ENERGY GENERATION WITH GREYWATER REUSE SYSTEMS:
THE CASE OF ORGAN PIPE CACTUS NATIONAL MONUMENT

by

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STATEMENT BY AUTHOR

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APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below.

12/07/16

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Professor of Architecture

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Abstract

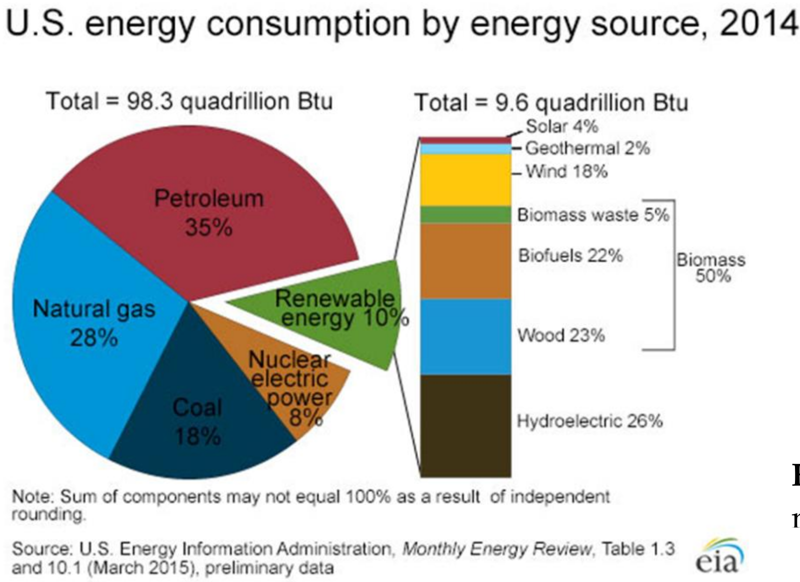
At the rate the population is growing it is important to find ways to be more efficient with the energy and water we use. The increase in population increases the need for electricity and water, but the way we are using our sources will not leave us with enough for future generations. The constant use of "dirty energy", energy that emits CO2 and other chemicals into the atmosphere, will continue to harm our environment. A new system is needed to help preserve water and produce green energy that will not harm the only earth we have.

Environmental Concerns

The world's population has increased drastically over the past hundred years. In the past 50 years the population has doubled. (coolgeography.co.uk-PopulationGrowth). This growth will make the demand for resources rise dramatically. The demand for energy is a major issue for the planet, as it contributes to global warming.

The United States creates 90% of its electricity from fossil fuels, which sends Carbon Monoxide into the air and traps solar radiation in our atmosphere. The building sector is responsible for 46% of the energy use in the United States and 34% of this carbon monoxide released into our atmosphere from energy use. Not only is carbon monoxide being released, but so is methane, CFC's (chlorofluorocarbon) and aerosols, which are even more harmful to our atmosphere. This air pollution also causes health problems, such as cardio-vascular disease, respiratory system health issues and even death. 7million people died on earth in 2012 alone from air pollution. (Dotearth-persistent-air-and-water-pollution-challenges)

It is important to use renewable resources to produce electricity to limit the amount of air pollution and to make this earth a healthier place to live. It is vital to stop using components that cause harm to our environment. Building more sustainably is a great way to minimize the use of fossil fuels and other toxins that will pollute our environment. The major environmental impact areas are energy use, water depletion, and air and water pollution.



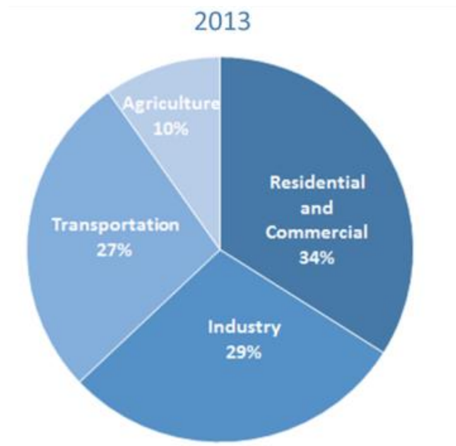


Figure 2: Diagram showing the carbon monoxide released By Sector

Figure 1: Diagram showing U.S. energy consumption by energy source

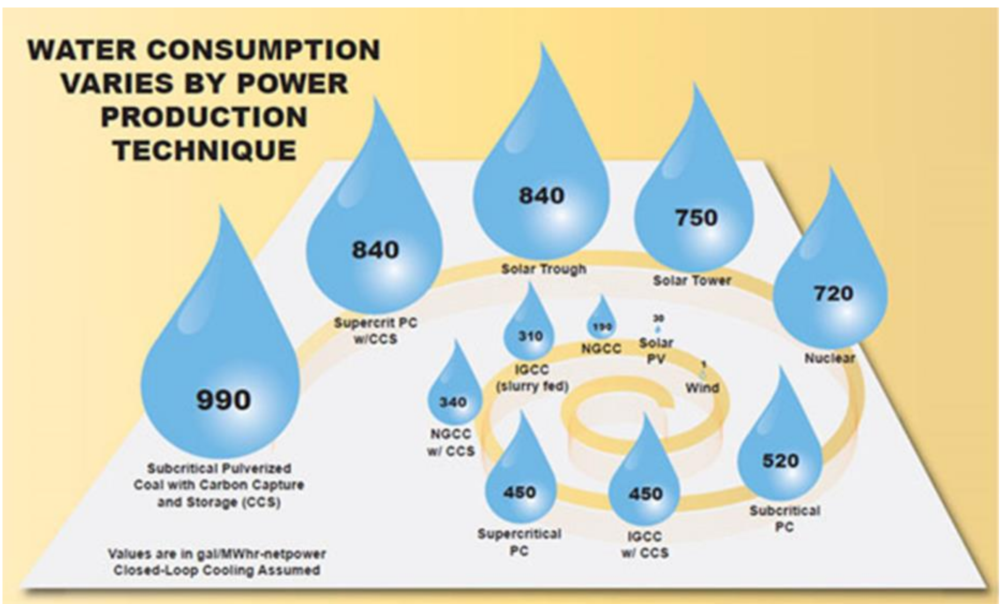
Figure 3: Pollution from Energy Production

Figure 4: Photo from author showing pollution over Chicago

Figure 5: Pollution over Houston, Texas
Figure 6: Pollution over Los Angeles

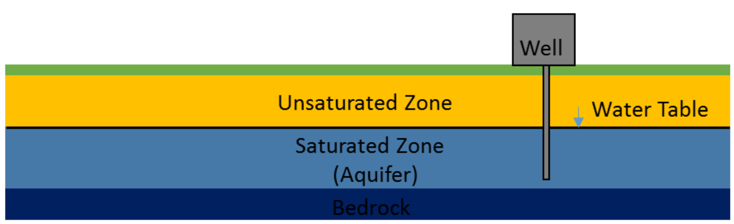
Water is also a major resource that's demand will increase outrageously, as it is a necessity for life. It is important to know that water is used in the process of making electricity. As the water nexus explains, water is energy and energy is water. To explain farther water is needed to produce electricity and electricity is needed to provide water. Although, it is not the quantity of water that should concern us, it is the quality. 71% of the Earth's surface is water and only 3% of it is fresh water. 2/3's of that water is stuck in glaciers. We are using this water inefficiently and are lowering our reservoirs and aquifers at an extreme rate. The small amount of fresh water that we have left is becoming contaminated by chemical leaching and algae blooms due to global warming.

"By 2025 at least 3.5 billion people—about half the world's population—will live in areas without enough water for agriculture, industry, and human needs...

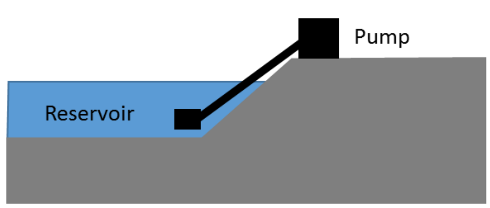


Worldwide, water quality conditions appear to have degraded in almost all regions with intensive agriculture and in large urban and industrial areas." —World Resources Institute, October 2000

Ground water - Aquifers



Surface water - Reservoirs / Lakes



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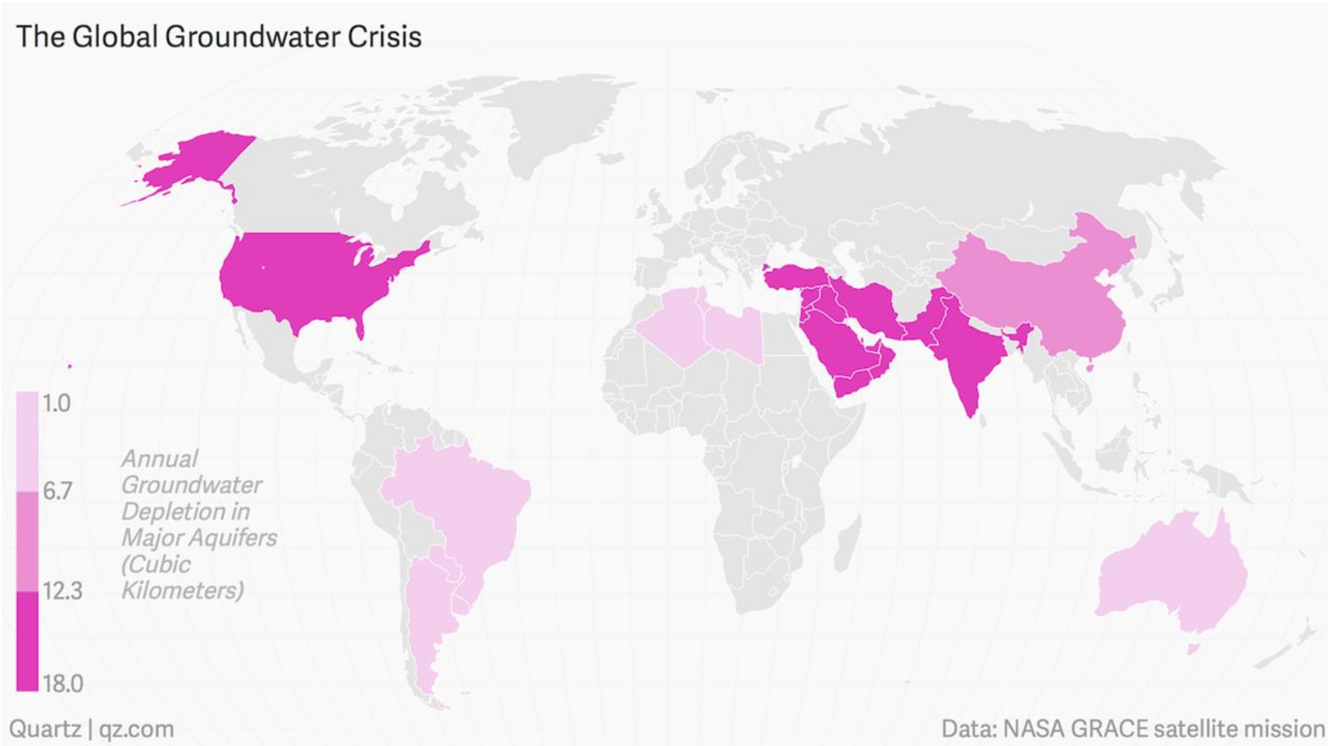

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Since the United States is one of the major counties with a large amount of groundwater and reservoir depletion, it will be the main focal point for this research. The small percentage of the water left in America that can be used is furthermore becoming unusable. A large percentage of the water we have left is getting polluted with chemicals from leaching and algae growth from fertilizer run off. This makes the water unsafe and useless. With demands for resources increasing, it is important to start using the water left more efficiently.

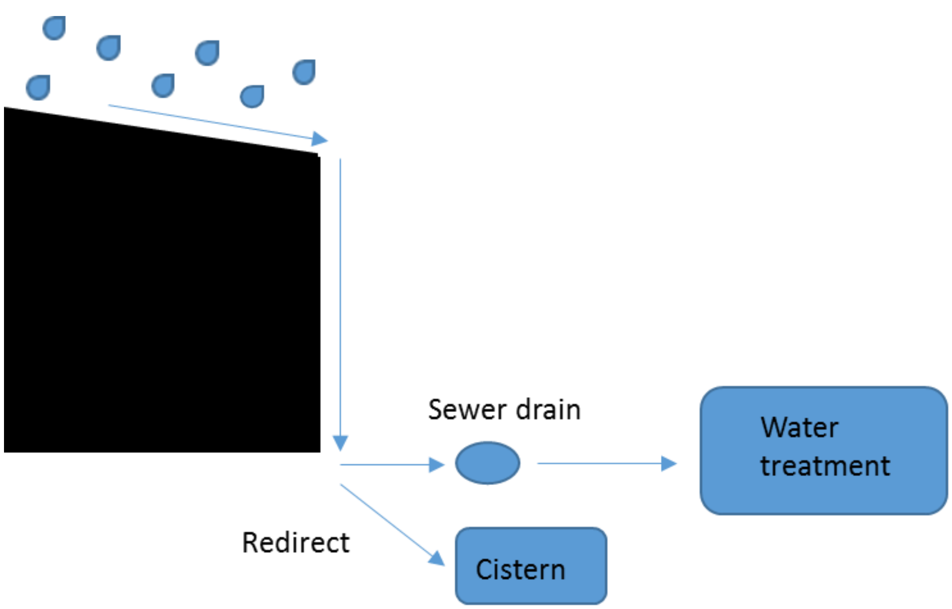
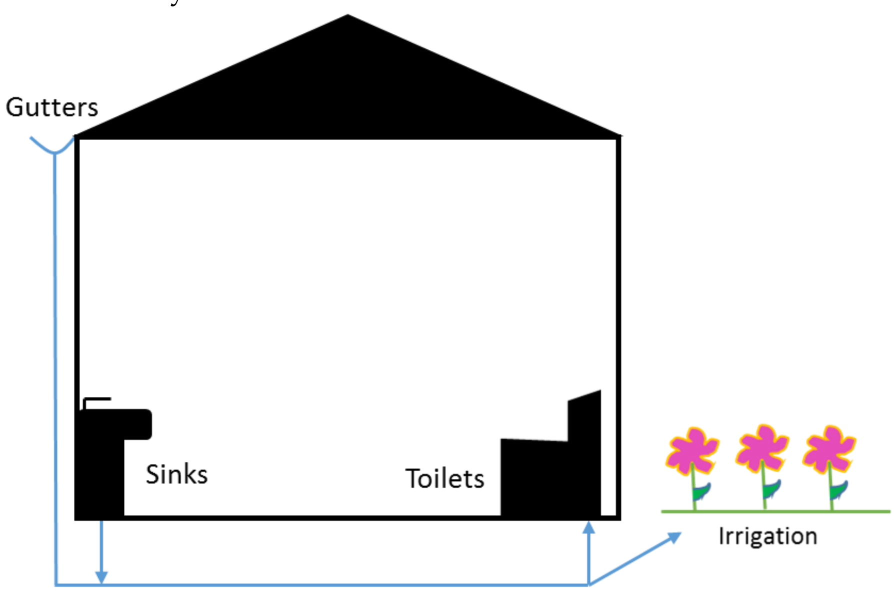


Figure 13: Diagram of keeping rainwater onsite by author

Introduction

Instead of continuing to take water from reservoirs and aquifers, people should make better use of rainwater that is landing on site. A large amount of rain water is unutilized by directing it to storm water drains that may be sent to water plants to clean the water and send it back. It is a waste of energy to send it off site to be cleaned just to send it back when it can be kept on site. It is vital to save as much potable water as possible and to utilize the rainwater and grey water from showers, bathroom sinks and washing machines, for toilets, irrigation and washing cars. By reducing the amount of potable water, it will allow our reservoirs and aquifers recuperate. The goal of this research is to protect and preserve the world for future generations. To continue this research, the focus is on saving as much potable water as possible, keeping water on site, using greywater for toilets, irrigation and washing cars and use the water flow in the pipes to create electricity.



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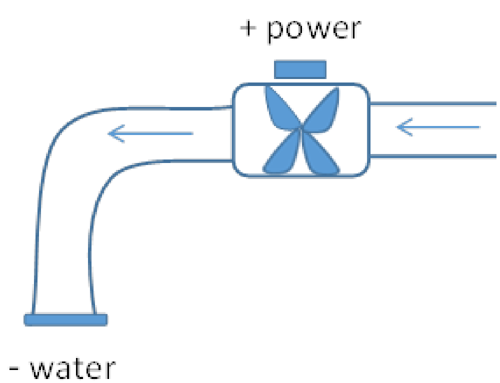


Research

The research begins with four research labs in the United States, Argonne National Laboratory, Laurence Berkeley Research Lab, NREL- National Renewable Energy Lab and ORNL- Oak Ridge National Lab. The research will look into whole building systems and micro-water turbine applications.

Argonne National Laboratory

Figure 16: Pictures of Argonne National Laboratory and Campus

"Argonne's world-renowned scientists and engineers conduct pioneering research to take on the nation's greatest environmental challenges" U.S. Department of Energy. It is located in Argonne, IL and recently built a new energy science building.

Related Program

Energy

- Batteries and Energy Storage
- Energy Systems Modeling
- Materials for Energy
- Nuclear Energy
- **Renewable Energy**
- Smart Grid
- Transformational Manufacturing
- Transportation

Renewable Energy

- **Hydropower**
- Solar Energy
- Wind Power
- Geothermal Power

Hydropower

Variables:

- Volume of water
- Elevation of water storage
- Duration of release
- Pipe size
- Turbine size
- Flow rate
- Watts/hr

Laurence Berkeley Research Lab

"Berkeley Lab fosters groundbreaking fundamental science that enables transformational solutions for energy and environment challenges" -U.S. Department of Energy. Located in Berkeley, California.

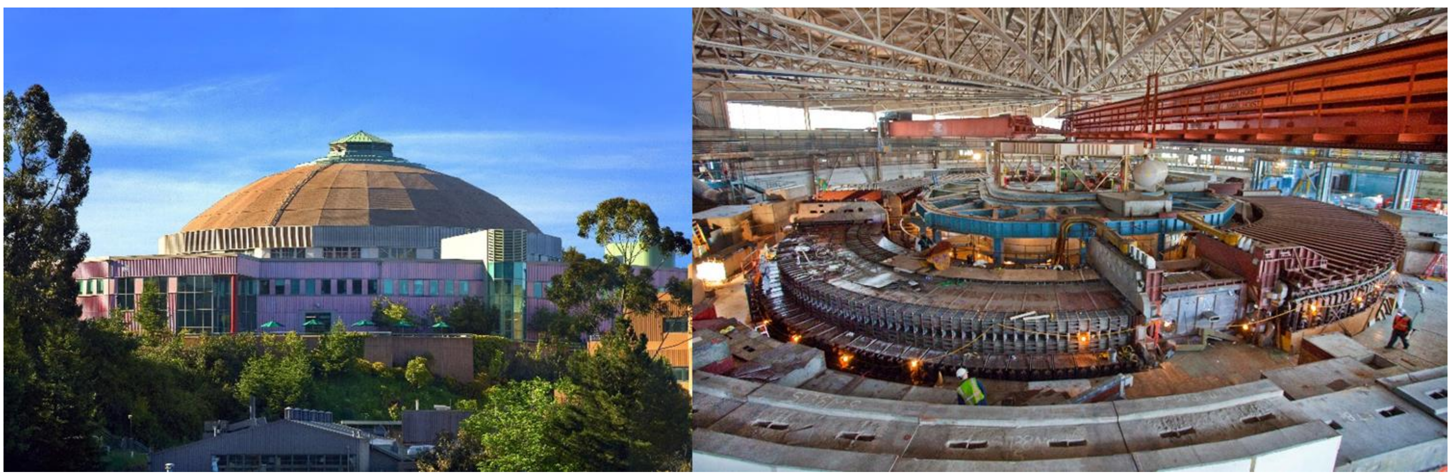


Figure 17: Pictures of Laurence Berkeley Research Lab

Related Program

Energy Technologies

- Energy Technologies (ETA)
- **Building Technology & Urban Systems**
- Energy Analysis & Environmental Impacts
- Energy Storage & Distributed Resources

Building Technology & Urban Systems

- Commercial Building Systems
- Electronics, Lighting, and Networks
- High Tech and Industrial Systems
- **Residential Building Systems**
- Simulation Research
- Sustainable Federal Operations
- Window and Envelope Materials

Residential Building Systems

- Promoting whole building system integration
- Looks at ways to minimize energy use and improve efficiency through
    - HVAC system
    - Organizational behavior
    - Indoor air quality
    - Retrofits and Whole House Energy
    - Ventilation and Infiltration

National Renewable Energy Lab

"At NREL, we focus on creative answers to today's energy challenges. From breakthroughs in fundamental science to new clean technologies to integrated energy systems that power our lives, NREL researchers are transforming the way the nation and the world use energy." -U.S. Department of Energy. Located in Denver, Colorado.

Figure 18: Picture of National Renewable Energy Campus

Water Power

- Marine and Hydrokinetic Technology
- Technologies and processes to improve the efficiency, flexibility, and environmental performance of hydropower generation.
- **The Benkatina Turbine:** Designed to be integrated into any existing or planned pipes as well as other downhill flow systems.
    - Horizontal efficiency: 59%
    - Vertical efficiency: 30%
    - Vertical pipe with pump efficiency up to 60%

Figure 19: Picture of National Renewable Energy Lab Building

Figure 20: Picture of Benkatina Turbine

Oak Ridge National Laboratory

"Oak Ridge National Laboratory is the largest US Department of Energy science and energy laboratory, conducting basic and applied research to deliver transformative solutions to compelling problems in energy and security" U.S. Department of Energy. Located in Oak Ridge, Tennessee. **Figure 21:** Picture of Oak Ridge National Campus

Figure 22: Picture of Oak Ridge National Lab Building

Related Program

Advanced Materials

Clean Energy

National Security

Neutron Science

Nuclear Science

Supercomputing

Clean Energy

- Reducing Fossil Energy
- Transportation
- **Buildings**
- Energy Efficient Refrigerators
- System Biology
- Climate and Environment

Buildings

Looking towards:
- Alternative Energy Sources
- Efficient Materials
- Energy Efficient Appliances

Existing Technology

Each lab had a great amount of information about energy and water efficiency, but didn't have any information about implementing micro water turbines. The research continued with a focus on capturing rainwater, storage and distribution of greywater and generating power from the greywater. There were other systems that exist that can be utilized in the following proposal to help reduce potable water and energy use. The LucidPipe power system is utilized in Portland, Oregon to produce energy from the flow of the water in the city pipes. The lift-base turbine works very efficiently and does not slow down the water flow in the pipes.

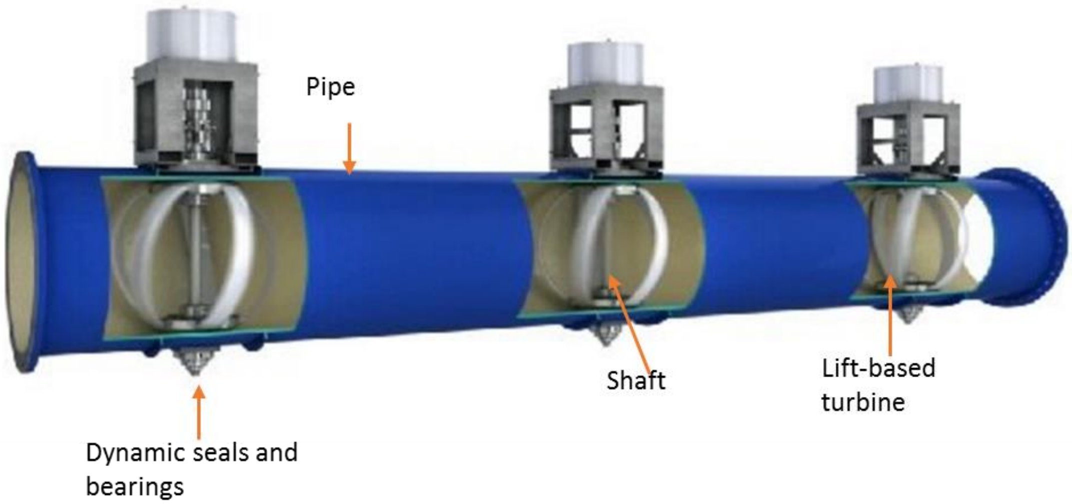


Figure 23: LucidPipe Water Turbine Diagram

The HighDro Power system is used on high rise building and produces energy from the waste water that is traveling down the pipes. It will save a building $1,410 a year in high rise buildings.

Figure 24: The HighDro Power Sewer Turbine and Designer

Figure 25: The Solar Power and Pump Co. SunRotor brand solar water pump

Harvesting Rainwater

After finding existing technologies that could be used in a new system, more detailed components needed to be researched. How to capture the rain water is the first question. There are two ways: collecting water from the roofs through gutters and pipes and from the hardscapes with gutters and rain gardens. This water is usually directed towards sewers and storm water drains. This water can easy be redirected to cisterns. Although a large amount of water that can be collected from hardscapes, there are concerns about chemicals from cars getting into the greywater that will be used. The proposal will only be dealing with rainwater captured from the roofs of houses.

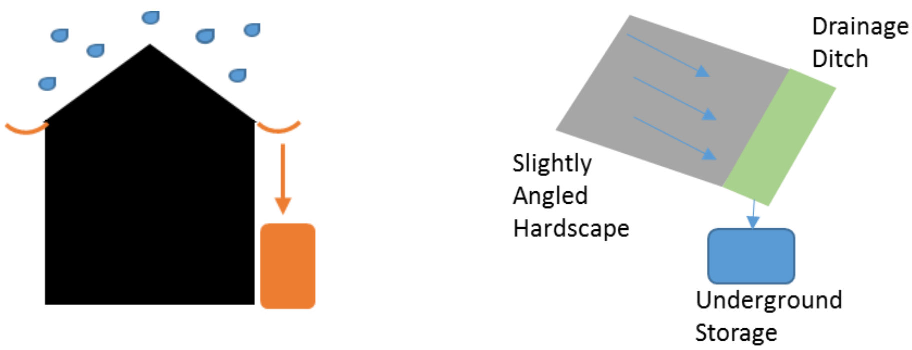


Figure 26: Diagrams by author showing rainwater harvesting techniques

The next question is what kind of cistern will be used to store the greywater. The most common cisterns are vertical water cistern (top), underground cisterns (left) and Cone bottom tanks (right). Vertical water cisterns are set on the ground outside, which allows for easy maintenance. Underground Cisterns are great for keeping the water a more consistent temperature and less likely to freeze, but is difficult for maintenance. Cone-Bottom tanks are made to be placed on roofs or structures to allow gravity to pressurize the water. When using cisterns that will be stored on the roof, it is important to know how much water weighs. If you have a large cistern that needs to be stored on the roof, you need to know if the building is structurally sound. As water gets warmer it becomes less dense and starts to weigh slightly less. At 39.2°F water weighs 8.36lbs per gallon and at 62°F water weighs 8.34lbs per gallon.

Figure 27: Popular types of water tanks/cisterns

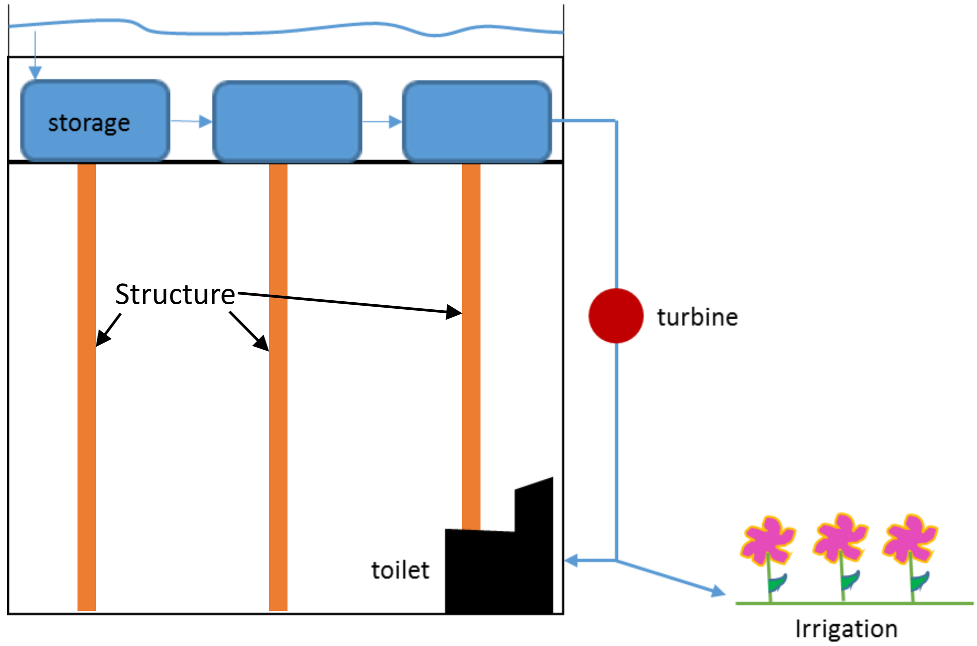
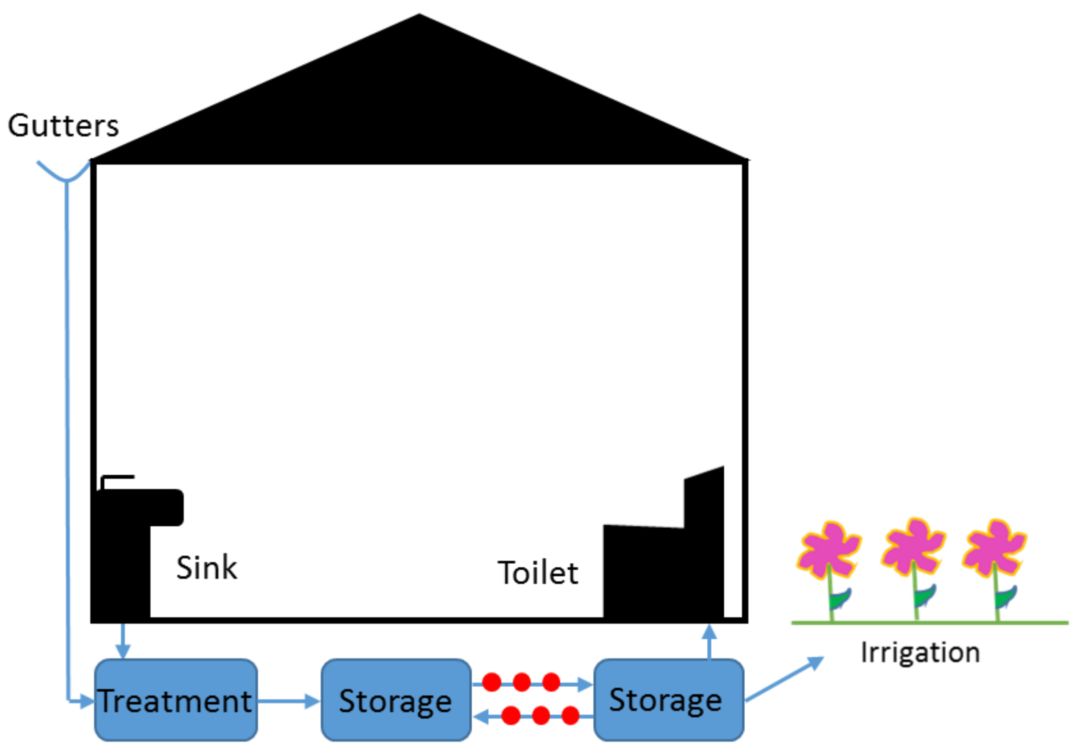


Figure 28: Diagram by author showing structure is needed to support water tanks

Design Proposal

The design proposal is to collect rain water from the roofs of the building and greywater from bathroom sinks and showers, to be reused and limit the use of potable water. This greywater can then be used to power the building by utilizing the water flow to create electricity through micro-water-turbines. Although this is a great way to reduce potable water use and provide green energy for building, the proposed system on single buildings is not cost effective.

Figure 29: Diagram by author showing single home design proposal.



Community Greywater Tank

After looking at single home systems, it seemed that the cost of the system was not very possible for most building owners, especially when looking at payback time. One proposal that would be great is for community water tanks that already exist in most cities, be integrated so that water can be collected on multiple building sites and be sent to the community water tank. This would be more economically feasible, since the city can help implement this green strategy and would have the best way to generate electricity through the constant flow of water through the community water pipes. Collecting grey water from all homes and sending it to one tank to be cleaned and then sending it to the main greywater storage tank will save on the amount of water pumps needed. One solar powered pump can be used to transfer the water from all houses rather than a pump per house. Storing the water higher than the houses allows gravity to pressurize the water for building use and turbine efficiency. Sending the water through micro water turbines will create electricity for the buildings in the community. By using greywater it is possible to save 27% of potable water for single residential and 38% for multifamily residential buildings.

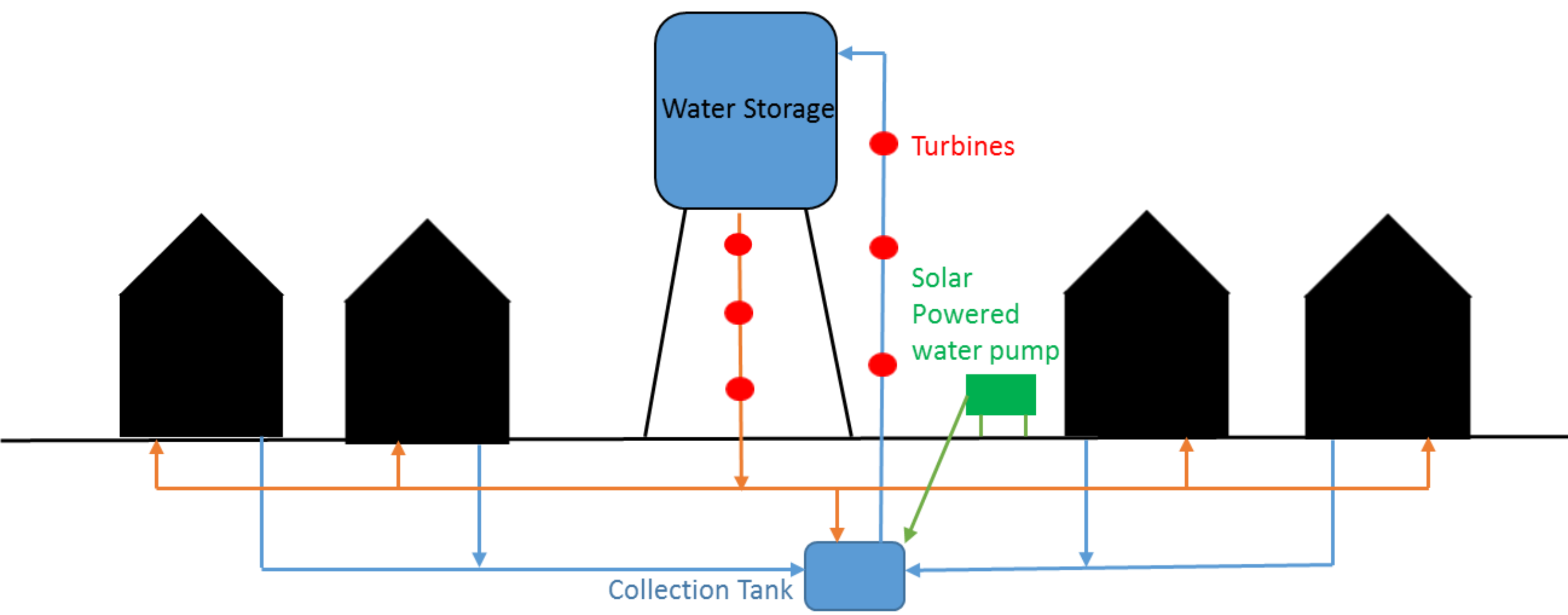


Figure 30: Diagram by author showing community greywater tank proposal

Organ Pipe Cactus National Monument Scenario

In order to test how well this system will work, the base case of Organ Pipe Cactus Nation Monument will help decide whether or not this system will be practical. The Organ Pipe Cactus National Monument is located in Pima County, on the boarder of Arizona and Mexico.

There will be a focus on ten houses located in the residential loop. The ten houses use 77,576 kWh/yr.

Figure 31: Maps showing location of Residential Loop in the National Monument

Gathering Information for Scenario

1. How much rain water can be captured from homes?
2. How much greywater can be reused?
3. Where can the water be stored?
4. What type of turbine should be used?
5. How many turbines can be placed along the system?

Figure 32: Revit 3D view of the residential buildings

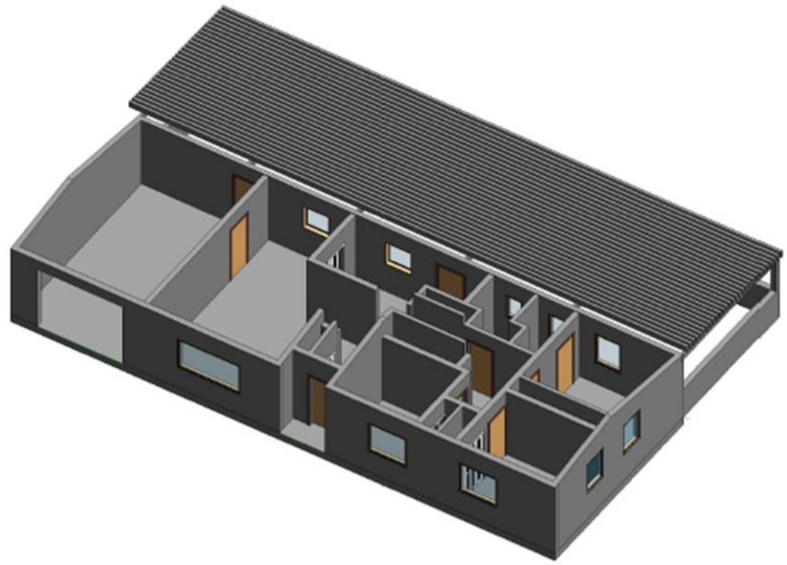


Figure 33: Photo showing one of the houses that had a level 3 energy audit.

Calculating Rainwater Harvesting

The Eastern states get more precipitation throughout the year, so a smaller square footage is needed to provide enough water for building use. It also doesn't require as big as a storage device either, since the rain falls in most of the seasons. In the Western states more square footage is needed to catch enough water for building uses. It also requires a larger storage device to hold water throughout the year, since rain fall is mostly in one season and not spread across the year.

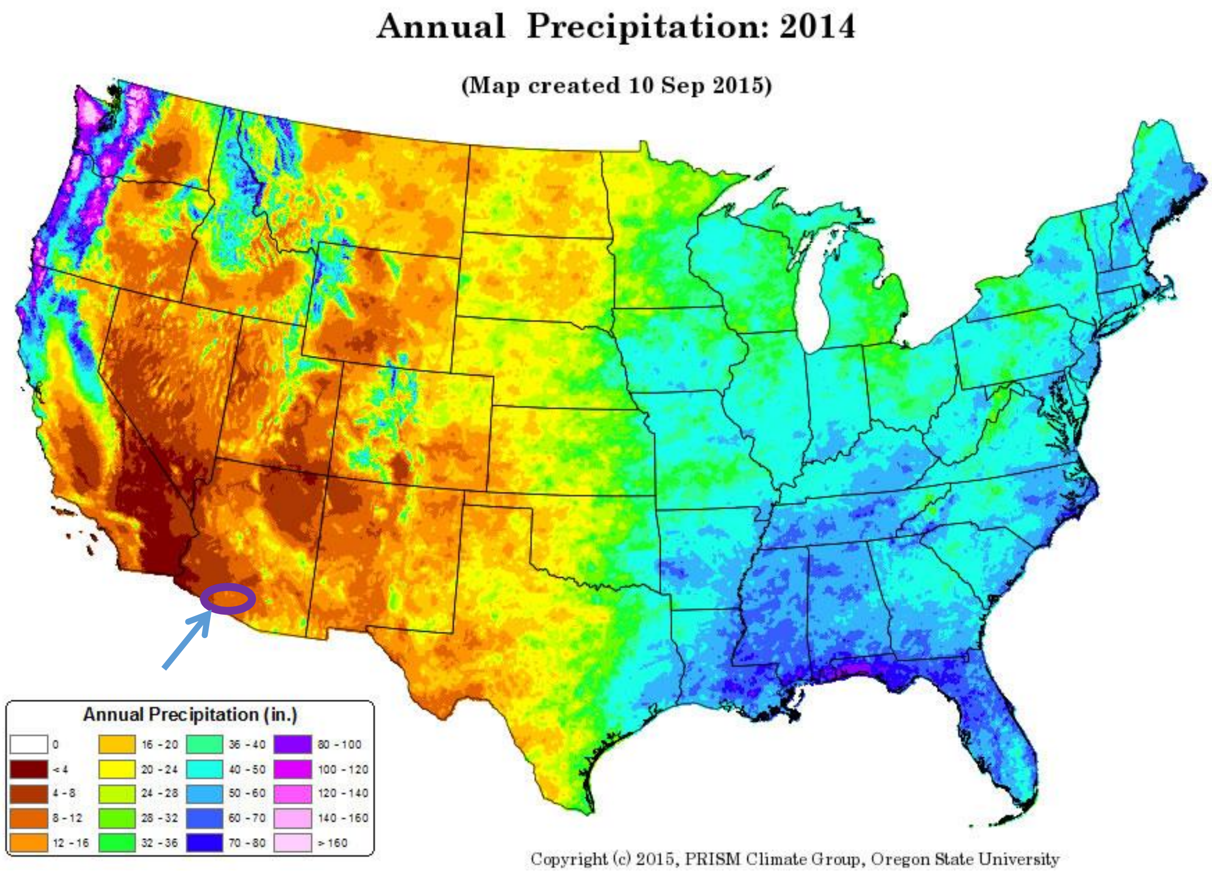


Figure 34: Map showing the annual precipitation from 2014

When sizing a water storage tank/cistern, this equation should be used to calculate the amount of water that can be collected from a given area.

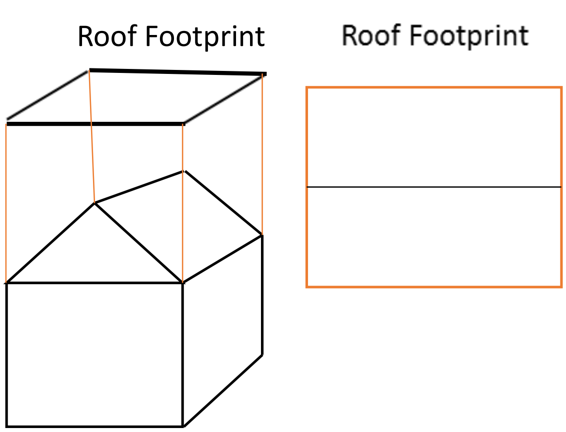
Catchment Area (ft^2) x Rainfall Depth (in) x 0.623 Conversion factor = Harvested water

Catchment Area x **Rainfall Depth** x **0.623** =

1,960 ft² **10 in/yr** **12,210.8 gal**

x 10 houses = 122,108 gal/yr ÷ 12 months = 10,175.7 gal/m

Figure 35: Diagram from author showing how to take the roof footprint



Calculating Greywater from Homes

The average four member household uses 400 gallons of water a day. 280 gallons of that water are used indoors alone. By looking at how much water is used per fixture, stated by EPA, the greywater collected from bathroom sinks, showers and washing machines can be calculated. 135.8 gallons of water will be accumulated from one house every day. Over 30 days, from all ten houses, 40,740 gallons of greywater will be collected and 50,915.7 gallons including the rainwater that can be harvested.

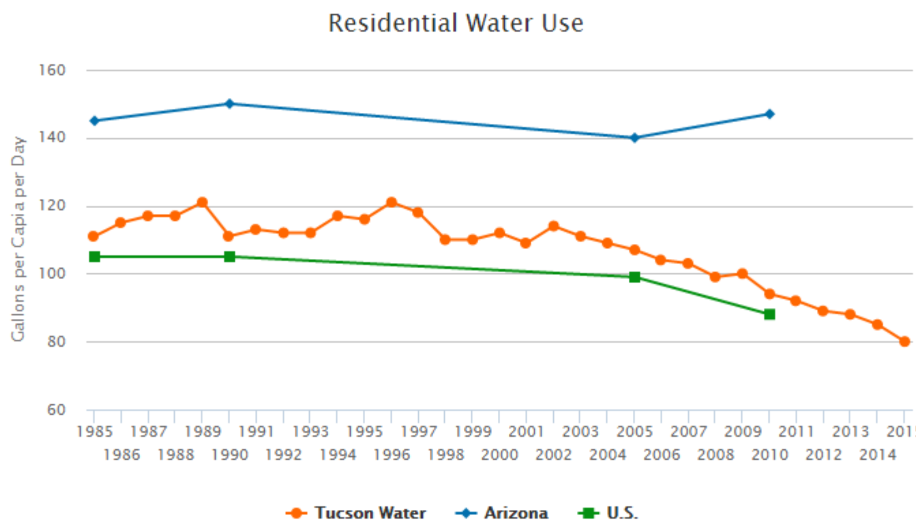
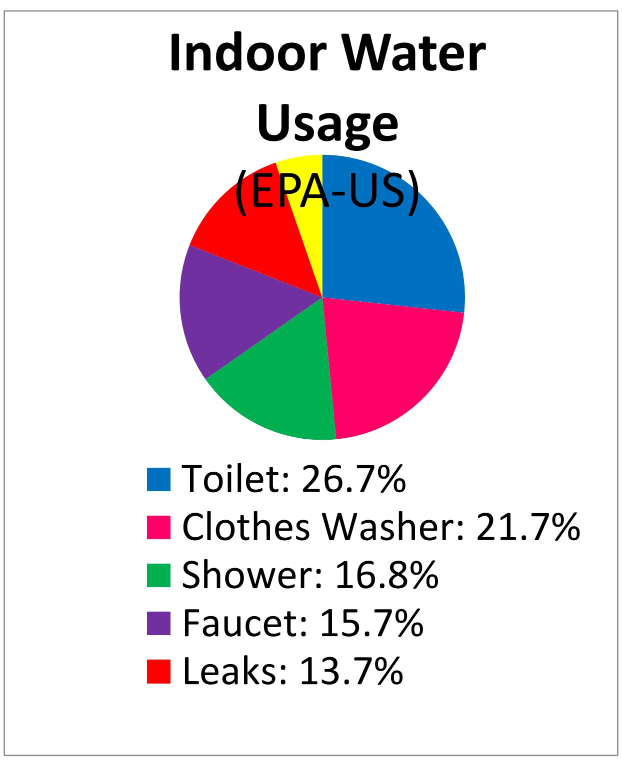


Figure 36: Chart showing residential water use averages

Figure 37: Diagram showing indoor water usage by fixtures



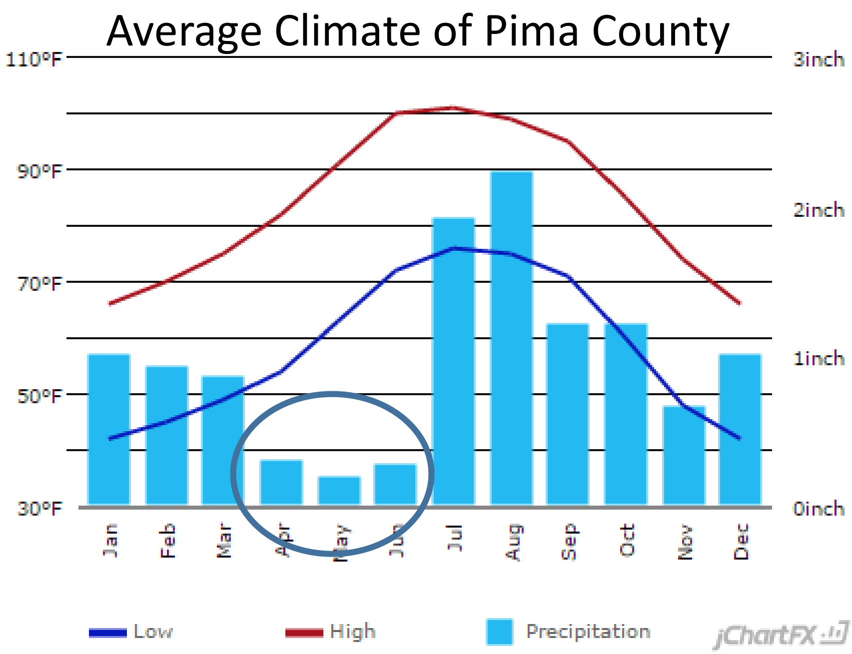
Water Use

The grey water will be used for washing toilets, irrigation and washing cars. It is important to see if there will be enough water for these uses. Toilets use 56 gallons per day per household, Irrigation uses 96 gallons of water per day per household and washing cars uses 30 gallons per car when using a house with a turn off nozzle. Assuming they will wash their cars once a month, all ten houses would use 45,900 gallons every month. This system allows for an extra 5,015.7 gallons of water that can be used for maintaining roads, flushing out sewage pipelines and more.

Estimating Greywater Tank Size

When sizing a greywater tank it is important to use the worst case scenario. By looking at the average climate of Pima County, there are 3 months were the county barely gets any rain. Extra storage is needed to collect more water for the months that rain might not occur. Comparing the water used from toilets and irrigation and comparing it to the water collected from fixtures, you find that 4,860 gallons are used more than collected. Over the three months 14,580 gallons are need. Then add two more months' worth of water used more than collected to insure enough water is stored for drought.

Figure 38: Chart showing Average Climate in Pima County, Arizona



Grey Water Storage

The existing potable water tank for the Organ Pipe Cactus National Monument holds about 12,860 gallons. The tank sits at 1,886 feet above sea level, while the houses sit at 1,680 feet above sea level. This gives the system a 206 ft head. This is important to know when calculating the pressure in the system and will create a stronger flow of water that will pass through the turbines.

Figure 40: Map of existing potable water tank and proposed water tank (in purple)

Figure 39: Picture of existing potable water tank.

After estimating the storage needed for the greywater, it can be said that two tanks, the same size as the existing potable water tank, can be used to effectively store enough water for the ten houses. The two tanks should be stacked on top of each other to reduce the footprint being scarred. The two tanks would hold about 25,720 gallons of water, which is 1,420 gallons more that estimated.

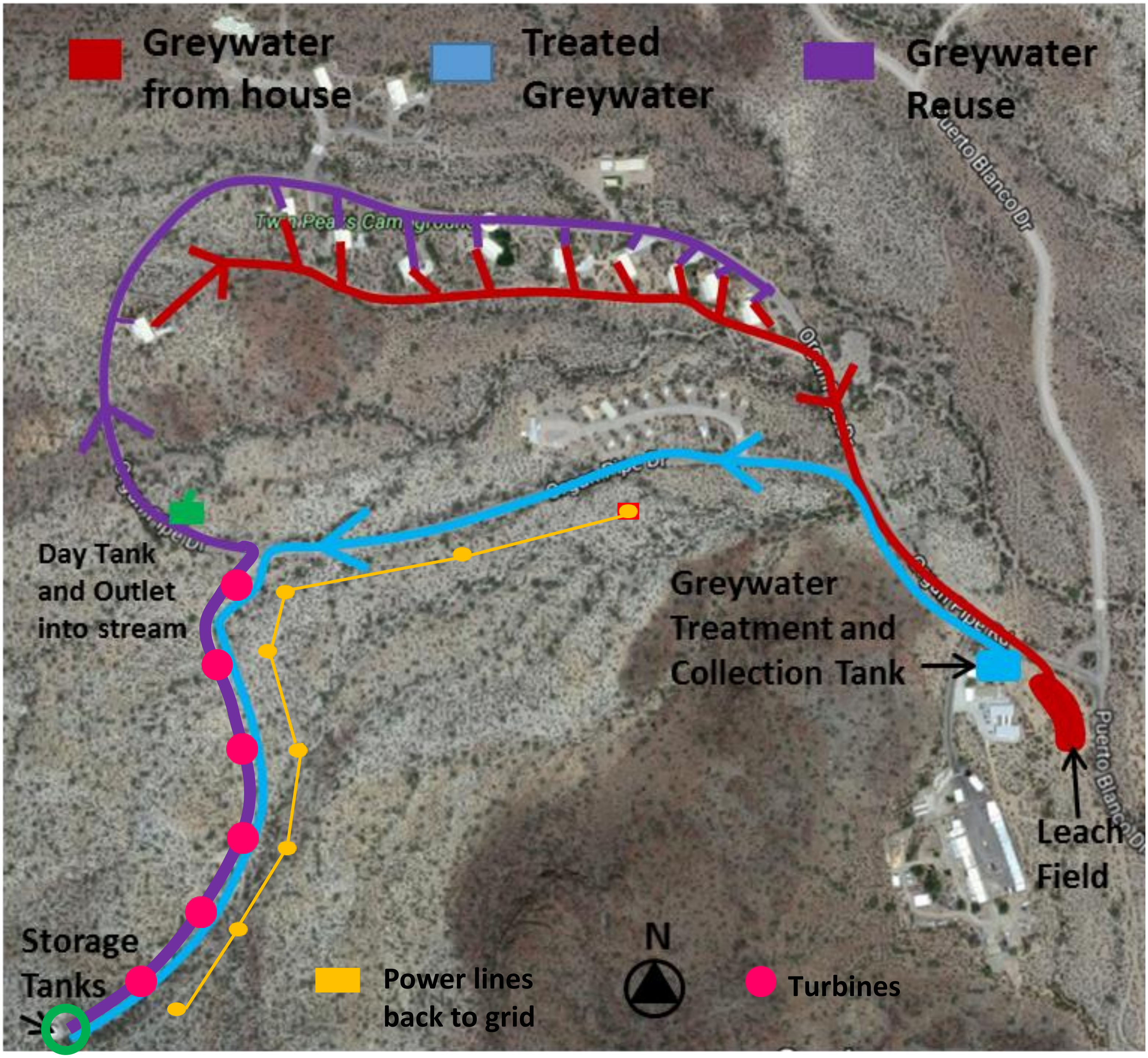


Figure 41: Plan of proposed greywater reuse system with energy generation

Greywater Treatment

The greywater collected from each house will drain downhill towards the leach field, so no pumps are needed, where the water will be treated and the sludge and particles will be emptied right into the leach field (shown in red). The greywater needs to go through a level of treatment so that it can be stored in a water tank for further use. Treatment is to improve the quality of water by filter, treating or disinfecting it. The higher the quality of water the more uses it can be used for. Since the water would be returning to the inside of homes for flushing toilets, the maximum treatment needs to be done to meet local regulations. Water from kitchen sinks and dish washers require chemical treatment to kill food bacteria, which is why these sources of water will not be used. The treatment technologies needed for the greywater being used are sedimentation tank, sand filter, bioreactor and a disinfection unit. The sedimentation tank is a "settling" tank that allows for heavier particles to fall to the bottom of the tank and separate from the water. A scum skimmer may be implemented to get smaller particles that will flat to the top. A sand filter catches suspended particles as the water passes through the sand and gravel. Bioreactors are a semi-permeable membrane that has a biological process that filters out suspended particles based on size and electric charge. The last process is the disinfection unit, which can me UV or chemical based. The UV will be used in this system, which is used to remove, deactivate or kill any pathogenic microorganisms in order to terminate the growth and reproduction. After the water is treated it can then be pumped up to the water tank using a solar powered water pump (shown in blue).

Figure 42: Diagram of Sedimentation tank

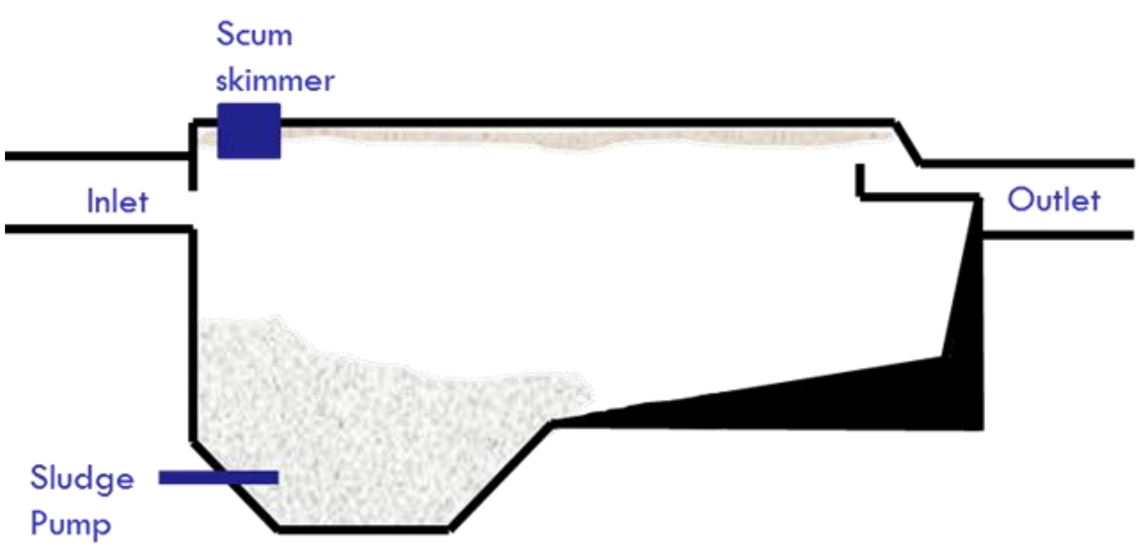


Figure 43: Diagram of Sand filter

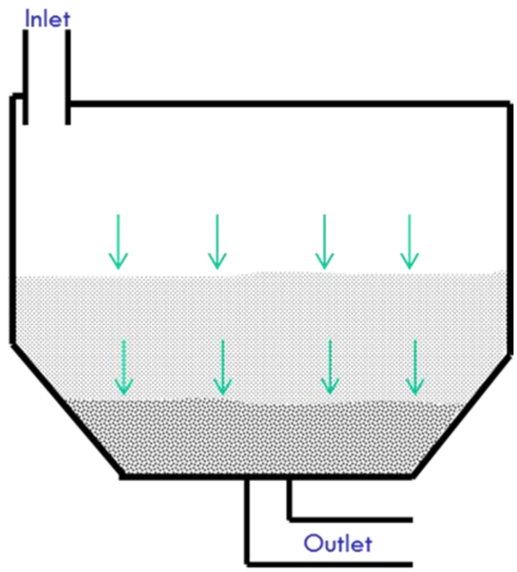


Figure 44: Diagram of Bioreactor

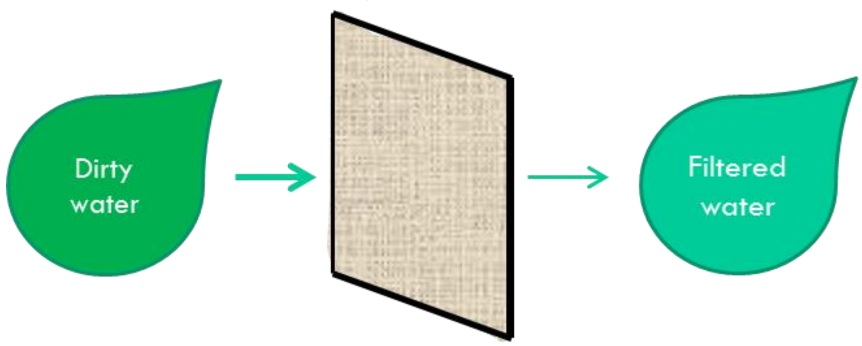
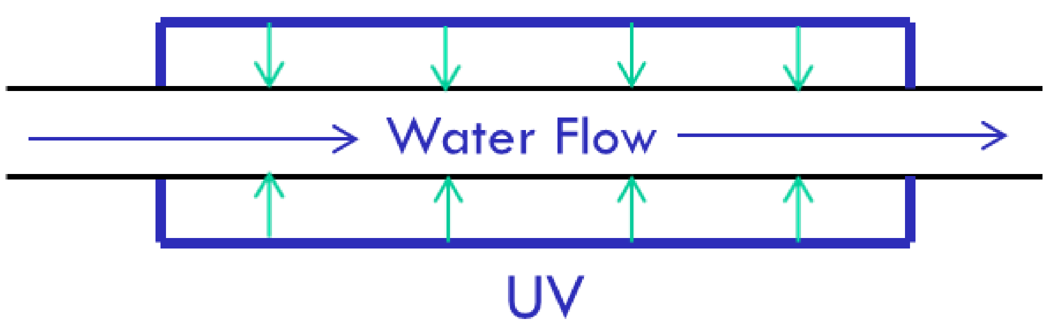


Figure 45: Diagram of UV disinfection unit



Choosing a Turbine

To find a turbine that will be best suited for this system, the head and flow rate need to be determined. If the system is using an 8in pipe to deliver the water to a day tank by the houses, the maximum flow in that pipe is 1,600gpm.

Unfortunately no single recommendation will be correct for all possible circumstances, but the table below can be used as a general guidance for the water flow capacity in Steel pipes schedule 40:

Pipe Size (inch)	Maximum Flow (gal/min)	Velocity (ft/s)	Head Loss (ft/100ft)
2	45	4.3	3.9
2 1/2	75	5.0	4.1
3	130	5.6	3.9
4	260	6.6	4.0
6	800	8.9	4.0
8	1,600	10.3	3.8
10	3,000	12.2	4.0
12	4,700	13.4	4.0
14	6,000	14.2	4.0
16	8,000	14.5	3.5
18	10,000	14.3	3.0
20	12,000	13.8	2.4
24	18,000	14.4	2.1

The 206 ft head is 62.8 meters and 1,600gpm = .1 meter cubed per second

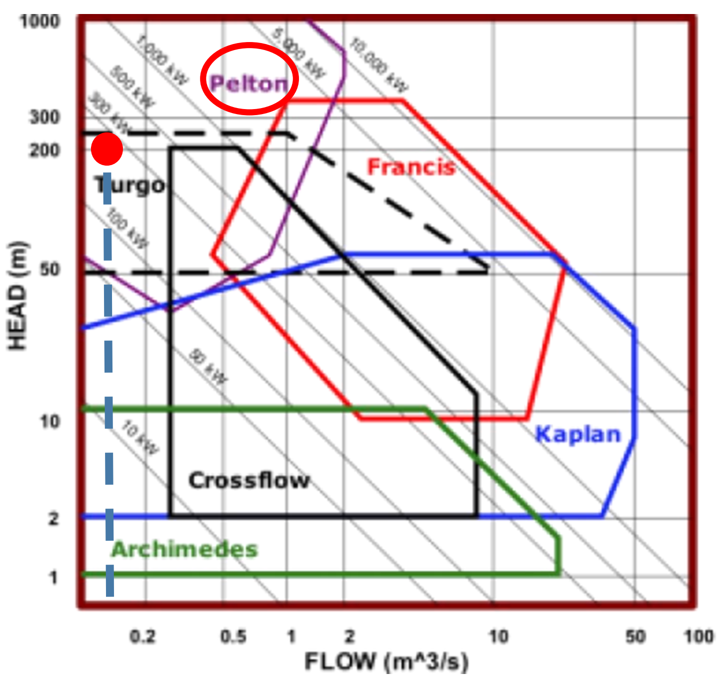


Figure 46: Chart showing general guidance for water flow capacity in steel pipes

Figure 47: Chart for determining turbine type

The impulse turbine is the best type of turbine to use for the high head system. An impulse turbine takes the total head of incoming fluid and coverts it into a large velocity head and sprays into buckets or blades. Of the impulse turbines the Pelton turbine is the most efficient over a variety of flows. The turbine works best with a small flow rate. Since the flow rate is rather low the pipework can be relatively small and makes the system less expensive and easier to install than an equally powered Kaplan turbine. The efficiency of the Pelton turbine grows quickly and stays the same efficiency as the flow increases. The efficiency of the turbine is how well the turbine produces electricity from the torque of the buckets rotation. The buckets in the Pelton turbine are able to get the best torque from the water nozzle since it is able to capture the full momentum of all the water. On a "micro" scale system Pelton turbines maintain a high efficiency of around 80% and 90% at its peak.

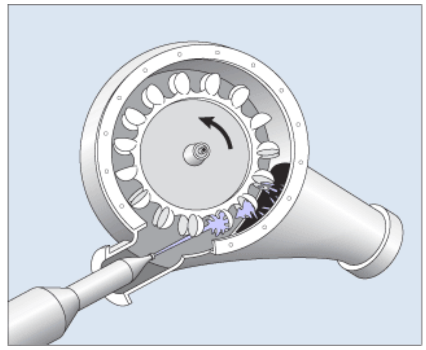
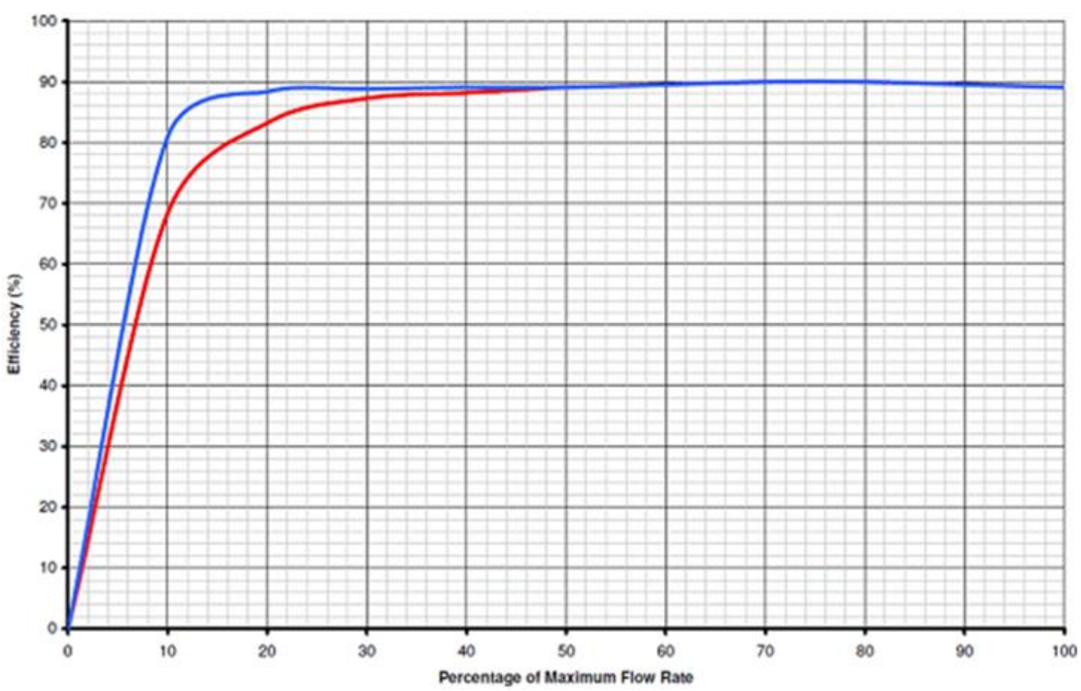


Figure 48: Diagram showing how an Impulse turbine runs

Figure 49: Picture of a Pelton turbine

Figure 50: Chart showing the efficiency of a Pelton turbine. Efficiency is the vertical axis and flow rate is the horizontal axis.



Energy Generation

The energy generation from a single jet Pelton turbine on a 8 inch pipe line can be determine by the head of the system multiplied by the water flow divided by the system factor of the turbine. The system turbine is determined by a range from 9 – 13, 9 being a large AC (alternating Circuit) system and 13 is for a small battery-based turbine. This system uses a medium size turbine for a system factor of 11. It is important to include the head loss from friction in the system before finding the energy generation.

198.4 head (after head reduction) x 1,600gpm ÷ 11 = 28,858 Wh = 28.85 kWh

Each turbine can produce 28.85 kWh. In 30 days one turbine can produce 865.5 kWh. There will be 6 turbines placed along the steepest part of the pipeline to insure water pressure(shown in pink). Over the length of a year this system can produce 62,316 kWh, while the homes use 77,576 kwh/yr. This system allows 80% of the energy used to be from a green energy source and will limit the amount of CO_2 that will be emitted into the atmosphere. This system also saves 610,988.4 gallons of potable water every year.

The cost of electricity is 11.78 cents/kWh and the cost of water is $2.88/ 1,000 gal. After adding up how much water and energy this system can save it is possible to figure out how much money can be saved every year. This system saves $7,340.82/yr from energy savings and $1,759.65 from water savings, a total of $9,100.47 every year.

Cost estimates to build system:

Water Tank Price: $10,000/tank

Turbine Price: $10,000/set

Greywater Treatment System: $25,000

Greywater System for Homes: $15,000

Piping down to treatment and up to storage: $6,000

Yearly Maintenance: $1,000

Estimated Total Cost of System: $126,000

Payback Time: 15 years.

Conclusion:

This payback time may seem like a long time, but this monument will be there for hundreds of years to come. The amount of environmental impact that this system can have over a long amount of time will be colossal. If more communities would use energy generation turbines within a greywater reuse system, it will have an outstanding positive effect for the environment we need to survive. This case is a great way to inspire others to implement a similar system in order to help improve the Earth's conditions from its atmosphere down to its aquifers.

Figure 51: Arial drone picture of existing residential loop

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