Currently, Tucson Water is in working to create an Indirect Potable Reuse (IPR) system by the time these shortages are expected to hit. Their system will consist of releasing filtered effluent into settling basins so that water can percolate through the ground and be filtered by the soil until it reaches aquifers deep below. The water will then be pumped back out eventually and ran through normal filtration systems before being delivered to the customer.

IPR is a good solution for the water shortage, but the main downfall is that it is still energy intensive. It still requires electricity to pump water from its source (a central plant), to the user, back to wastewater treatment plants, out to infiltration basins, back out of the ground to the surface, and back to the water treatment facility where it begins its journey again. Tucson Water has an estimated $15 million/year electricity bill (Tucson Water, 2014) and this would do nothing to lower Tucson's energy footprint. In addition, the majority of energy derived from

Tucson Electric Power (TEP) and other smaller electricity distributors is derived from coal-based power plants. Not only is coal already the number one producer of greenhouse gases in the country, it also consumes massive amounts of water necessary to spin the turbines. Unless TEP converts to renewable and sustainable energy sources, they will be using coal; a finite energy source, which contributes to greenhouse gases and consumes water that will soon be in short supply.

Shifting to renewable energies would be an ideal solution, but for a company as vital as TEP for Tucson citizens and their electricity needs, the technology to shift to renewables isn't viable yet. Energy can be captured throughout the day when the sun shines by photovoltaic panels and wind can produce energy when breezes spin massive turbines, but there is no clear-cut way on how to store energy during periods of renewable energy-inactivity to provide constant day-in, year-round coverage. Contributing to this dilemma, the efficiency of renewables is so low that the cost to implement them on a scale large enough to have any noticeable effect would be tremendous.

DPR and Decentralization

Since renewables are not cost-effective right now, direct potable reuse (DPR) and decentralizing the system make sense. DPR would be optimal for activities such as showering, washing dishes, laundry, toilet flushing, and anything where water is extracted through plumbing pipes. For processes like irrigation and outdoor purposes where water is lost, other alternative such as rainwater harvesting and xeriscaping would be necessary in order to retain water in a closed loop. One of the largest problems affiliated with DPR is public perception. With a populace that has been accustomed to receiving water from "clean" sources, perception of potable water sources that have been accrued from effluent is understandably a daunting concept. Studies conducted by the National Research Council have shown that current technology can produce a quality of water that is equal to or even greater than traditional water standards required (NRC, 2012). The cost incentives of using DPR could also be used to help facilitate public acceptance. An inaccessible water source will inevitably be a water source that costs a lot more to provide, so citizens interested in avoiding exponentially more-expensive water to live on will need to be open-minded towards the environmental predicament that the Southwest is in. A second obstacle of DPR is the lack of national regulation. Current water distribution systems are nationally regulated through acts such the SDWA and CWA, but DPR is an entirely new system that has not been optimized and regulated on a national level. Multiple barriers for robust, fail-safe systems and constant monitoring are necessary in case of any sort of failure, but no "industry standard" has been set. The last mentionable obstacle is that DPR consumes a lot of energy. These systems require pumping water through multiple membranes and disinfection treatments. Pushing water through extremely fine membranes to filter out microscopic chemicals and microbial contaminants then using chemicals such as hydrogen peroxide and UV light to finish off the job consumes large amounts of energy. When compared to traditional systems, DPR is probably more energy intensive, although it is difficult to gauge since systems vary so much in size, filtration technologies, etc. DPR will probably find its greatest advantage when utilities begin decentralizing to relieve stress on traditional centralized systems.

Decentralization would be used to make water systems more manageable. Eventually, current centralized infrastructure will reach its limits as far as water-volume potential, how many booster stations can be utilized, and cost-efficiency of extending pipelines to far reaches of municipalities. There are alternatives to requiring that water supplies be transported back-and-forth across large distances and up elevations (a very energy intensive process), a suburb, square city-block, neighborhood, or high-rise implemented decentralized water-reuse system could be implemented instead. Thus in the full analysis of savings; water, energy, the water necessary to create that energy, and the emissions associated from that energy creation would all be decreased. Given that current infrastructure is in place, it will probably be most advantageous for decentralization to occur as newer periphery developments are created. Municipalities that have invested millions of dollars in infrastructure for central water services and are not likely to abandon these services while they are still operable.

Case Study: Battery Park, New York

A case study in New York has successfully implemented a decentralized reuse system in multiple buildings for one area of urban development. Battery Park City is a redevelopment area of 92 acres of New York City and has outfitted five water reuse systems for six total buildings. The first constructed building of the six, the Solaire, was the first project in New York City to enable wastewater reuse. The basement of the building is equipped with a state of the art system that treats wastewater with micro-filtration membranes, UV disinfection, and finally oxygen and non-oxygen-based treatments for nitrogen removal. Each day the Solaire recycles 25,000 gallons of water and uses that water for toilet flushing, cooling towers, and landscape irrigation (amwater.com). Although this system is not utilizing potable reuse, the Solaire has reached a 48% reduction in water use and a 56% reduction in wastewater discharge (Cisterna, 2011).

Given that decentralization of water systems and potable reuse are such varying techniques with no finite "one size fits all" solution, it is difficult to calculate how much energy, water, and emission expenditures could be saved by utilizing decentralized systems. If 80% of electricity used by water utilities is for pumping water to different areas of municipalities, massive energy cuts would be saved since water would be kept localized in a semi-closed loop system. Not only would this save energy, but it would reduce loads on power plants, reduce associated emissions, and preserve water necessary for running power plants. In systems where effluent is recycled, such as the residential Solaire building in New York, a water savings of nearly 50% was found just by reusing treated wastewater for toilets, cooling, and irrigation.

Supporting decentralization, renewables would be easier to implement on a smaller scale. Less energy storage is necessary, it is easier to estimate energy needs, inefficiencies are pinpointed with greater ease, and different types of renewable sources can be used on a more specific basis depending on availability. A more definitive application of renewable energy sources for single decentralized systems would allow systems to focus on and utilize their climatic advantages. A smaller system in the southwestern cities, such as Tucson, could use photovoltaic panels to cut down energy costs and emissions during peak hours (the daytime), and greatly reduce energy loads necessary from nonrenewable sources, such as coal. A larger centralized system would require greater renewable investment, modification, and maintenance.

Possibilities in Renewable Technology

Some potential options for the future are being explored to help implement renewables when sources are intermittent and store them more efficiently. A potential solution that is being investigated is the use of compressed air energy storage (CAES). CAES uses excess solar power captured from photovoltaics or other renewable sources to compress air and store it in vessels. When the solar energy (or any other renewable energy) is absent, the compressed air is heated slightly to be expelled for turning turbines for energy production. For smaller applications, such as homes or high-rises, the compressed air could be stored in tanks similar to those for propane. For larger applications such as neighborhoods, suburbs, and even cities, researchers are looking into storage of compressed air into aquifers, caves, and abandoned mines (Arroyo, 2010).

Another ideal solution that is being explored is the use of hydrogen fuel cells. Simply put, these fuel cells take hydrogen and oxygen, and combine them to create energy and water, an ideal solution to the water-energy nexus problem. Research done at Arizona State University by Paul Westernhoff found that a fuel cell capable of satisfying an average household creates about four gallons of water a day, just enough for their drinking water supply. While this solution is favorable, it has only been successfully implemented in space by astronauts and is still being developed for use on Earth (Arroyo, 2010).

Nanotechnology will also be a key player in renewable energy storage as well. Developing more advanced materials will allow researchers and scientists to create new mediums for batteries and other storage solutions that will enhance efficiency, cost-effectiveness, and be more environmentally sound. This is a very new field however, so it is hard to say what will be developed and when, but the possibilities are nonetheless exciting.

As technology improves, there is no doubt that solutions to more efficient water distribution and use will be unveiled. They will be found in advances in filtration technology, decentralization systems, compaction of current systems, more efficient pumps, and ultimately a renewable source of energy that can be stored to power it all.

Recommendations

To put these systems in context and relate them to the Southwest, and even more particularly to Tucson, a series of steps can be taken to prolong water supplies and reduce energy

1. **Water conservation must be taken seriously at a consumer level and awareness must be instilled in residents that water is indeed a limited resource.** Awareness is raised in different ways, but one of the most simple and effective ways will be to raise prices of water from the tap. The price of water is so cheap that users have no incentive to use water rationally. At current tiers of water costs, the first tier of up to 10 Ccf (1 Ccf =748 gallons), or 7480 gallons per month calculates to $.003 dollars per gallon, or a third of a penny for a gallon of a water. The second tier of water from 11 Ccf through 15 Ccf is priced at $.005 per gallon, or half a penny per gallon. As the tiers advance the pricing increases with the most expensive tier being 31 Ccf (23,188 gallons/month) and over at approximately $.016 per gallon, or slightly over a penny and a half per gallon. This pricing simply does not promote rational water use! If prices were raised people would instantly become more aware of their water use habits and aim to reduce their water consumption.
2. **Eliminate the rest of wasteful fixtures in houses.** According to the figures calculated in the table a few pages above, an estimated 2.4 billion gallons of water can be saved per year in Tucson alone without changing water use

habits whatsoever. Tucson Water needs to create more incentives and rebates for other fixtures other than toilets, and get the word out on it. There are still plenty of people who do not realize how easy it is for them and their families to reduce the stress on precious water supplies. Additionally, if water prices were raised, consumers would jump at the opportunity to purchase water efficient fixtures, as the payback period for these fixtures would be greatly reduced. Tucson Water should start offering incentives to give rebates on high-efficiency washers and dryers. Other municipalities offer benefits for these appliances and it would be yet another way to improve home water use and electricity consumption.

3. **Utilize water-harvesting, gray water systems, and native landscaping/xeriscaping.** We depend on the CAP to supply us with the majority of water. Tucson Water has stated that the aquifers we use for our water supply are recharged and consist of approximately 90% CAP water today. Tucson Water estimates that our allotment of the CAP will be cut starting January 2017. Landscaping, which accounts for almost half of single-family residential use and more than a third of commercial use, is going to need to be xeriscaped, or use some means of water other than potable sources if we are to take water conservation seriously. Xeriscaping can be easily achieved by only using landscaping that requires no water or vegetation that is drought tolerant and can survive off natural precipitation. For this reason, it is a good idea to start pushing more residents to utilize water harvesting and gray water systems for irrigation and outdoor applications. Tucson Water and city officials need to collaborate and launch a more aggressive campaign to get users to install water-harvesting systems. According to Tucson Water officials, they estimate that around one percent of Tucson citizens utilize cisterns for water harvesting, and even less that one percent use gray water systems. Using the calculations from the discussion and analysis, a mid-sized house with 1700 square feet of roof surface can capture about 10,625 gallons of water per year with average rainfall. In

Tucson, an average family of four using just under 90 gpcd accounts to about 10,560 gallons per month. In other words, if a household uses a properly fitted water harvesting system that captures all rainfall, that household can replace more than a months supply of water per year with water that falls from the sky for free. Gray water systems have potential to mitigate irrigation usage as well and can be reasonably easy to install if plumbing isn't fixed in walls or concrete. Installation can be as simple as rerouting an outdoor washing machine's wastewater through a few downward sloping PVC pipes to plants or trees or as difficult as running internal plumbing through a series of pumps to cisterns. Savings are more difficult to calculate because systems can vary greatly and sources can include faucets, showers, laundry machines, all of the prior, or any number of different variations.

4. **Utilize either indirect potable reuse (IPR) or direct potable reuse (DPR).** Tucson Water already has plans for this and will be doing it soon. It has been proven to be safe, and is a viable source of water considering that our number one source (the CAP) will likely be decreasing in supply. Case studies across the globe including Singapore, Cloudcroft in New Mexico, and Windhoek in Namibia have shown that public perception can and will accept potable reuse (either indirectly or directly) and that it is an achievable means to solve the problem of water shortages in different areas. As technology improves and nanomaterials are researched, more efficient membranes and filtration devices will be developed, and allow effluents to be filtered directly to potable sources easier, cheaper, and with greater reliability. Today DPR is possible, but robust and expensive systems are needed that require costly and constant monitoring. IPR is a good stepping-stone since it extends water supplies and alleviates public concern by using an environmental buffer. As populations grow and energy emissions are more strictly regulated though, DPR may be a more feasible option since technologies will improve and probably require less energy to pump water in and out of aquifers and throughout the city.

5. **Utilize decentralized systems.** Decentralization goes hand in hand with DPR. The main benefit of decentralized systems include saving on costly existing infrastructure modifications, saving on energy costs and emissions associated with having to utilize such a massive amount of energy to transport water back and forth across cities (and to cities in the case of the CAP), and finally saving the water that is necessary from the energy derivation back at power plants. Decentralized systems are not particularly feasible for existing areas where water utilities reach due to large investment in current systems and infrastructure. As periphery developments are built though and areas where current infrastructure cannot reach for varying reasons, decentralization is starting to make more and more sense for planners and government officials. Decentralized systems are smaller scale which means they are easier to service and maintain, it is easier to keep water closed loop (for potable reuse systems), and they are cheaper to operate and modify. In the future as population grows, decentralized systems will see significant attention and utilization as current centralized infrastructure meets its limiting potential.

Limitations

In the scheme of water-saving possibilities in Tucson, there are obviously limitations on what can be implemented, but these limitations can be overcome.

- **Limitations of raising the price of tap water:** Political and social limitations occur by trying to raise water prices. Residents will say it is unethical to raise the price of such a necessary resource, politicians will say it is unethical since some people are already financially challenged, and others will inevitably fight attempts to promote rational pricing. The public must become aware of the current water shortage situation though, an in order for them to have motivation to use water more wisely, rational prices must be forced.
- **Limitations of replacing all inefficient fixtures:** It is difficult to estimate the amount of high-efficiency fixtures that are being used today. Rebates and

construction dates can give us a basis as to how many toilets and fixtures are being utilized but there is no definitive way to account for houses with older construction dates that have not filed the rebate for new fixtures and for the amount of other fixtures that have been bought where no rebates exist. The only way to seek out users who have not installed these fixtures is to have them voluntarily identify themselves, go door-to-door and ask, or through similar means. And while many of these fixtures are cheap to purchase, residents are often not savvy enough to replace the fixtures themselves, are reluctant to do it, or cannot afford to pay someone to replace them.

- **Limitations of water harvesting and gray water systems:** Water harvesting systems tend to be pricey with the average cistern running around a thousand dollars. The city of Tucson offers rebates for systems with cisterns, but customers still often pay over $500 out of pocket after rebates have been claimed. Most families cannot afford invest over $500 for something such as a water harvesting system when they have been accustomed to using water that is priced so cheaply. Raising prices of water and offering better rebates will also help incentivize alternative sources of water such as active and passive water harvesting systems.

  Gray water systems are often limited by the location of fixtures and appliances that use the water. Indoor showers utilize plumbing that is underground, generally permanently embedded in concrete footers or similar foundations, and most households have washers and dryers that are located inside the house where wastewater cannot be easily routed to the outside. These sorts of situations prevent users from easily and cost-effectively implementing gray water systems.
- **Limitations of using drought tolerant vegetation or xeriscaping:** It is not very difficult to implement xeriscaping since the natural ecosystem does all the work for you. However, some people like to have vegetation for gardening, trees, shade, and general aesthetic appeal. It is difficult to tell people that they are not allowed to have these things when they have been accustomed to having them

for their entire lives. A combination of increasing the price of tap water and incentivizing water-harvesting systems would help achieve more motivation to use drought tolerant vegetation and xeriscaping.

- **Limitations of either DPR or IPR:** A limitation of both is public perception of using effluent for drinking water sources. This has been overcome in multiple places around the world though, including here in the US, and can be helped by scientific studies that show it is safe, monetary incentives (continued affordable water supply), and simply no option but to comply since water supplies are so low. A limitation of IPR is the need for an environmental buffer, such as an aquifer or body of water, to inject treated effluent in before it is filtered into a potable supply again. In conjunction with this limitation is the fact that it is still very energy intensive since it requires transportation of water supplies back and forth from the consumer, to an aquifer, out of the aquifer, to the filtration plant, and back to the consumer. Limitations of DPR are also that it is energy intensive, but mostly that technology is not as advanced as needed to make affordable, efficient, and robust systems that municipalities can easily adopt and implement.
- **Limitations of decentralized systems:** The biggest limitation of decentralized systems is how costly they can be to implement. Municipalities have invested so much into their current systems that unless major expansions to the centralized systems are necessary, decentralization is not financially feasible at that point in time. Also, in order to be a decentralized system, there still needs to be a source of water, and in Tucson where water sources are limited, that would mean the CAP or Tucson's aquifers. Once the CAP is shut down or flow is cut down, that means we are still going to be short on water. This is why DPR would go hand in hand with a decentralized system so that water could be theoretically kept in a closed loop and water would not need to be continually added to the system. Unfortunately as stated in the limitations for DPR above, technology is not there yet. Systems need to be robust, affordable, reliable, and somewhat cost-effective for this technology to be put into use.

Conclusion

Solutions to water use in the Southwest are not going to be easy. From the combination of naïve citizens, affordability of options, politics, and habits that have been forming since technology has enabled easy access to water, change is always difficult. Through greater awareness, rational pricing, and conservation measures, a great deal of water and energy can be saved. Further implementations down the road include potable reuse and decentralization of systems, but those are based on technological advances and massive infrastructure changes that are difficult to implement due to costs and technology limitations. As our greatest water provider, the CAP, becomes limited and rationed from the Southwest and populations continue to grow, real solutions to real problems are going to need to be found. It is important that we unite and conceptualize a workable plan of action to support a constantly growing population that inhabits an inhospitable and arid region.

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