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HYD 243

Rainwater Harvesting Systems Considerations in Monterey County

Abstract:

Rainwater harvesting has often been pushed as a top water conservation method for homeowners, particularly in geographic areas with distinct wet and dry seasons. A rainwater catchment system allows water to be captured and stored during the rainy season to later be utilized when water is not as readily available during the dry season. Though there can be many benefits to installing a rainwater catchment system, there are also large up-front costs associated with the purchase and installation of equipment. This project aims to compare the feasibility of installing a rainwater harvesting system in wealthier communities and disadvantaged communities of Monterey County. Additionally, this project examines the reliability of a rainwater catchment systems in the face of climate uncertainty. A cost analysis revealed that residents in wealthier communities such as Spreckles, CA would utilize 6% of their annual income to install a rainwater harvesting system whereas citizens in front-line communities such as Greenfield, CA would utilize 19% of their income. Reliability in the rainwater harvesting system is also lower on average for citizens in Greenfield as compared to Spreckles. From the years 2023-2050, a rainwater harvesting system in Greenfield would be full 62% of the time whereas in Spreckles, the system would be full 90% of the time. These results indicate that rainwater harvesting systems have the potential to further widen the gap in water accessibility between high- and low-income communities during extended drought periods.

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Introduction:

As California enters a third year of drought, water conservation practices have become increasingly important across the state. Last July, Governor Newsom called for Californians to voluntarily reduce their water use by 15%, but this voluntary reduction could soon become a mandate if drought conditions worsen, and water conservation goals are not met. Though there are many water conservation tactics which are accessible and easily utilized by everyone, there are also measures which require a significant amount of time, effort, and money in order to implement. One such strategy – rainwater harvesting – has the potential for large gains to an individual homeowner. A rainwater catchment system, once installed, can collect water during periods of high precipitation and store the water for use during later, drier periods (see Figure 1). Harvested rainwater is primarily used for irrigation, though harvested rainwater can be utilized for potable purposes provided proper filtration and cleaning mechanisms are in place (Thomas et al., 2014). Ultimately, rainwater harvesting can lead to potential cost-savings on a water bill, a benefit that is growing in significance as water rates increase across the state (Dallman et al., 2021; Chappelle and Hanak, 2021). While rainwater harvesting systems can provide many benefits, there are also many associated costs, particularly when considering the purchase of equipment and installation. These economic constraints can translate into a lower degree of rainwater harvesting adoption and implementation across communities (Campisano et al., 2017). High costs may pose a barrier to individuals who wish to engage in this water conservation practice but lack the funds to do so. During water shortages, rainwater harvesting systems have the potential to further widen the gap in accessibility to water between high-income households and disadvantaged communities. Disadvantaged communities are defined by the California Department of Water Resources as communities with an annual median household income of less than 80 percent the statewide annual value (Water Education Foundation). These front-line communities face significant financial barriers to adopting rainwater harvesting practices in addition to shouldering disproportionate drought impacts in relation to water scarcity and quality issues. Climate change further complicates these issues as a warming atmosphere has caused a shift in weather patterns across California. Where a distinct wet and dry season were once predictable, flashy precipitation and lengthy droughts have now become the norm for many communities (Swain et al., 2021). This may translate into a lack of reliability in rainwater harvesting systems when a scarce wet season leads to low water yield from the system and less overall water availability.

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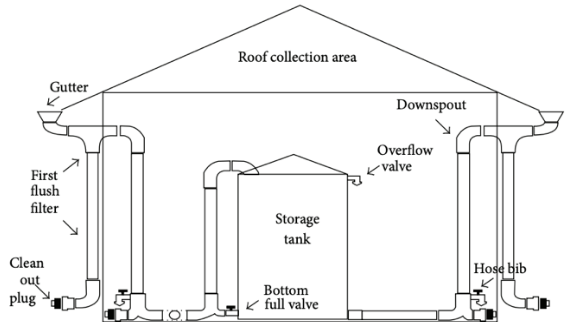

Figure 1. Rainwater harvesting system schematic (Rahman et al., 2014)

Objectives:

The main objective of this project is to quantify the costs associated with a rainwater harvesting system and then compare those costs across income levels in a high-income and disadvantaged, front-line community. Additionally, this project will analyze how climate change effects may interfere with the projected reliability of a rainwater harvesting system. This project will result in a table estimating the costs of a rainwater harvesting systems and comparting those costs in relation to income level for two different communities in Monterey County. Monetary benefits from a rainwater harvesting system will then be compared by utilizing local water rate and billing information. Utilizing climate data, this project will produce a plot illustrating how reliable a rainwater harvesting system may or may not be under a variable climate.

Methods:

Data was collected from various sources such as the US Census Bureau, CIMIS Weather Station data, Cal-Adapt, Google Earth, and online rainwater harvesting businesses. Google Earth data was utilized to obtain roof size estimates for five different homes in a Spreckles, CA, a high-income census tract community, and Greenfield, CA, a designated disadvantaged community in Monterey County. These roof sizes were then used to calculate the average amount of rainwater that could be harvested in these communities. From these averages, a 10,000-gallon rainwater harvesting system size was selected as this was the maximum amount of rainwater that could be harvested based off roof sizes in Greenfield, CA. The cost of a 10,000-gallon system was estimated using data from local and online rainwater harvesting businesses. These costs were then compared against household income data from the US Census Bureau to determine how feasible installation of a rainwater harvesting system is in wealthier and low-income communities. Benefits from a rainwater harvesting system were calculated by comparing offsets in water bills before and after rainwater harvesting system installation. Historic monthly precipitation data was gathered from CIMIS and Cal-Adapt and used to model how beneficial these systems may be under future dry weather scenarios.

Calculations and Results:

Two census tracts were selected to compare the relative costs and benefits of installing a rainwater harvesting system in Monterey County. Using census data, census tract 107.01 located near Spreckels, California was selected to represent a high-income census tract. Using DWR's DAC mapping tool, census tract 112.02 located near Greenfield, California was selected to represent a low-income, disadvantaged community. Median household income values from 2016 were utilized for this analysis as that is the data year utilized by DWR in creating the DAC mapping tool. To determine the appropriate size of rainwater harvesting system to use for this analysis, houses were randomly selected within these census tracts and roof sizes were estimated using Google Earth (see Table 1.)

City Census Tract	**Spreckles** 107.01	**Greenfield** 112.02
Median Household Income (2016)	$ 149,369.00	$ 50,337.00
Average precipitation (inches)	12.34	8.37
Roof 1 (m^2)	505.99	228.84
Roof 2 (m^2)	258.95	174.89
Roof 3 (m^2)	453.08	228.79
Roof 4 (m^2)	403.89	291.06
Roof 5 (m^2)	336.97	225.15
Average Roof Size (m^2)	391.78	229.75

Table 1. Income data and roof area estimations for census tract 107.01 and 112.02 in Monterey County (US Census Bureau; Google Earth).

The maximum potential amount of rainwater harvested in a year was then calculated using the average roof size within each census tract and the average amount of rainfall in a year for the specific area (see Equation 1). Average rainfall was calculated over the 2000-2021 time period using CIMIS weather data (see Table 1).

$$(1) \quad Inches\ of\ Rainfall\ in\ an\ Average\ Year * \ Roof\ Area\ (m^2) * 10.764\ (sq\ ft/m^2) * 0.623\ (conversion\ factor) * 0.85\ (efficiency\ factor) = Gallons\ of\ Rainwater\ Harvested$$

$$(1a - Spreckles) \quad 12.34\ inches * \ 391.78\ m^2 * 10.764\ \frac{sq\ ft}{m^2} * 0.623 * 0.85 = 27,557\ gallons$$

$$(1b - Greenfield) \quad 8.37\ inches * \ 229.75\ m^2 * 10.764\ \frac{sq\ ft}{m^2} * 0.623 * 0.85 = 10{,}961\ gallons$$

Based on these calculations, a 10,000-gallon system was selected as the size for comparison between census tracts. For this analysis, the costs of a rainwater harvesting system were assumed to consist of: 1) polyethylene cistern, 2) downspout diverter and piping, 3) sediment filter (cartridge), 4) sediment filter (housing), 5) pump, 6) labor (see Table 2.)

Equipment	Cost	Quantity
Polyethylene Cistern (5,000 Gallon)	$ 4,016.00	2
Diverter and Piping	$ 25.00	2
100 µM Sediment Filter (cartridge)	$ 70.00	2
100 µM Sediment Filter (housing)	$ 30.00	2
Pump	$ 100.00	2
Labor	$ 1,000.00	1
Total System Cost	$ 9,482.00	

Table 2. Equipment and cost estimates for a 10,000-gallon rainwater harvesting system.

The total system cost was then calculated as a percentage of median household income for both census tracts (see Equation 2).

$$(2) \qquad \frac{Total\ System\ Cost}{Median\ Household\ Income} * 100 = Percentage\ of\ Housheold\ Income$$

$$(2a - Spreckles) \qquad \frac{\$\,9{,}482.00}{\$\,149{,}369.00} * 100 = 6\%$$

$$(2b - Greenfield) \qquad \frac{\$\,9{,}482.00}{\$\,50{,}337.00} * 100 = 19\%$$

To quantify potential benefits from installation of a rainwater harvesting system, the average water bill in both census tracts was estimated along with the amount of water per month that could be offset using harvested rainwater (see Table 3 and Table 4). Utility rate information was obtained from the City of Greenfield and the California Water Service Company – Salinas District. The amount of water that could be substituted with harvested rainwater was assumed to be all outdoor-use water along with indoor-use water for toilet flushing (all non-potable water uses). Of the total amount of gallons utilized per day, approximately 53% was estimated to be used outdoors and of the total water used indoors, approximately 21.4% was estimated to be used for toilet flushing (DeOreo et al., 2011). In calculating the total amount of water used per household per month, each household was assumed to consist of four individuals with identical water use.

Average Monthly Water Bill		
City	Spreckles	Greenfield
Monthly Utility Charge	-	$ 12.97
Monthly Meter Charge (3/4-inch meter)	$ 28.94	$ 18.00
Residential Use (gallons per capita per day)	72	80
Water Utility Rate (per TGAL)	$ 4.06	$ 1.42
Charge for Water Use	$ 36.06	$ 14.00
Total Water Bill	$ 65.00	$ 44.97

Table 3. Average monthly household water bill for residents of Spreckles and Greenfield, CA.

Average Monthly Water Bill with Rainwater Harvesting		
City	Spreckles	Greenfield
Monthly Utility Charge	-	$ 12.97
Monthly Meter Charge (3/4-inch meter)	$ 28.94	$ 18.00
Residential Use – Non-Potable Use (gallons per capita per day)	45	50
Water Utility Rate (per TGAL)	$ 4.06	$ 1.42
Charge for Water Use	$ 13.32	$ 5.17
Total Water Bill	$ 42.26	$ 36.14
Total Monthly Savings	$ 22.74	$ 8.83

Table 4. Average monthly household water bill with rainwater harvesting offsets for residents of Speckles and Greenfield, CA.

The total monthly savings on a water bill from rainwater harvesting was then used to calculate the amount of time it would take to recoup the equipment and installation costs from the system (see Equation 3).

$$(3) \quad \frac{Total\ System\ Cost}{Total\ Monthly\ Savings} * \frac{1\ year}{12\ months} = Years\ to\ Recoup\ System\ Costs$$

$$(3a - Spreckles) \quad \frac{\$\ 9{,}482.00}{\$\ 22.74} * \frac{1\ year}{12\ months} = 35\ Years$$

$$(3b - Greenfield) \quad \frac{\$\ 9{,}482.00}{\$\ 8.83} * \frac{1\ year}{12\ months} = 90\ Years$$

Overall, average precipitation in Greenfield, CA was found to be lower than in Spreckles, CA. One outlier was found within the Greenfield, CA precipitation data (see Figure 2) and was eliminated to prevent data from being skewed. The general trend in both Greenfield and Spreckles is that annual precipitation has been decreasing over the 2000-2021 time period (see Figure 3).

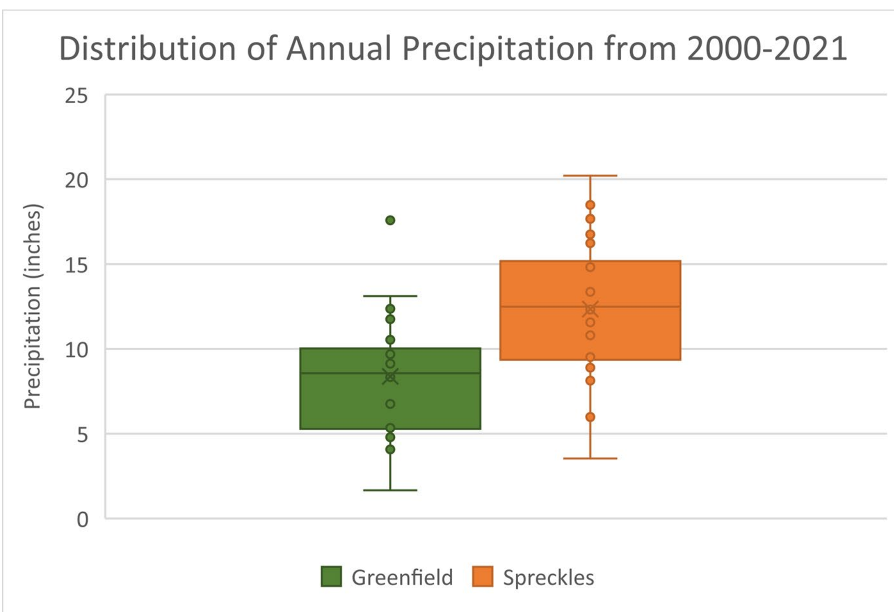

Figure 2. Spread in annual precipitation in Greenfield and Spreckles, CA.

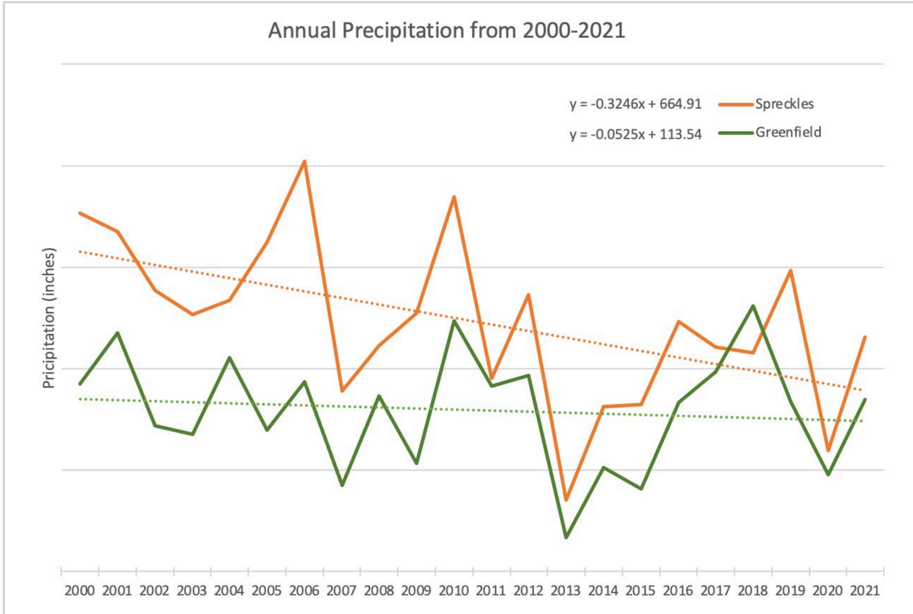

Figure 3. Trend in annual precipitation from 2000-2021 in Greenfield and Spreckles, CA.

Using historical data, precipitation in Spreckles and Greenfield was projected into the future for a medium (RCP 4.5) and high (RCP 8.5) emissions scenario using stochastic modeling methods (see Figure 4 and Figure 5).

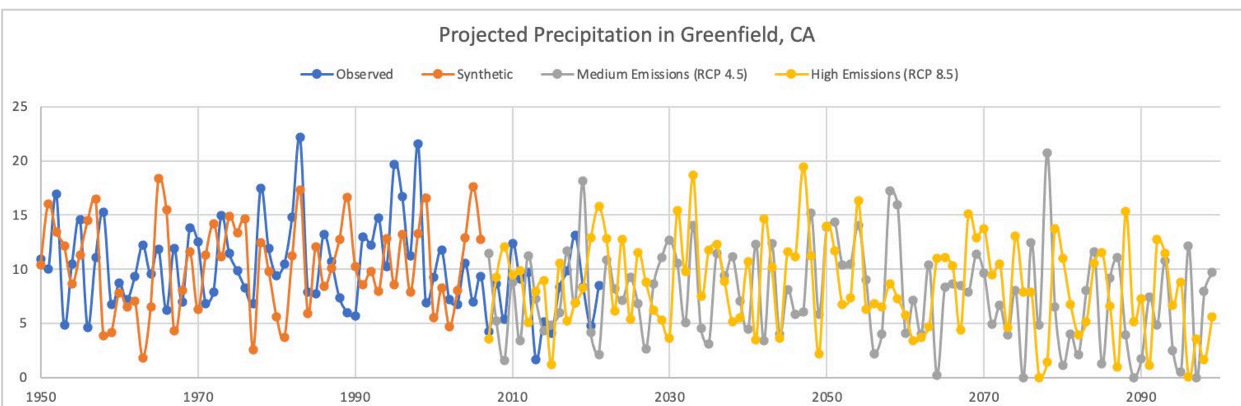

Figure 4. Projected precipitation in Greenfield, CA for a medium (RCP 4.5) and high (RCP 8.5) emissions scenario.

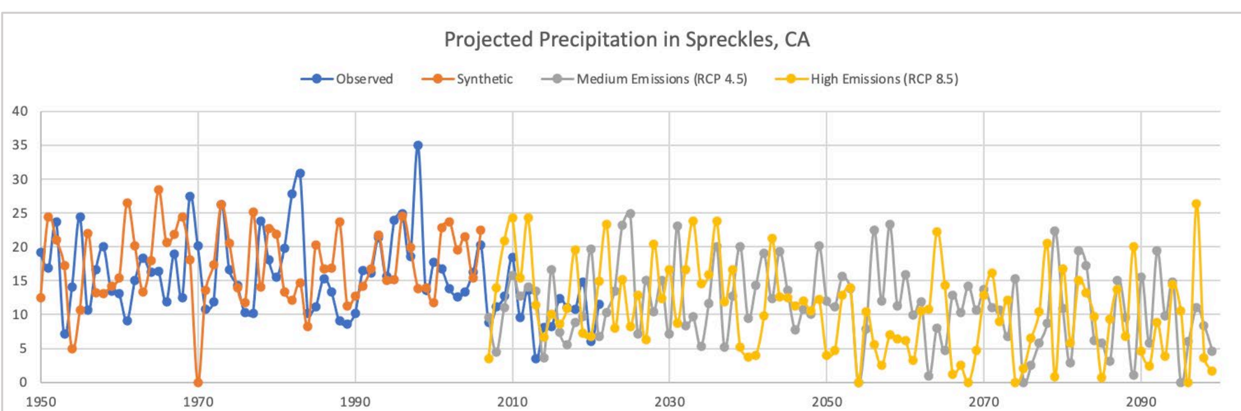

Figure 5. Projected precipitation in Spreckles, CA for a medium (RCP 4.5) and high (RCP 8.5) emissions scenario.

Projected data was then used to determine rainwater harvesting system reliability in both Greenfield and Spreckles through the year 2050. Rainwater system reliability was determined by counting the number of years where precipitation was high enough to fully fill the rainwater system (10,000 gallons). The stochastic model was run 15 times to plot a distribution of system reliability (see Figure 6).

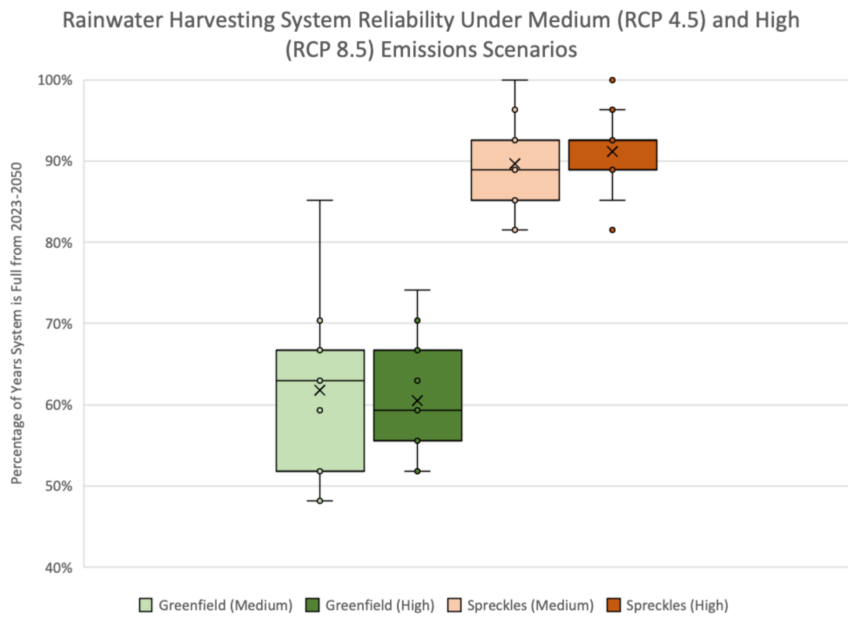

Figure 6. Distribution in rainwater harvesting system reliability in Greenfield and Spreckles, CA for a medium (RCP 4.5) and high (RCP 8.5) emissions scenario.

Discussion:

In comparing the cost of a 10,000-gallon rainwater system between communities in Spreckles and Greenfield, CA, it was determined that equipment and installation costs would represent 6% of annual median household income in Spreckles while costs would represent 19% of annual median household income in Greenfield. The proportion of income consumed by rainwater harvesting system costs is roughly 3 times higher in Greenfield, a DWR designated disadvantaged community. On average, residents of Spreckles would save $22.74 per month while residents of Greenfield would save $8.83 per month. These monthly savings translate into a 35-year recoup period for Spreckles residents wherein the accrued benefits have not exceeded the costs initially invested into the system while Greenfield residents would see a 90-year recoup period. These differences can be attributed to the fact that Spreckles residents pay higher prices for their water meaning the amount of savings produced when utilizing rainwater for non-potable purposes is much higher.

With regards to climate data, Greenfield, CA receives less annual precipitation on average than Spreckles, CA, but both localities have seen decreases in average precipitation over the past 20 years. This decrease in precipitation means less reliability in the rainwater harvesting system in the coming years. Through stochastic modeling, it was determined that a 10,000-gallon rainwater harvesting system in Greenfield, CA would be, on average, full 62% of the time in a medium emissions scenario and full 60% of the time in a high emissions scenario from the years 2023-2050. For Spreckles, CA, in a medium emissions scenario, the system would be full 90% of the time and 91% of the time for a high emissions scenario. These results indicate that residents in Spreckles would experience more reliability in their rainwater harvesting systems and higher water security than residents in Greenfield. This can be attributed to the fact that Spreckles receives higher rainfall on average than Greenfield even under variable climate and also that homes in Spreckles have larger roof areas. Both of these factors translate into a larger potential for a full rainwater harvest (10,000-gallons) each year.

Conclusion:

Overall, residents of disadvantaged, front-line communities face much steeper financial barriers when considering the equipment and installation costs of rainwater harvesting systems. Not only do these costs represent a much higher proportion of annual median household income, the pay-back period for these systems is much longer due to differences in water use and water rates across communities. For low-income homeowners, it may not be financially feasible or make financial sense to install a rainwater harvesting system when comparing the overall costs to benefits. Rather, these individuals may find lower costs and greater benefits in other water conservation measures such as installing low-flow shower heads and faucets or changing water use behaviors. Given that the overall weight of financial costs associated with rainwater harvesting systems is much lower in high-income communities, these communities are much more likely to install and utilize these systems which has the potential to further widen the gap in accessibility to water during extended drought periods between low- and high-income communities. These results are further compounded when considering changing precipitation patterns in the future. As precipitation becomes more variable, residents in front-line communities such as Greenfield may see less reliability in their rainwater harvesting systems as overall decreasing precipitation decreases the chance they will see a full rainwater harvest each year.

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