Evaluating Multiple Benefits of Urban Rainwater Catchment Systems in Austin, Texas

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Evaluating Multiple Benefits of Urban Rainwater Catchment Systems in Austin, Texas

A Group Project submitted in partial satisfaction of the requirements for the degree of
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by

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EVALUATING MULTIPLE BENEFITS ASSOCIATED WITH RAINWATER CATCHMENT SYSTEMS IN AUSTIN, TEXAS

As authors of this Group Project report, we archive this report on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

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The Bren School of Environmental Science & Management produces professionals with unrivaled training in environmental science and management who will devote their unique skills to the diagnosis, assessment, mitigation, prevention, and remedy of the environmental problems of today and the future. A guiding principal of the School is that the analysis of environmental problems requires quantitative training in more than one discipline and an awareness of the physical, biological, social, political, and economic consequences that arise from scientific or technological decisions. The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

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Dr. Naomi Tague, Faculty Advisor

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Date

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I. Abstract

Over the next century, climate change adaptation measures will require significant investment in building, improving, and changing urban water infrastructure. These measures will require multifaceted strategies that can simultaneously address many challenges, such as flooding, impaired water quality, and lowered efficiency. These strategies will also provide key co-benefits, such as energy savings and lowering greenhouse gas emissions. To meet the need for a standardized approach to quantifying these co-benefits, the Pacific Institute developed the Multi-Benefit Framework (MBF). As part of its efforts to improve urban hydrology in Austin, Texas, the city's Watershed Protection Department (WPD) installed rain cisterns and rain gardens on twenty-five homeowners' properties within its upper Waller Watershed in 2017. Austin WPD's Rain Catcher Pilot Program (RCPP) aimed to improve watershed health, reduce flooding, and augment local water supplies within the greater Austin area. This project used the Pacific Institute's MBF to quantify co-benefits that will occur when RCPP is scaled up to 1200 homes in 2022. Co-benefits include urban heat island temperature reductions, energy savings, and improved health and equity outcomes within the Waller-3 project area. We have (a) quantified energy savings from improved water conveyance and urban heat island temperature reductions, (b) identified and evaluated opportunities for incorporating equity into the RCPP, and (c) compiled useful resources for decision-makers who plan to employ the framework in evaluating future water projects.

II. Executive Summary

Background

This project utilized the Pacific Institute's Multi-Benefit Framework, a water decision-making framework developed by researchers at the Bren School and the Pacific Institute[1], the group project client. The Pacific Institute's multi-benefit framework provides a systematic approach for assessing benefits and tradeoffs within water infrastructure projects, watershed improvement programs, and water policies. Ultimately, this framework helps water managers maximize their investments in water by creating a system that facilitates comparisons of project costs and co-benefits that projects can provide to ecosystems, communities, and local economies.

Over the past year, researchers at the Pacific Institute have collaborated with the National Wildlife Federation and Texas Water Trade in applying the multi-benefit framework to an urban rainwater capture pilot program in the city of Austin, Texas. Initially, Austin's rainwater capture pilot program was developed to address erosion in local waterways, low creek flow, nuisance flooding within the Waller Creek Watershed, and to improve reliability of urban water supply. Two public agencies, Austin Water and Austin Department of Watershed Protection, are working to pilot the green stormwater infrastructure (GSI) project through the Rain Catcher Pilot Program (RCPP), within the upper Waller Creek Watershed, a residential neighborhood north of downtown Austin. The pilot project supports the installation of trees, rain gardens, and large-capacity rain cisterns in the project area. The RCPP was first offered to 25 residents in 2017, and will expand to 1,200 homes between 2019 and 2022.[1]

This group project has quantified two important co-benefits associated with the RCPP: energy savings from reduced outdoor potable water demand and urban heat island reductions within the upper Waller Creek Watershed. Additionally, we have identified opportunities for participating stakeholders to ensure equitable distribution of potential benefits within the RCPP implementation process. Lastly, our project has created a comprehensive "toolbox" of resources for decision-makers to apply to water projects in their own communities.

Project Objectives

We have accomplished the following objectives within the scope of this project:

[1] The Pacific Institute is an Oakland, California-based global water think tank that combines science-based thought leadership with active outreach to influence local, national, and international efforts in developing sustainable water policies.

1. Quantified potential energy savings from reduced potable water demand resulting from scaling up the rain-catcher pilot program (RCPP) within the Waller-3 neighborhood[2] in Austin, Texas;
2. Quantified possible urban heat island effect incidence resulting from implementation of the RCPP within the Waller-3 neighborhood;
3. Identified and evaluated potential opportunities for incorporating equity into the RCPP; and
4. Compiled useful resources for decision-makers who will use the framework for evaluating other water projects in the future.

<u>Methodology</u>

This project has quantified and modeled two co-benefits resulting from implementation of the RCPP, (i) energy savings associated with reduced outdoor potable water demand and (ii) reductions of urban heat island effect incidence within the project area. We have also (iii) conducted a primary literature review to determine opportunities to make the RCPP more effective, equitable and inclusive; and (iv) created a "toolbox" for use by water managers interested in implementing GSI projects within their own communities. We have briefly described our quantitative methods below.

1. **Energy**
   To quantify energy reduced through offsetting potable water demand in the project area, we have used the Pacific Institute's Water-Energy Simulator Model (WESim). The WESim model separates components of the water treatment and transfer process, and uses each part in calculating the overall energy intensity of water treatment through summing the flow through individual facilities. After finding an estimate of energy reductions, we used current electricity rates to calculate the estimated savings resulting from RCPP implementation, and to be conveyed to Austin Water. We will also incorporate estimated reductions in Urban Heat Island (*see Component 2 below*) from the RCPP to quantify potential reductions in energy use.

2. **Urban Heat Island (UHI) Effect**
   Within the UHI component of the project, we have quantified reductions in summertime temperatures in Waller-3 resulting from implementation of the RCPP. We then used these predicted temperature reductions to estimate reductions in residential energy consumption. To calculate temperature reductions resulting from

[2] We refer to the portion of the upper Waller Creek Watershed that is within the RCPP study area as the "Waller-3 neighborhood" throughout this report.

increased irrigation, we selected the Surface Urban Energy and Water Balance Scheme (SUEWS) Model, which used meteorology, tree cover, soil moisture and other data inputs to predict sensible heat reductions. To calculate temperature reductions from additional tree cover, we compared land-surface temperatures (LST) determined from satellite imagery to estimate the effect of tree cover on temperature reductions. To translate reduced temperatures to energy savings, we used existing literature, described in detail in the methods section, on the relationship between temperature and energy consumption in the southwest United States.

3. **Equity**
   We emphasize that equity should be viewed as a holistic lens through which one should view our project, rather than a discrete component. Therefore, we have identified opportunities to consider equity within each step of our project. Additionally, we have created tools to help water managers think through equitable implementation of water projects in their own communities. This "toolbox" includes (i) an interactive web application that quickly identifies areas that would benefit most from UHI and energy reductions resulting from RCPP based on UHI socioeconomic data, and (ii) a list of recommendations for more equitable rebate structures and financing that would assist low socioeconomic status residents in installing GSI on their own properties.

4. **Toolbox for Water Managers**
   Lastly, we have created a "toolbox" of recommendations and resources for water managers interested in implementing GSI projects in their own communities. Our recommendations include best management practices for maximizing benefits associated with Austin RCPP, which would be applicable to other GSI projects similar to the RCPP. We have also compiled a list of resources useful to water managers who are also interested in using our methodology to quantify multiple, secondary benefits associated with their own GSI projects.

<u>Results</u>

A) Energy offsets modeling

For every thousand gallons of potable water offset by RCPP implementation, we estimate that Austin Water will gain 2.15 - 2.82 kWh in energy savings. Carbon dioxide emissions will be reduced by 0.0015 - 0.0020 tons per thousand gallons of offset potable water.

B) Urban heat island effect incidence

Through our analysis of land-surface temperatures (LST) and vegetation in satellite imagery, we determined that fully-shaded parcels are expected to be approximately 4.2 degrees Fahrenheit cooler than parcels with no trees. After new shade trees provided by the RCPP achieve maturity, this could lead to 0.17-0.33 degrees Fahrenheit cooling. Additionally, we expect that increases in irrigation from rain cisterns and rain gardens provided by the RCPP will decrease in mean temperature by 0.35 degrees Fahrenheit. We have expressed these temperature decreases as a range, as high and low estimates are affected by RCPP implementation levels, number of trees planted, and future climate scenarios. At the individual homeowner leve, UHI decreases can be higher, depending on unique land characteristics of their property, and residents' choices for placing cisterns, rain gardens, and trees. The effects of additional trees on temperature reductions are expected to increase over time as the planted five-year-old saplings reach maturity.

<u>Conclusions & Recommendations</u>

Overall, RCPP potable water offsets have a small impact on energy reductions. The RCPP contributes most to UHI reductions within the Waller-3 neighborhood. We have determined that these large reductions are the result of (i) increased evaporative cooling from slow-release irrigation from cisterns and rain gardens, and (ii) increased shading from shade trees provided by the RCPP and planted adjacent to homeowner residences.

An increase in evaporative cooling and an increase in shading both have the potential to cool the Waller-3 neighborhood significantly over time. When the RCPP is implemented to the entire Waller-3 neighborhood, residential energy consumption from decreases in energy use resulting from RCPP implementation is significant. Reductions in energy use from potable water offsets are negligible.

We recommend that the RCPP prioritize voucher programs that distribute trees within the Waller-3 neighborhood to maximize the potential UHI reduction benefit of the project. Along with aforementioned benefits of a reduction in energy use and UHI, the project's other potential benefits of helping to improve stormwater flows in the Waller-3 neighborhood and preventing flooding events downstream are being analyzed further by the City of Austin and the Pacific Institute. In order to ensure that the co-benefits created by the RCPP are distributed equitably throughout the project area, we also recommend the creation of grant programs that subsidize installation of green stormwater infrastructure on homeowner properties. As the City of Austin determines which neighborhood to implement this project in next, we recommend that it conduct an analysis of potential UHI reduction and consider socioeconomic factors in its decision-making in order to maximize the potential benefits of the project.

II. Introduction

A. Background

1. Project significance

Climate change is expected to negatively affect water resources; both by decreasing supply and by the increased intensity of storm events and flooding.[2] Climate change and related water supply challenges will require significant investments in green infrastructure, which the World Economic Forum estimates to be about $5.7 trillion annually.[3,4] In order to maximize the return on these investments, interdisciplinary strategies that address multiple challenges will be required. Two of these challenges, urban heat island (UHI) effects and the energy embedded in water treatment and conveyance, will have significant impacts on urban populations in the future. In central Texas, average temperatures are expected to increase between 3-7 degrees Farenheit over the next century.[5] While UHI effect is not a direct result of water quantity or quality issues, it is a result of development, and can be potentially mitigated by solutions such as green infrastructure.[6,7] Therefore, it will become increasingly important for water managers to evaluate water projects that have the potential to decrease UHI incidence in order to improve human comfort while also providing traditional stormwater benefits. Additionally, about 4% of the electricity generation in the US is used for water-related purposes, primarily treatment and transport of water from source to tap.[8] Water projects that identify new sources of water- such as rainwater- will reduce reliance on energy intensive water. This is particularly relevant for states where energy is sourced primarily from fossil fuels, such as Texas, which consumes primarily natural gas, oil and coal.[9] Lastly, decision making frameworks must consider equity in the distribution of benefits. Access to urban green spaces is negatively correlated with both income and race[10] and it is important to ensure that there is equal access to these projects.

This group project has been completed in cooperation with the Pacific Institute, the group project client, in support of the City of Austin's Watershed Protection Department (WPD). This group project will use the Pacific Institute's Multiple Benefits Framework to evaluate the benefits associated with Austin WPD's rain catcher pilot program in Austin, Texas. This work is intended to inform WPD on whether the program has the potential to provide benefits beyond traditional stormwater management such as UHI and energy consumption, and to explore equitable distribution of these benefits. More broadly, the resources used during the project will be added to the multi-benefit framework database to be used for future water projects.

2. About the Multiple-Benefits Framework

In collaboration with Bob Wilkinson of the Bren School, the Pacific Institute has developed a multiple-benefits framework to help water managers quantify and evaluate all of the potential benefits of water management projects, and to incorporate these benefits into their decision-making. Additionally, the framework seeks to bring diverse stakeholders together to invest in progressive water management projects that solve more than one problem. Our analysis of the benefits of the City of Austin pilot program will provide real world context for the multiple-benefit framework, particularly for evaluating benefits related to UHI reductions and evaluating equity.

The framework divides potential benefits into five categories: Water, Energy, Land and Environment, People and Community, And Risk and Uncertainty (Figure 2).[11] The purpose of using these categories is to list and organize the potential benefits of water projects in a more systematic way.[11] The City of Austin has already evaluated and selected the pilot project area Waller-3 based on its potential benefits in the 'Water' category, which include much of the traditional reasons for selecting stormwater management projects (*see Overview of Waller-3 Rain Capture Pilot Project).* Our project focused on 'People and Community' which includes equity and UHI, and 'Energy', which includes the energy intensity of water.

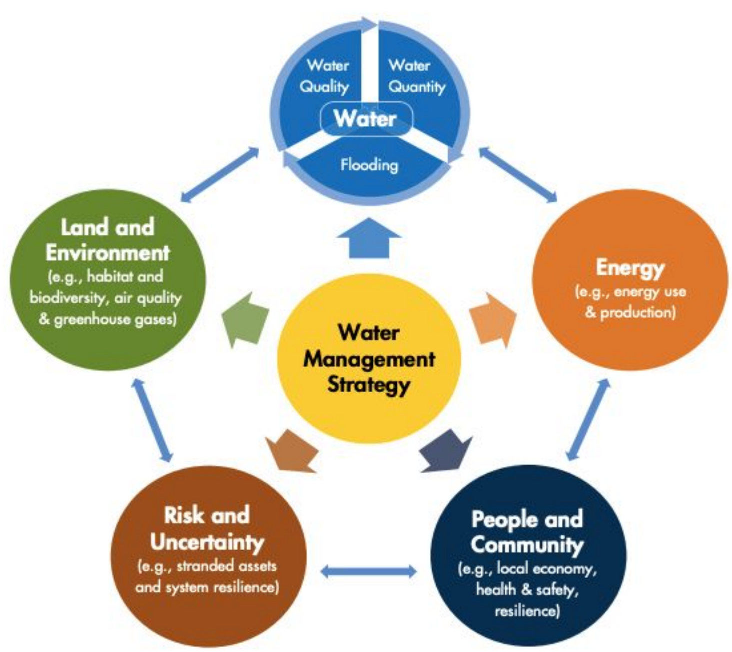

Figure 1. Categories of benefits under the Multi-Benefit Framework. *Source: Diringer et al, 2019.*

Additionally, the framework consists of four primary steps (Figure 2). In the Austin test case, Steps 1 and 2 were identified by the Pacific Institute and the City of Austin. Our project completed Step 3 for our identified benefits, UHI and energy. Although equity can be categorized under ‘People and Community’, our project approached equity not as another benefit to be quantified in Step 3, but a lens through which the entire project should be evaluated. Thus, the equity portion of our work focused on Step 4, informing decision-making.

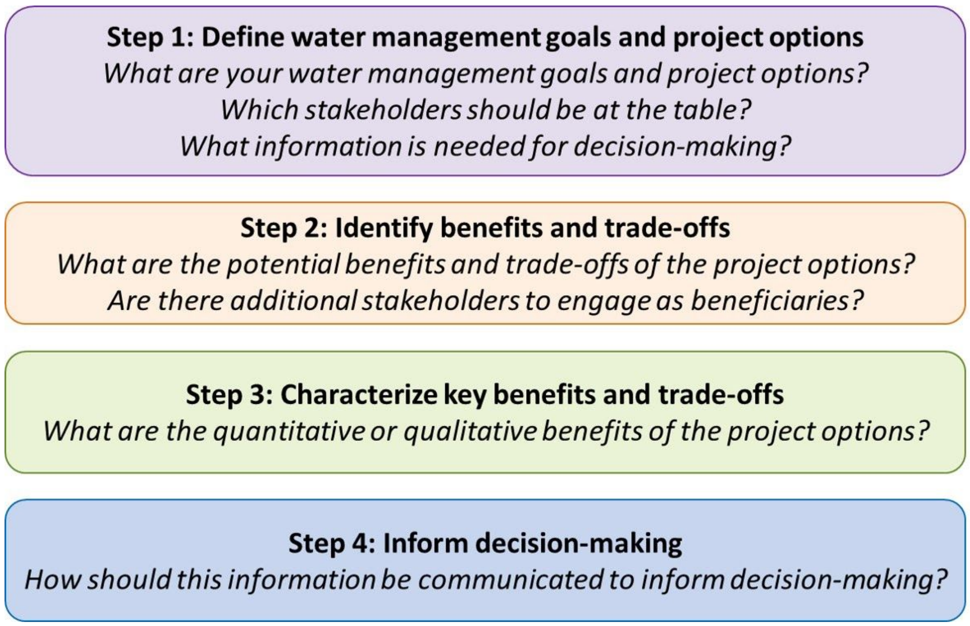

Figure 2. Flowchart of multiple benefits framework decision-making process. *The Pacific Institute has identified three key steps within the multi-benefit framework: (1) defining water management goals and project options, (2) identifying potential benefits and trade-offs within a project, (2) characterizing key benefits and trade-offs, and (3) communication information from steps 1-3 into a useful format for decision-makers. Source: Diringer et al, 2019.*

3. Literature Review of Existing Research

Urban Green Infrastructure

Investments in green infrastructure (GI) for water management can provide many benefits to a community. From reductions in the urban heat island effect, to flood control and community empowerment.[7] GI is defined as “the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters.”[12] Compared to human-engineered, “grey” stormwater management techniques (e.g. concrete channels, pipelines, and reservoirs), GI mimics the water capture and filtration abilities of a natural landscape. GI either captures rainwater on site through storage in a rain barrel or other structure, or allows water to percolate into pervious ground surfaces (such as in a rain garden). Examples of GI commonly found in urban and suburban landscapes include green roofs, rain gardens, rain cisterns, and bioswales. In both urban and suburban landscapes, GI benefits include increased absorption of rainwater into the ground and resulting recharge of local and regional groundwater systems, filtration of pollutants, runoff capture and storage for beneficial use, and beautification of cityscapes and neighborhoods.[13] The U.S. Environmental Protection Agency estimates that the natural ability of the soil in such green infrastructure fixtures can remove 70 to 98 percent of pollutants from stormwater runoff.[14] Over long periods of time, GI can also save energy costs and increase local stormwater capture and infiltration, which effectively irrigates landscaping while offsetting usage of potable water that has been pumped from surface water or groundwater and treated at a municipal water treatment facility.[13] In addition to improving water quality, green infrastructure has a number of other major benefits, such as creating more aesthetically pleasing neighborhoods, reducing heat pollution and providing insulation to reduce heating and cooling costs.[7]

Compiling all information detailing the many benefits of GI presents a significant challenge, and is out of the scope of this research project. However, necessary tools for evaluating the multiple benefits associated with GI projects have been identified in previous case studies. A study conducted by the Pacific Institute examined the potential for multiple benefit water management for private businesses in Santa Ana, California.[14] This case focused on benefits in water efficiency and stormwater retention. While the value of the benefits varied spatially, this case illustrated how water-positive green infrastructure could result in both private businesses and community benefits. In addition to the aforementioned benefits of stormwater retention and flood mitigation, residential GI for water management can have impacts on livability and affordability. However, the multi-benefit framework has not yet been applied at the residential level. Residents in urban areas have different priorities for adopting multi-benefit frameworks than businesses, such as improving quality of life for individuals and communities.

After a review of existing literature, the following benefits have been identified as priorities for this group project's analysis of multiple benefits associated with green infrastructure in Austin, Texas:

1. Urban Heat Island Effect
2. Energy Reductions from Potable Water Demand Reduction
3. Equity

Using the multi-benefit framework, our project has quantified several benefits resulting from a rainwater catchment project implemented by the city of Austin, Texas. We have compiled existing literature about the three aforementioned benefits below.

Urban heat island effects

Most of the world's population resides in cities, and urban populations continue to increase in both size and density.[15] In urban areas, many people live within heat "islands" characterized by localized, elevated temperatures, sparse vegetation, and widespread prevalence of hard, impermeable surfaces such as concrete and asphalt. People residing within urban heat islands often experience negative health outcomes, such as harmful heat-related illnesses (e.g. heatstroke), discomfort, and death. These impacts to human health are expected to worsen as the climate warms. [16] Excessive heat is the leading cause of weather-related deaths across the United States.[5] To improve health outcomes and quality of life within the world's cities, city planners and resource managers must work cooperatively to reduce the heat load in these urban microclimates through climate-responsive design. Creating parks, green spaces, and other types of green infrastructure is a proven method to reduce urban populations' vulnerability to heat stress. For example, Phoenix, Arizona reduced maximum air temperatures by 1.9 degrees Celsius by creating "cool islands" of parks and green spaces. Similarly, Toronto, Canada used green infrastructure to reduce average summertime air temperatures by 4.9 degrees Celsius in areas with parks and open space. [15]

UHI incidence in Austin is likely increasing as a result of climate change and increases in urbanization. Austin has rapidly developed over the last 30 years, and daily average urban temperatures have correspondingly increased by 5 degrees Farenheit.[19] Satellite imagery shows higher land surface temperatures in urban areas compared to cooler rural areas.[17,18]

Relationship between temperature and energy consumption

As temperatures increase due to climate change, energy consumption is also expected to increase as more electricity is needed for artificial cooling of residences. [19] In the United States, air conditioning comprises approximately 17 percent of residential electricity consumption, and Texas has a higher air conditioning adoption rate than the US average.[20] In 2009, over 90 percent of Texas homes had some form of air conditioning. Most homes had central air conditioning systems.[7]

Energy reductions in water conveyance and treatment

The water-energy nexus refers to the connection between water and energy, and the concept that these resources must be managed together, with consideration to their influence on each other.[13,21] Nearly 4 percent of the electricity generated in the United States is associated with the treatment and conveyance of water.[22] Therefore, potential energy reductions in water usage, both through reduced demand of potable water, and reduced stormwater treatment, are an important benefit to be considered when planning and implementing green infrastructure.[13,22] Existing literature suggests that water usage from cost savings can be significant when aggregated at a water utility level.[21] For instance, a case study on the Charlotte–Mecklenburg Utility Department in North Carolina examined the potential energy savings associated with reductions in demand resulting from adoption of integrated stormwater management practices (e.g. green infrastructure). The study estimated that the utility could save up to $410,000 annually through installing rainwater harvesting systems.[21] Similarly, a life cycle assessment study was conducted on a city block in New York to determine cost savings from reduced energy and greenhouse gas emissions (GHGs) associated with investment in green infrastructure materials. The study also investigated how green infrastructure impacted GHGs from energy expended on stormwater treatment.[22]

Equity and green infrastructure

The Santa Ana case identified two of the benefits of increased green infrastructure as community livability and increased property values.[2] Higher property values may be a benefit for businesses and residents that own property. However, increased property values may raise rents for leasing residents. Increased rents can lead to lower socio-economic and racial diversity as well as a decreased standard of living for lower income residents that stay in these areas. This can lead to distributional injustices and potentially create tension between stakeholders. Different types of green infrastructure appeal to different demographics and their lifestyle and needs. Designing green infrastructure that matches the needs of the community is important for maximizing its benefits. To prevent these equity issues, project goals should be sensitive to the community's needs and concerns. Incorporating this sensitivity into project design can lead to projects that work best for each individual community by implementing the "just green enough" strategy and eliminating this tension.[10] Focusing on the specific community's interest since the beginning of a project can lead to improvements in local environmental quality and health without causing displacement, increased cost of living, incompatible green infrastructure, and changing neighborhood character.

Collecting firsthand information on community interest before the beginning of a project ensures that the project is more likely to meet the wants and needs of the local community. In a green infrastructure project in Los Angeles, where alleyways were converted into permeable green space, focus group interviews were conducted before the start of the project.[11] These interviews showed the communities adjacent to the alleyways cared most about improving safety and providing outdoor opportunities for children. This allowed the project to design the program so communities could control access to the newly green spaces, improving safety and allowing for access for adjacent children. Ensuring infrastructure addresses the correct issues will prevent benefits from becoming burdens to the area.

Green infrastructure has the potential to reduce energy costs and allow residents to save more money on their energy bill or enable local governments to redistribute these savings to communities in need. Developing strategies to maximize energy savings to low-income communities, either through lower energy bills or re-investment in the community can create positive feedback loops of funding for additional green infrastructure or community projects. Green infrastructure can help reduce stormwater runoff that disproportionately low-income communities at a higher rate.[23]

Additionally, reducing stormwater runoff can prevent much of the flooding and pollution that comes with stormwater runoff. These co-benefits affect individual households as well as neighborhoods and entire communities.

4. Overview of Waller-3 Rain Catcher Pilot Project (RCPP)

The city of Austin has selected a neighborhood located in the upper portion of the Waller Creek Watershed to be the site of a rain catcher pilot program (RCPP). The program is a distributed stormwater control measure that involves installing rain gardens and rainwater cisterns on residential properties to provide a number of benefits for the Watershed (Figure 3).[1] The neighborhood, called Waller-3, is situated upstream of Austin's urban center, and was selected because of its large proportion of impervious cover (47%), and the potential for the catchments to reduce nuisance flooding downstream.[1] The benefits of the RCPP include reduced stormwater runoff, fewer erosive events, reduced flooding, and potential biodiversity improvements.

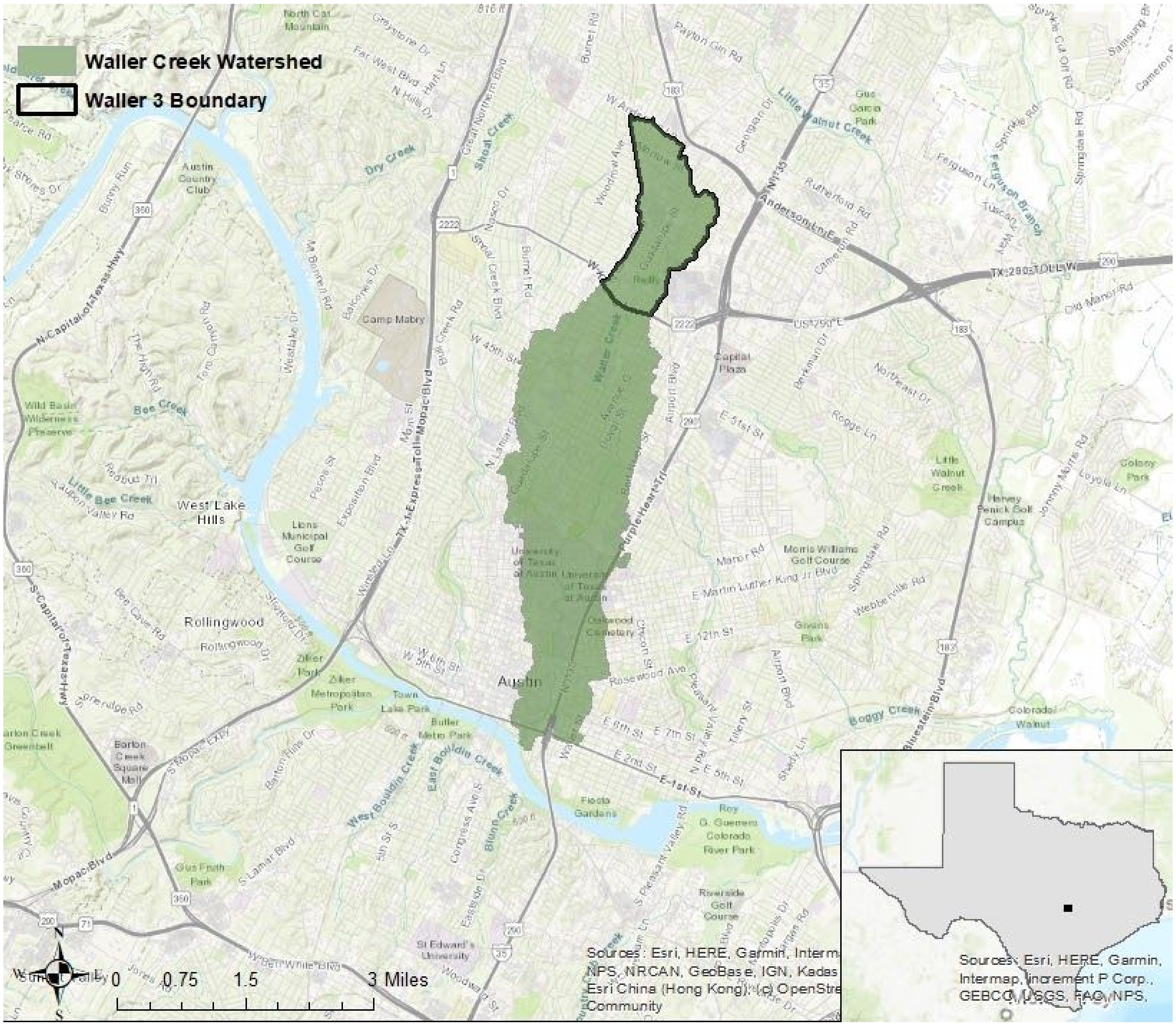

Figure 3. Map of Upper Waller Creek Watershed. *The Upper Waller Creek Watershed is to the north of downtown Austin and was chosen to minimize downriver impacts during flooding events. This map shows the extent of the planned rain catcher pilot program (RCPP). 75 percent of homes within this area are expected to participate in the program. Source: AustinTexas.gov.*

The goal of the RCPP is to achieve a 75 percent adoption rate of rain gardens and rain cisterns in the Waller-3 neighborhood over the next three years. In total, about 1200 homes will have either a rain cistern, a rain garden, or both.[22] Within the RCPP, rain cisterns are 1000 gallons (Figure 4), and rain gardens are 100 cubic feet (Figure 5). Through a partnership with a local nonprofit organization, homeowners will also have the option to plant five-gallon trees on their property via a tree voucher program. The rain cisterns are intended to decrease stormwater runoff within the Waller-3 neighborhood, while rain gardens increase infiltration of stormwater into the ground. Additionally, the RCPP is expected to reduce energy consumption through using collected water in rain cisterns, thereby reducing use of energy-intensive potable water for outdoor irrigation. UHI will decrease as a result of increased evaporative cooling from slowly-released water from cisterns, and increased evapotranspiration and shading from planted trees.

Figure 4. Large rain cistern. *Cisterns used in the Waller-3 Rain Catcher Pilot project are able to hold 1,000 gallons of captured rainwater. Source: gardening.stackexchange.com.*

Figure 5. Rain garden. *Rain gardens in the Waller-3 Rain Catcher Pilot Project are approximately 100 cubic feet. Source: U.S. Environmental Protection Agency.*

B. Objectives

This group project improved the methods used to quantify co-benefits of water projects evaluated with the Pacific Institute's Multiple Benefits Framework. Within this group project, we evaluated methods used to quantify co-benefits within a test case of distributed rainwater catchment systems in Austin, Texas. Specifically, this group project has:

1. Identified the incidence and potential reduction of urban heat island effect (UHI) within the Waller-3 project area using the Surface-Urban Energy and Water Balance Scheme (SUEWS) model and comparison of land-surface temperature (LST) differences in satellite imagery. The SUEWS model has calculated an estimate of temperature reductions resulting from increases in irrigation simulating 30 different scenarios of program implementation, additional tree adoption, and projected climate change temperature increases projected for the year 2050 in Austin, Texas. LST satellite image comparison will reveal the temperature reductions from additional tree shading.

2. Identified potential energy savings associated with reduced potable water demand of water treatment within the Waller-3 project area and the city of Austin using the Pacific Institute's WESim model. Identify potential energy savings from resulting reductions in UHI from RCPP implementation.

3. Conducted a review of successful cases of equitable distribution of funds to encourage green infrastructure (GI) in other cities and municipalities. Understanding the city of Austin's current rebate structure for GI, recommend additional strategies to make implementation of GI more affordable and equitable in the city of Austin and other cities that are interested in promoting GI benefits.

4. Provided recommendations for further refinement of the Pacific Institute's multiple benefits framework to improve effectiveness and applicability across varying water management projects and locations.

III. Methods

A. Energy offsets modeling

Water systems in Austin, Texas

Austin, Texas uses a single-source water system, and sources its entire municipal water supply from the Colorado River (Figure 6). All three of the city's active water treatment plants are located on the banks of the Colorado River and purchase energy from Austin Energy, the city's energy utility (Table 1). Austin's stormwater infrastructure does not contain a combined storm wastewater system. Cities with combined storm wastewater systems treat all stormwater with wastewater infrastructure, creating a high energy intensity. As Austin's stormwater does not flow into wastewater infrastructure, no energy will be saved through decreasing inputs to the stormwater system. Therefore, we have concluded that the energy intensity of wastewater infrastructure will not be changed after implementation of the RCPP.

Table 1. Energy intensity of Austin, Texas water treatment plants. *Source: City of Austin Open Data Portal.*

Water Treatment Facility	Flow (MG/day)	Energy Use (Gj/year)	Energy Intensity (Gj/MG)
Ullrich	63	151,263	6.56
Davis	53	127,843	6.59
Water Treatment Plant 4	26	66,855	7.12

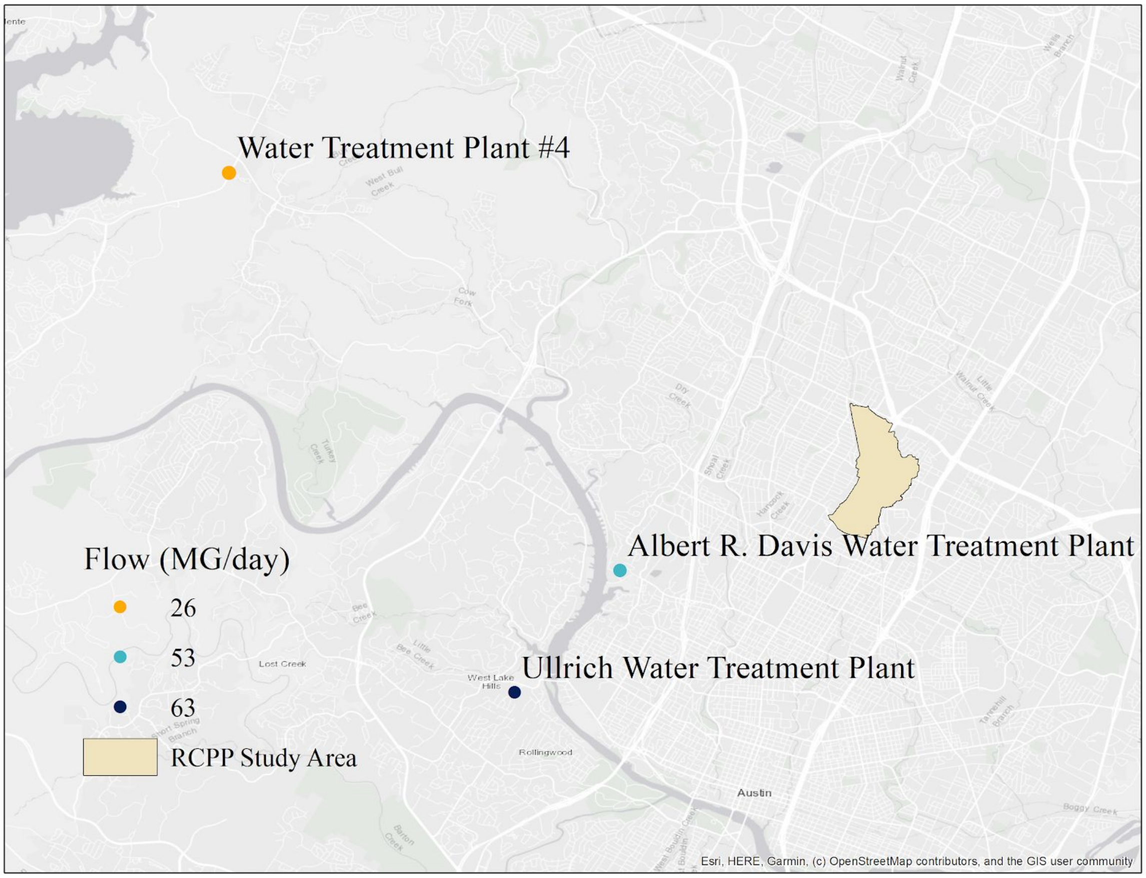

Figure 6. Three water treatment plants within the city of Austin. *Note that all three water treatment plants are located on or near the Colorado River, requiring minimal energy to convey water sourced from the Colorado River over short distances.*

Calculating potable water energy offsets using the WeSim model

The Water-Energy Simulator (WESim) model allows users to determine the energy required for municipal water systems and their greenhouse gas footprints. First, WESim breaks the water system into eight sequential steps, from source extraction to discharge as wastewater. Volumes going through each of these phases are accounted for by summing the flow through individual facilities. The energy intensity of each of these phases is estimated or directly calculated through energy bills.

Installing cisterns may offset potable water demand, but it will not affect wastewater treatment or consumer end use energy because landscape irrigation is not directed through wastewater flows and does not require heating. In addition, the Colorado River does not require substantial energy for extraction and conveyance because treatment plants are adjacent to the river. As a result, only the energy used in treatment and distribution needs to be considered for the cistern project. Water treatment costs come from the energy required to treat water to drinking water standards and distributional energy is the energy required to bring this treated water to consumers. The volume of water treated and energy intensity was determined through data provided by the city of Austin via the Austin Data Portal (See Table 1). Raw data was the average daily reported flows by month from the three wastewater treatment plants and the total annual energy consumption over each year between 2011-2019. Daily flow in Table 2 is an average of all recorded months between 2011-2019, and energy use is the annual average over 2011-2019 in Table 2.

Table 2. *Energy intensity of water conveyance from water treatment plants in Austin, Texas.*

Facility Name	Flow (MG/day)	Energy Use (Gj/year)	Energy Intensity (Gj/MG)
Ullrich	63	151,263	6.56
Davis	53	127,843	6.59
Water Treatment Plant 4	26	66,855	7.12

No Austin distributional energy data were available. Therefore, we used a range of distributional energy values based on WESim model defaults. The Pacific Institute studied 41 different US water utilities to create a low, median and high estimate of distributional energy intensity (Table 3).

Table 3. *WESim distributional energy intensity estimates from 41 water utilities from across the US.*[24]

Utilities (n=41)	**Energy Intensity (kWh/MG)**
Low Estimate	360
Mid Estimate	540
High Estimate	860

The median estimate is the median, the low estimate is the lowest calculated distributional energy, and the high estimate being the highest calculated distributional energy for the 41 studied utilities. This gives a reasonable range of the distributional energy involved in transporting water from Austin water treatment plants to the RCPP study area. Therefore, the potable water offset by RCPP can be calculated by adding the energy intensity of water treatment and distribution.

Energy cost-saving distribution for equity benefits

As discussed in the WESim Potable Water Offset section, we expect a relatively low amount of energy-related cost savings to Austin Water as a result of the installation of rain cisterns and gardens in the pilot project in Waller-3. These savings could be more significant if the pilot project was expanded to suitable areas city-wide. Currently, Austin Water offers a range of rebates to residents that upgrade their water infrastructure.[25] However, the City of Austin and other cities that seek to implement similar green infrastructure projects should be aware of potential inequities with a rebate-only strategy to encourage further green infrastructure implementation among residents. Rebates usually require residents to own their property, have suitable lawn space to implement green infrastructure, and access to information on the rebate program. Municipalities should account for this and develop feasible and equitable incentives to encourage green infrastructure.

Model risks: dealing with uncertainty

While the WESim model is a useful tool for estimating the energy intensity of water, it does not inherently consider risk and uncertainty. The inputs of the model are direct energy use records from the utilities and the low, middle or high model defaults. The model is best used to describe the energy intensity of the time period the data came from. However, year to year there will be variation in water system flow and energy consumption. WESim assumes the given data is a reasonable representation of the average annual energy consumption of treatment plants in Austin. This may not be the case. Additionally, as we have no data on the distributional energy component, we will need to use model defaults. These defaults are based on 41 utilities across the United States, which includes utilities from a similar region as Austin. However, it's possible the Austin system may be outside this range. To address this uncertainty, we will present our WESim findings as a range. This range will include both the standard deviation of the average energy intensity and the maximum range of distributional energy estimates.

B. Urban heat island effect

We estimated the impact that the rain capture pilot program will have on UHI incidence within the Waller-3 pilot project area. Our methodology for quantifying urban heat island incidence has:

1. Established the magnitude of UHI in the Waller-3 project area
2. Evaluated the potential cooling ability of the pilot project. The Austin pilot project is expected to provide cooling benefits through (1) increasing shading from trees that

are installed as part of each rain garden and (2) increasing evapotranspiration as water is slowly released from cisterns.

3. Determined the relative importance of tree shading and increased irrigation for reducing UHI

1. Establishing current UHI levels

Average land surface temperature data calculated by Texas State for the city of Austin between April 2014-September 2014 was used in determining the extent of UHI in the Waller-3 area.[26] Land surface temperature (LST) was calculated by interpreting Landsat 8 OLI/TIRS scenes with 30-meter resolution taken from USGS Earth Explorer.[27] The thermal band 10 of the Landsat scan was converted to LST using Landsat metadata and equations 1-6, as described by Ugar and Gordana (2016).[28] To ensure that spatial autocorrelation does not bias our results, Moran's I has been calculated using the R package spdep for the tree cover fraction and land surface temperature.

Table 4. Metadata retrieved from Landsat 8 thermal scans of Austin, TX between April 2014-September 2014.

Metadata Constant	Value
Radiance Mult Band 10 (A_L)	0.0003342
Radiance Add Band 10 (M_A)	0.1000
K1 Constant Band 10 (K_1)	774.8853
K2 Constant Band 10 (K_2)	1321.0789

Equation 1: Atmosphere radiance (L)

$$L_\lambda = M_L Q_{cal} + A_L$$

L = top of atmosphere spectral radiance $\left(\frac{Watts}{m^2 * srad * \mu m}\right)$

M_L = band specific multiplicative rescaling factor from metadata

A_L = band-specific additive rescaling factor from metadata

Q_{cal} = quantized and calibrated standard product pixel values (the values of the raster of band 10)

Equation 2: Brightness temperature (BT)

$$BT = \frac{K_2}{\left(ln\left(\frac{K_1}{L}\right) + 1\right)} - 273.15$$

K_1 = band-specific thermal conversion constant
K_2 = band-specific thermal conversion constant

Equation 3: Normalized Difference Vegetation Index (NDVI)

$$NDVI = \frac{Float(Band\ 5\ value - Band\ 4\ value)}{Float(Band\ 5\ value + Band\ 4\ value)}$$

Equation 4: Proportion vegetated (Pv)

$$Pv = \left(\frac{NDVI - minimum\ NDVI}{maximum\ NDVI - minimum\ NDVI}\right)^2$$

Equation 5: Emissivity (ε)

$$\varepsilon = 0.004 * Pv + 0.986$$

Equation 6: Land surface temperature (LST)

$$LST = \left(\frac{BT}{\left(1 + \left(\frac{0.00115(BT)}{1.4388}\right)\right) * ln(\varepsilon)}\right)$$

<u>2. SUEWS model</u>

Model selection: motivations for selecting the SUEWS model

In order to estimate the impact on UHI that the RCPP will have on the Waller 3 neighborhood, a model was selected to predict air temperature before and after implementation of the pilot project. In determining which model to use, six different surface energy models were examined and evaluated against several criteria: spatial scale, usability, inputs, and case studies in literature. All UHI modeling options considered during the project used environmental parameters (e.g. albedo and percentage impervious surface cover associated with roads, sidewalks, and other concrete surfaces, vegetation cover, tree canopy, surface water cover), sources of water in the environment (e.g. irrigation, soil moisture), anthropogenic heat, and meteorological data (e.g. temperature, incoming solar radiation, air pressure, etc.). We also compared the usability of these models relative to each other, and rated them from 1 (most difficult to use) and 6 (least difficult to use).

Table 5. Model options for estimating urban heat island effects. *Note that the Surface Urban Energy and Water Balance Scheme (SUEWS) was ultimately selected for its relative simplicity, and ability to simulate changes in irrigation and tree cover. Note that ENVI-met requires the purchase of software (indicated by asterisk in "Usability" column.)*

Model	Impervious Surface Cover	Albedo	Vegetation Cover	Tree Canopy	Surface Water Cover	Irrigation	Soil Moisture	Anthropogenic Heat	Scale	Usability	Examples
FRAISE	X	X	X	X				X	City	6	Loridan and Grimmond 2012
UWG	X	X	X						Neighborhood	5	Nakano et al. 2015
LUMPS	X	X	X	X	X			X	Neighborhood or Smaller	4	Loridan et al. 2010
ENVI-met	X	X	X	X	X		X	X	Block or Smaller	3*	Nakano et al. 2015; Karimipour 2017
SUEWS	X	X	X	X	X	X	X	X	Neighborhood or Smaller	2	Ao et al. 2018; Ward et al. 2016; Järvi, Grimmond, and Christen 2011
WRF/LSM/ UCM	X	X	X	X	X	X	X	X	Neighborhood	1	Chen, Kusaka, and Tewari 2011; Vahmani and Hogue 2015; Vahmani and Jones 2017

Ultimately, the Surface Urban Energy and Water Balance Scheme (SUEWS) model was selected (Table 5). Unlike other urban energy balance models, SUEWS does not primarily rely on changes in surface cover types (for example, conversion of large impervious surfaces to green spaces) as an input in the model. SUEWS calculates surface energy fluxes using meteorological forcing data (incoming shortwave radiation $K\downarrow$, air temperature $Tair$, atmospheric pressure p, relative humidity RH, wind speed U and precipitation P), vegetation cover, and water use (irrigation)[29]. Additionally, SUEWS allows its user to manipulate changes in (1) irrigation, and (2) tree cover, which are the primary ways in which the pilot project will affect the energy balance. Lastly, SUEWS was advantageous because it is relatively simple to use, and does not require advanced computational skills.

In addition to meteorological data, the SUEWS model allows the user to specify up to seven land cover types: paved surfaces buildings, evergreen trees, deciduous trees, grass, bare soil, and open water.[29] Fractions of each cover type are required, and characteristics of each, such as albedo, emissivity, moisture storage capacity, building height, tree height, must be specified.[29] For some of these values, like building height, the model does contain defaults based on studies of different urban environments that can replace missing data.

The SUEWS model uses these inputs in two equations (Figure 7):

First, an energy balance equation:

Equation 7: Energy balance

$$Q^* + Q_F = Q_H + Q_E + \Delta Q_s$$

Second, a water balance equation:

Equation 8: Water balance

$$P + I_e = E + R + \Delta S$$

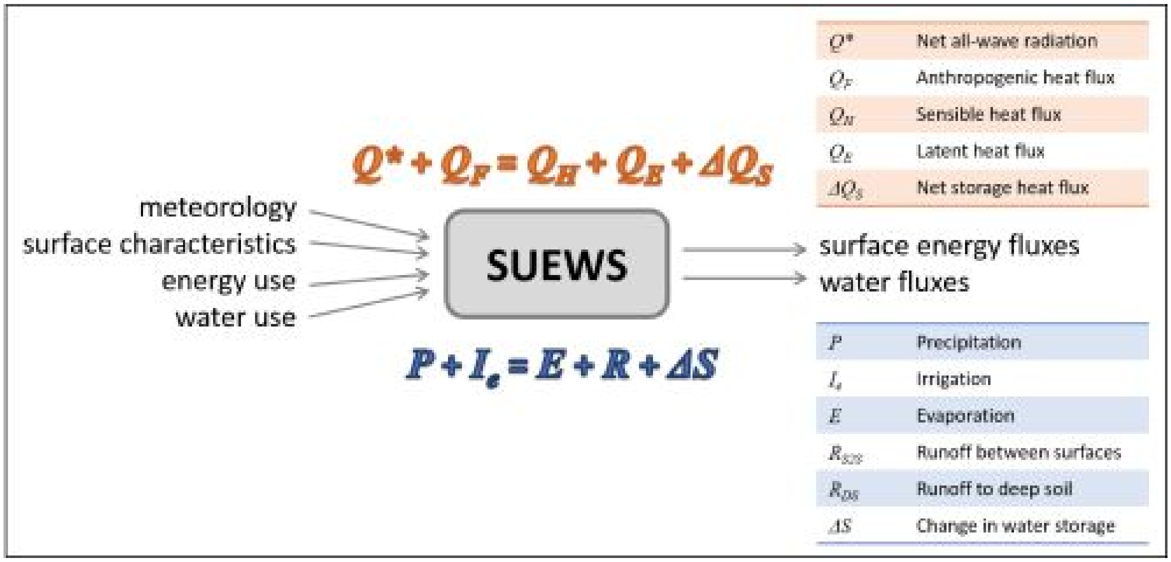

Figure 7. Surface Urban Energy and Water Balance Scheme (SUEWS) model schematic. *Model inputs include meteorological data, surface characteristics, energy usage, and water usage. Model outputs include (a) surface energy fluxes (on right, in orange), which were calculated using Equation 7 (center top equation in orange), and (b) water fluxes (on right, in blue), which were calculated using Equation 8 (center bottom equation in blue). Source: SUEWS model documentation.*[30]

Model scenarios

First, we will model three "control" scenarios that simulate the status quo, with 0% levels of green infrastructure implementation and using 2017, 2019 and 2050 meteorological data. We will use each of these control scenarios as a baseline for comparison with other scenarios from each meteorological year (2017, 2019, 2050). We will use the SUEWS model to predict the outcome of the pilot project with respect to UHI under several scenarios.

To calculate UHI reductions under other scenarios, the following inputs were used at different levels within our model:

- Levels of green infrastructure implementation and corresponding changes in irrigation
- Number of shade trees on property
- Projected climate scenarios

A detailed description for each of these model inputs have been provided within this section; please also see Table 7 below for a summary of all model inputs.

Levels of green infrastructure (GI) implementation

The City of Austin aims to achieve 75 percent participation in their GI pilot program within the Waller-3 neighborhood. Therefore, we have chosen to model different levels of GI implementation adoption rates within our scenarios. First, we model the project's goal adoption rate (75 percent participation among households), then we will model scenarios where the goal adoption rate has not been met (50 percent participation among households). Finally, we model scenarios where only 25% GI implementation occurs.

Number of trees on property

Homeowners participating in the green infrastructure project will have access to rebate vouchers that enable each household to plant either a single tree in their rain gardens, so we have chosen to simulate different scenarios based on levels of household participation in this tree voucher program. First, we assume that no homeowners participating in the Waller-3 pilot project have used tree vouchers and have not planted trees in their rain gardens. Next, we assume that half of homeowners participating in the project have used the tree vouchers to plant a single tree in their rain gardens, and lastly, we simulate that all homeowners participating have used a tree voucher to plant a single tree in their rain gardens.

Land cover fractions

The fractions of land in Waller 3 that were bare soil, grass, buildings, deciduous trees, evergreen trees, paved, and covered by water were calculated. Bare soil, buildings, grass and water areas were calculated using 2014 land cover data from the City of Austin.[31] Fraction covered by trees was calculated using 2014 tree canopy cover data from the City of Austin Data Portal calculated with Landsat 8 scans. Model scenarios will not change the fraction of land in soil, buildings, or paved. Increases in tree numbers on property are accounted for by subtracting new tree area from grass area. The area of a single tree was calculated by taking the mean crown size of the trees RCPP provides at 5 years old.[31] The larger tree scenario was the average of all trees tagged as "large" from Austin Tree Folks and smaller tree scenario was the average of all trees tagged as "small" from Austin Tree Folks. Additionally, for the 2050 scenario trees are considered to be fully mature. The change tree canopy for 2050 scenarios was calculated by using the average mature canopy size of all of possible Austin Tree Folks.

Projected climate scenarios

Next, we simulate the effects of installing rain gardens within a future, warmed climate scenario using daily average temperature data from the Multivariate Adapted Constructive Analogs (MACA) method, downscaled to central Texas temperature projections for the year 2050 (in degrees Celsius).

Historical meteorological data

We use meteorological data collected during the warmest months of the year during the years 2017 and 2019. We have chosen to run model scenarios using two years' meteorological data in order to conduct a sensitivity analysis to get an estimate of the year to year variation in meteorological forcing (Table 6). There are limitations to this approach, especially as climate continues to alter the "normal" climate in Austin.

Table 6. *Average annual precipitation and temperature data near RCPP. Data taken from NOAA at the Camp Mabry station. The average is calculated using 30 year periods, this average is from 1981-2010.*

YEAR	PRECIP (IN)	MIN TMP (°F)	AVG TMP (°F)	MAX TMP (°F)
2017	34.73	61.3	72.1	82.9
2019	31.87	59.9	70.6	81.4
Average	34.32	59	69.4	79.8

Additionally, we have chosen to model the warmest months of the year in order to (a) model peak UHI incidence and (b) capture changes in energy usage during peak cooling periods.

Table 7. *SUEWS model scenarios based on levels of green infrastructure implementation, number of trees placed on property, and projected future climate scenarios. Additionally, sensitivity analyses were conducted via conducting additional runs from sourcing meteorological data from a second year.*

Variable	**Factors**	**Notes**
% green infrastructure implementation	0 % implementation, 25%, 50 % implementation, 100% implementation	The percentage of people participating in green infrastructure influences the amount of total irrigation that will occur in the project area
Number of trees placed on property	0 trees, half gardens have trees, each garden has 1 tree	

Year meteorological data was collected	2017, 2019, 2050	2017 and 2019 meteorological data were used to create upper and lower bounds of "typical" climate conditions 2050 used to simulate future meteorological conditions in a warmed climate (using RCP 4.5 climate projections)

3. Tree shading and UHI analysis

Implementing RCPP could also have parcel scale impacts on UHI. Specifically, increasing tree canopy cover on a parcel would increase shading, which is not reflected in the SUEWS model calculations. To create an empirical model for this shade driven localized cooling, spatial data of tree canopy cover and land surface temperature will be used. Tree canopy cover data was taken from the 2014 tree canopy dataset from the City of Austin, Watershed Protection using four Landsat 8 image scans from summer 2014 at 5:00 pm. The tree canopy was reclassified to the 30 by 30 m level to allow for direct comparison with mean land surface temperature calculated to establish summer UHI in Waller-3. A linear regression model from these sampled two values from each of these 30-by-30 meter raster pixels was performed in R to show the relationship between tree shading and localized UHI.

4. Energy reductions From UHI modeling

Cooling degree days

In order to estimate the impact of reduced summertime high temperatures on residential energy consumption, we have calculated the change in energy consumption based on cooling degree days. Cooling degree days (CDD) are used as a measure of the energy needed to cool a home or business from a baseline outdoor temperature.[32] The baseline temperature is, theoretically, the temperature at which the building in question needs to be cooled.[32] Thermostat set points, the temperature at which people turn on their air conditioning, are primarily dependent on two things: the local climate, and the insulation and cooling characteristics of the building itself.[32] For the purposes of this project, we will use a cooling baseline of 75.3 degrees Fahrenheit, as found in National Renewable Energy Laboratory (NREL)'s report on residential indoor temperature. The study evaluated web connected thermostat data from single family homes in seven climate regions, including Texas, which is categorized as the ‘hot and humid’ climate region in the United States.[33] The mean annual cooling temperature for hot-humid region was 75.3 degrees Fahrenheit.[33] This number is corroborated by a report by the Florida Solar Energy Center (University of Central Florida), which estimates that cooling thermostat set points averaged 75 degrees Fahrenheit for the United States.[34]

Annual energy consumption

Using meteorological data from Austin, we will compare actual and estimated daily high temperatures, and convert these temperatures into cooling degree days using our baseline.[19] Deschênes et al. 2011 estimates that an additional 100 cooling degree days is associated with a statistically significant ($\alpha = 0.05$) increase in residential energy consumption for the west coast central region of the US (which includes Texas).[19] Deschênes and Greenstone (2011) estimate that annual energy consumption increases by 1.3 percent after every 100 cooling degree days.[19] Using residential energy use data from the City of Austin, as well as our distribution of summertime temperatures under both the status quo scenario and the pilot project, we estimated the impact on energy consumption resulting from fewer cooling degree days.

Identifying communities in need of green infrastructure

Equity should be a priority when determining where to develop future green infrastructure projects. This is due to the benefits outlined in this project as well as the improvement in human health and livability that a reduction in UHI can provide. Project benefits should be equitably distributed in order to be categorized as successful. In order to identify neighborhoods that are best-suited for future green infrastructure projects in Austin, we accounted for current urban heat island effect as well as other factors in census tracts in the Austin area. We developed a Shiny application with equity parameters, such as median income, social demographics, and statistics on air quality, water quality, and human health that can be considered when identifying where GI is in most need in the Austin area.

The environmental factors of UHI, human health, air quality, and water quality were chosen for the shiny application because they relate to human wellbeing. Green infrastructure projects have a variety of benefits outside of these factors that could be considered when choosing where to implement similar projects. However, these parameters were chosen for this tool due to their direct relationship with human wellbeing and equity considerations. The tool allows for decision makers in Austin to overlay these parameters to determine where green infrastructure is potentially most needed and beneficial. Census tract data was aggregated into “neighborhoods” in the Austin area.

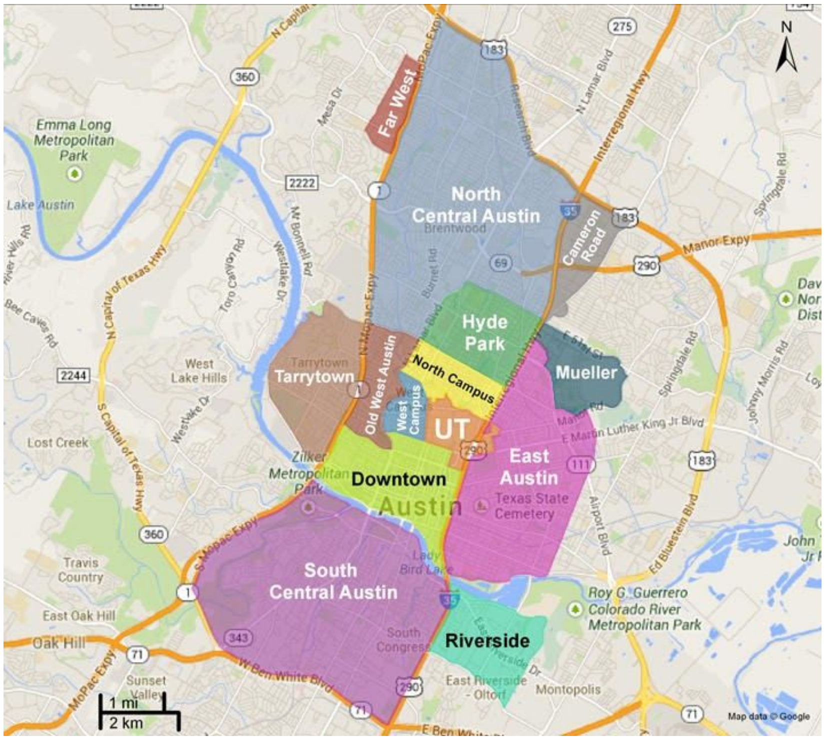

***Figure 8. Neighborhood map of Austin used for Shiny application**. Data for incident UHI, air quality, water quality, human health, median income, and social demographics were compiled from census tracts and aggregated into neighborhoods. Census tracts outside of neighborhoods outlined on the map were labeled as 'suburbs.' Source: austinresidence.com.*

The tool is a guide for decision makers to use when determining where the RCCP or similar project can be scaled in the city. Each neighborhood has unique characteristics outside of the parameters of the tool that make it attractive or difficult to implement a green infrastructure project. Green infrastructure projects that differ from the RCPP may be needed depending on neighborhood characteristics.

IV. Results

A. Modeling energy offsets

WESim estimates for every thousand gallons of potable water offset by the RCPP, Austin Water will reduce energy use by 2.15-2.82 KWh (Table 8). In addition, Austin Energy will reduce greenhouse gas emissions by 0.0015-0.0020 tons of CO_2-eq (Table 8). These ratios allow for a calculation of the energy and greenhouse gas savings with an estimate of the potable water offsets from different adoption scenarios. Widespread adoption could scale up these energy savings due to the high energy intensity of water treatment.

Table 8. Energy intensity of treatment and distribution for water treatment facilities in Austin, Texas. *Source energy intensity, site energy intensity, and source emissions calculated using the WESim model. Note that defaults were used to calculate source energy intensity and site energy intensity.*

Facility Name	Flow (MG/day)	Source Energy Intensity (KWh/KG)	Site Energy Intensity (KWh/KG)	Source Emissions (tons CO_2-eq/KG)
Water Treatment				
Ullrich	63	6.1	1.8	0.0013
Davis	53	6.1	1.8	0.0013
Water Treatment Plant 4	25	6.6	2.0	0.0014
Average	47	6.3	1.9	0.0013
Distribution				
Potable	142	1.8	0.36-0.86	0.0003-0.0006
Total			2.15-2.82	0.0015-0.002

B. Establishing UHI incidence

We found that land surface temperatures in Travis County were spatially heterogeneous on hot days. Figure 8 shows mean land surface temperatures at 5 p.m. on a summer day. Temperatures range from 66 degrees Fahrenheit to 103 degrees Fahrenheit. Areas in downtown Austin and the Waller-3 neighborhood (indicated in black rectangle in Figure 9) are warmer relative to other areas in Travis County.

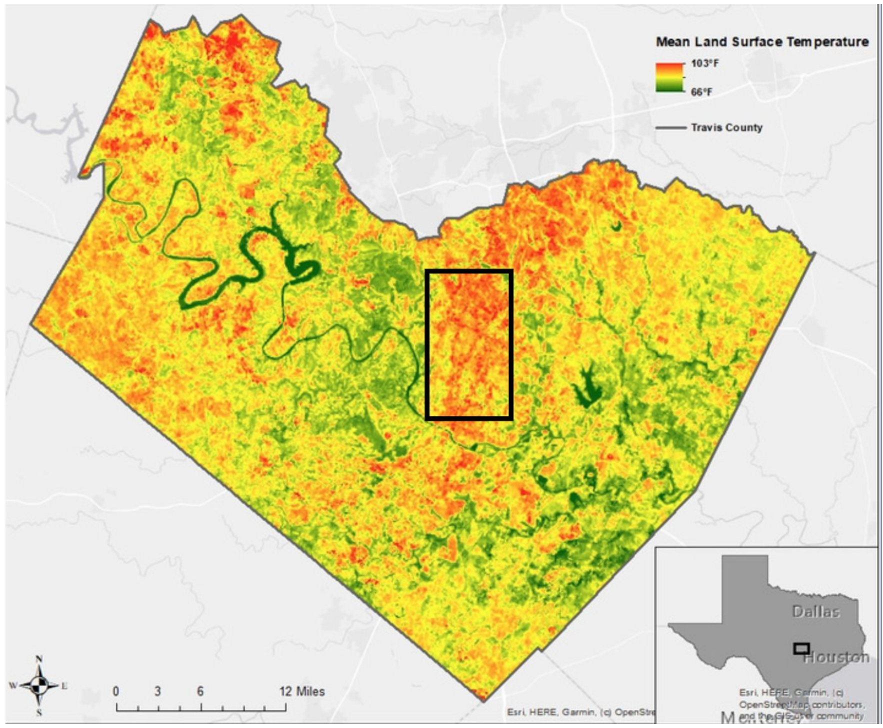

Figure 9. Mean land surface temperature in Travis County, Texas in 2014. *Mean land surface temperatures collected from seven Landsat 8 thermal scans of Austin, Texas, between April 2014 and September 2014. Locations with high temperatures are located in Austin's urban core (indicated in red), and locations with cooler temperatures are mostly open/green space and rural areas (indicated in green). The black rectangle indicates downtown Austin. Source: Department of Geography, Texas State University.*

C. Modeling UHI reductions

The results of our SUEWS model scenarios reveal that across our scenarios, irrigation has a larger effect on temperature than tree cover (Figure 10). shows the cooling potential of each scenario. Temperatures are constant across different levels of tree cover (low represents 27.8% of land cover, high represents 28% of land cover). This is likely because a 0.2% change in land cover is not enough to have an impact on temperature at the neighborhood scale. However, in our 2050 model scenarios, where trees have matured, tree cover does have an impact of about 0.02°F. However, the majority of the difference in temperature across scenarios in 2050 can be attributed to increases in irrigation.

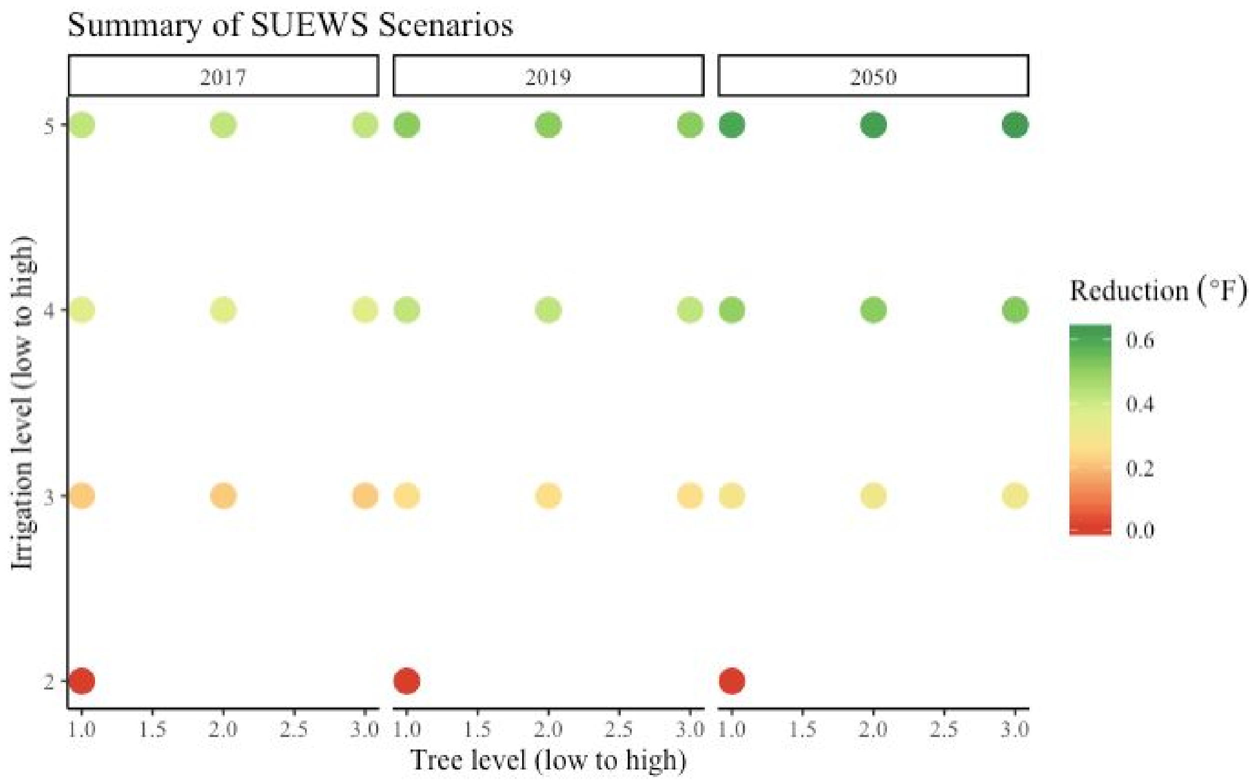

Figure 10. Summary of SUEWS model scenarios. *Colors indicate the mean temperature decrease from status quo (in red). The maximum temperature decrease was 0.63°F in 2050 (dark green). Average change in high temperature is the mean decrease in peak temperature for the entire summer. Irrigation level 2 and tree level 1 correspond to the status quo.*

We found that the RCPP has the potential to reduce the average temperature Waller-3 by approximately 0.51°F (Figure 10). This represents the highest implementation scenario for 2019. However, 2019 was an unusually hot year in Austin, and our 2017 results predict a smaller difference from the status quo temperature.[35] Overall, predicted temperature reductions range from 0.22 to 0.51°F between 2017 and 2019. By 2050, the RCPP has the potential to cool average temperatures in Waller-3 by up to 0.63°F (Figure 10).

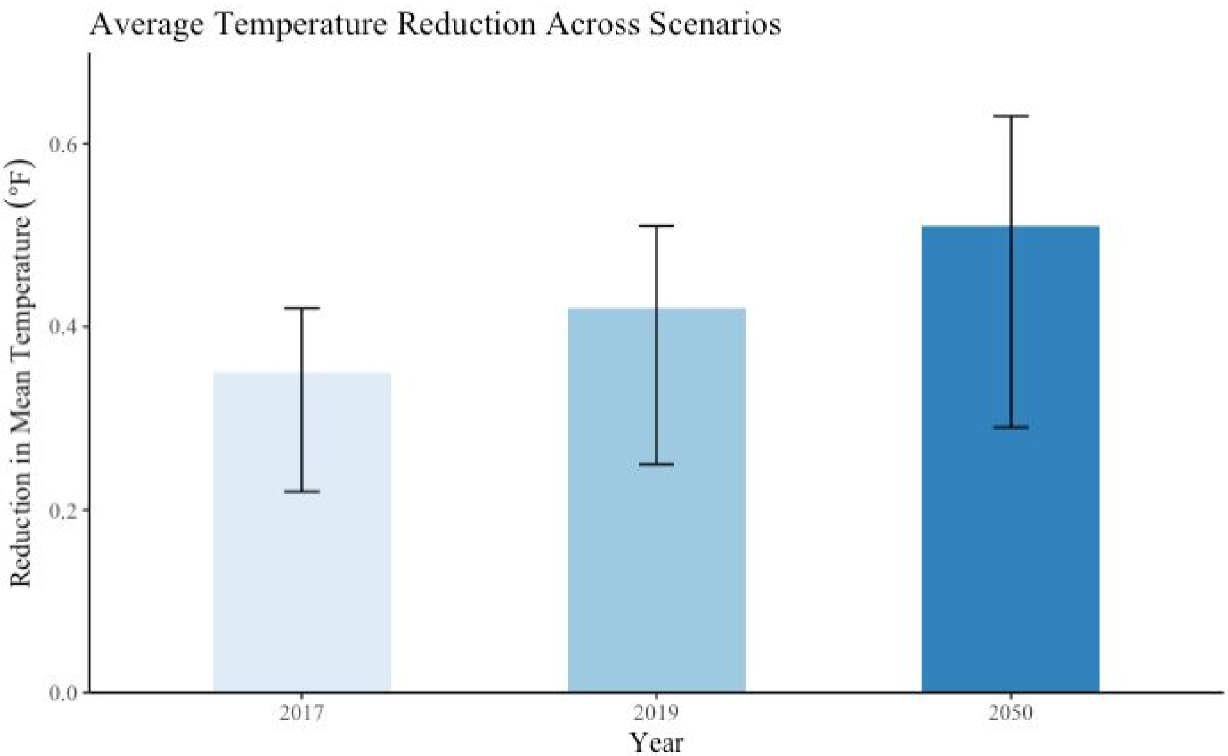

Figure 11. Average temperature reductions across 2017, 2019, and 2050 climate scenarios. *Each bar corresponds to the mean reduction in average temperature between the middle implementation scenario and the status quo scenario for that year. Error bars represent the lowest and highest levels of project implementation. In 2017, the average temperature reduction was 0.35°F (range = 0.22-0.42°F). In 2019, the average temperature reduction was 0.42°F (range = 0.25-0.51°F). In 2050, the average temperature reduction was 0.56°F (range = 0.29-0.63°F).*

While the average predicted temperature reductions for Waller-3 were calculated to be less than 1°F, on certain days, temperature reductions were much higher on certain days. Figures 13, 14 and 15 show the distribution of daily temperature differences between the status quo and the highest level of implementation for the years 2017, 2019 and 2050, respectively. These show that the RCPP has the potential to cool temperatures by up to 2°F on certain days, and up to 2.5°F in a warmer, future climate projected for the year 2050.

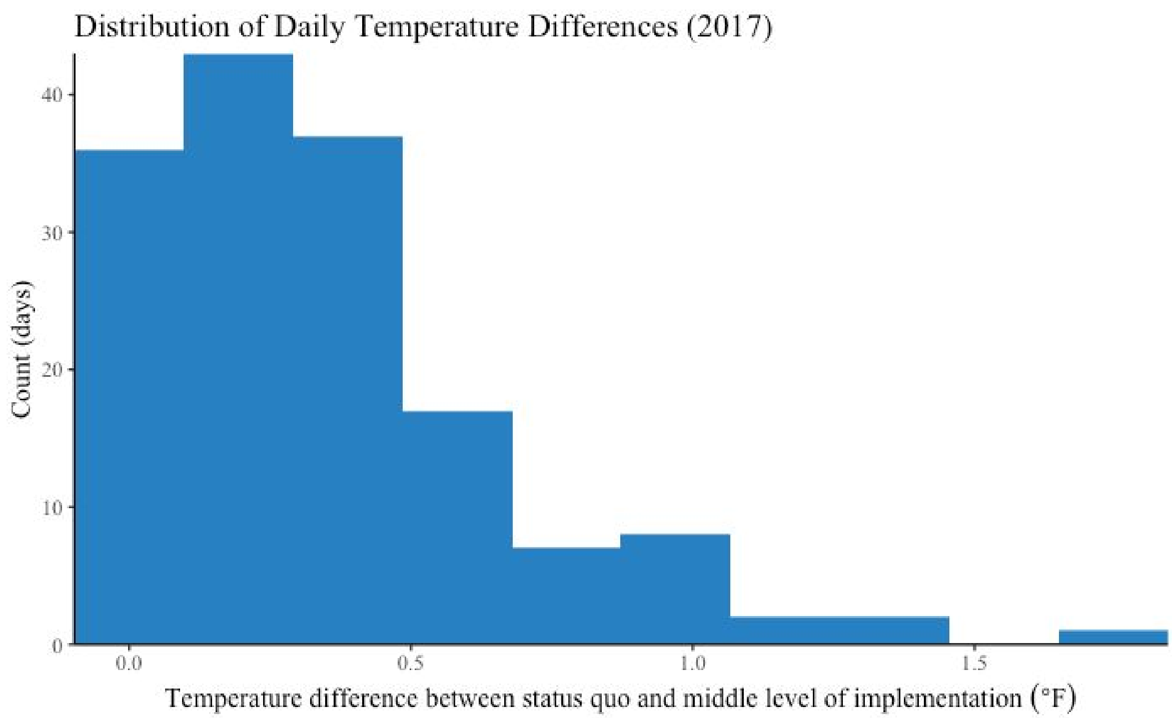

Figure 12. Distribution of daily temperature differences for the year 2017. *Temperature differences ranged from zero to 1.75 degrees Fahrenheit.*

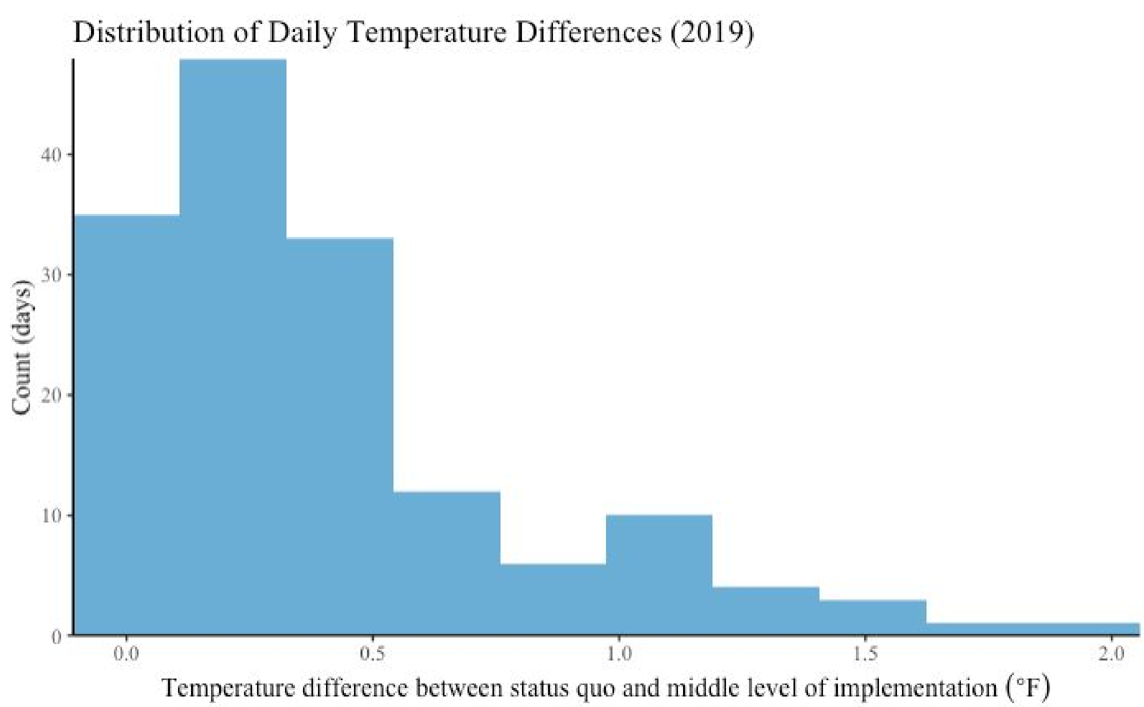

Figure 13. Distribution of daily temperature differences for the year 2019. *Temperature differences ranged from 0-2°F.*

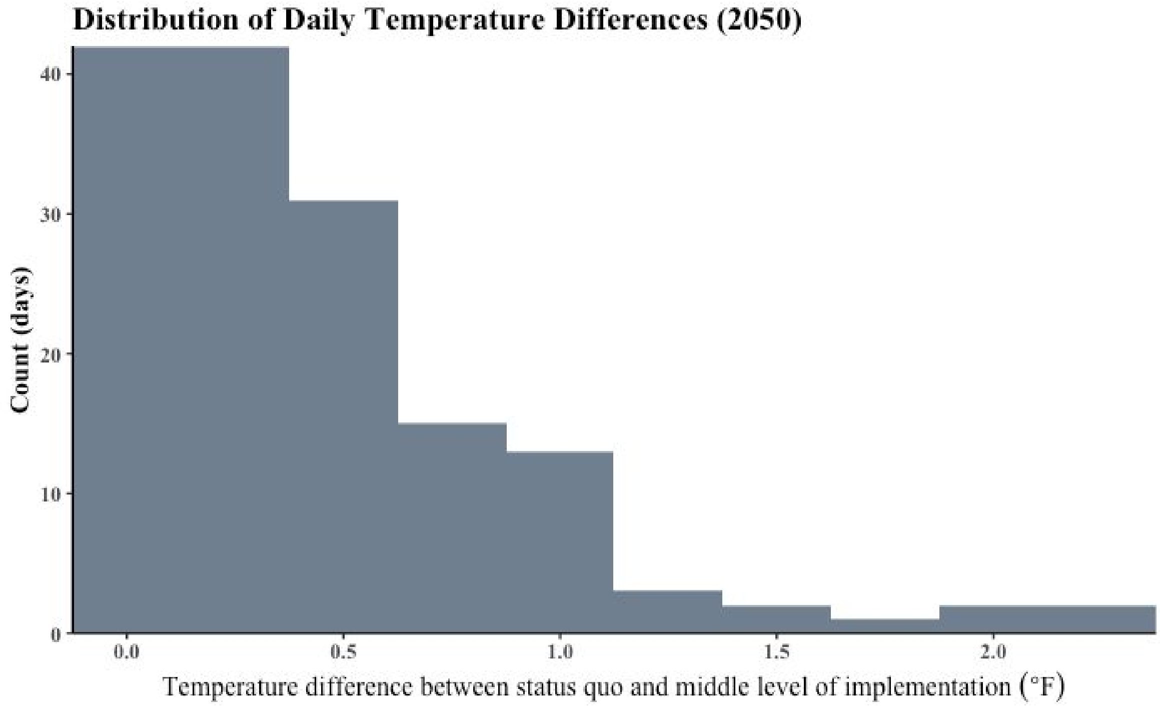

Figure 14. Distribution of daily temperature differences for the year 2050. *Temperature differences ranged from 0-2.5°F.*

Analyzing peak temperatures

We also wanted to analyze the RCPP's effect on peak daily temperatures, as UHI effects are highest during the hottest hours of the day.[6] Figure 16 shows the mean reduction in peak temperature across our scenarios. The RCPP has the potential to reduce peak temperatures by 0.47-1.12°F during the hottest time of the day for 2017 and 2019, and by up to 1.28°F for 2050. Additionally, we found that the distribution of temperatures varied more during peak temperatures, decreasing by up to 15°F on certain days.

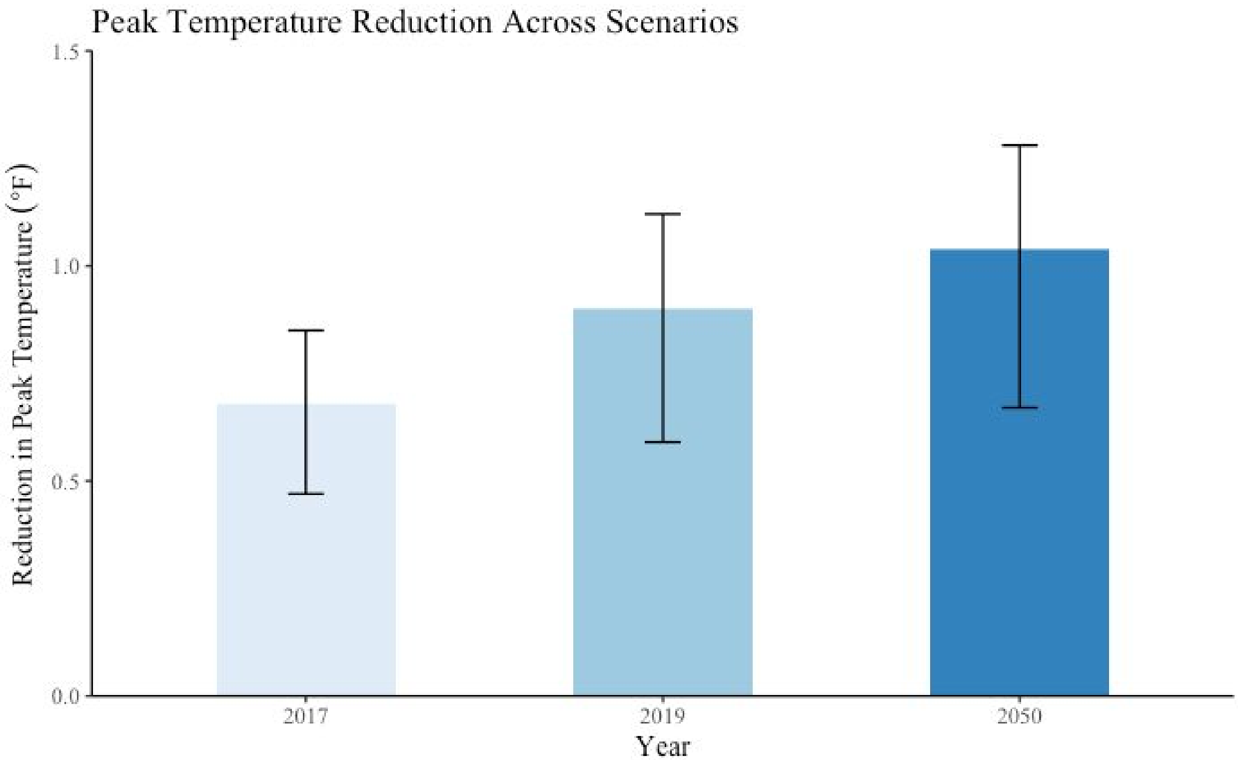

Figure 15. Peak temperature reductions across scenarios. *Each bar corresponds to the mean reduction in peak temperature between the middle implementation scenario and the status quo scenario for that year. Error bars represent the lowest and highest levels of project implementation. The predicted temperature reduction in 2017 was 0.68°F (range = 0.47-0.85°F), the average temperature reduction in 2019 was 0.9°F (range = 0.59-1.12°F), the average temperature reduction in 2050 was 1.04°F (range = 0.67-1.28°F).*

Reductions in energy consumption

Table 9 summarizes our findings for the amount of reductions in energy consumption resulting from the RCPP in Waller-3. Residential energy reductions for 2017 scenarios were calculated using Austin's energy rates and average annual household energy consumption for 2017.[3] The RCPP is expected to reduce energy consumption by between 46 and 84 kWh/year, corresponding to between $5 and $9 worth of savings on consumer's annual energy bills. When aggregated across 1200 homes, annual energy savings ranges between 55,335 (low implementation scenario) and 100,233 kWh (high implementation scenario), equivalent to between $5,815 (low implementation scenario) to $10,534 (high implementation scenario) of savings. Translating this energy savings into CO_2 emissions reductions, the project will save between 109 (low implementation scenario) and 197 tons (high implementation scenario) of CO_2 equivalent annually.

[3] The City of Austin has not yet published its 2019 residential energy data set. Therefore, estimated 2019 reductions were not calculated in this project.

Table 9. Annual savings by household and aggregated over Waller-3 (2017). *Low, medium and high estimates correspond to low, medium and high levels of project implementation.*

	Annual Household Savings			**Annual Aggregate Savings**		
	Energy Savings (kWh)	*Monetary savings (USD)*	*Emissions reductions (CO2 eq)*	*Energy Savings (kWh)*	*Monetary savings (USD)*	*Emissions reductions (CO2 eq)*
Low	46	5	0.09	55,335	5,815	109
Medium	71	7	0.14	85,773	9,014	170
High	84	9	0.17	100,233	10,534	197

3. Analysis of tree shading and UHI

Regression between the average land surface temperature taken from the four Landsat 8 satellite image scans in the Waller area and tree canopy cover from the city of Austin showed a significant relationship (R^2 = 0.2619, p<0.001, F =1125, df = 3166, Figure 16).

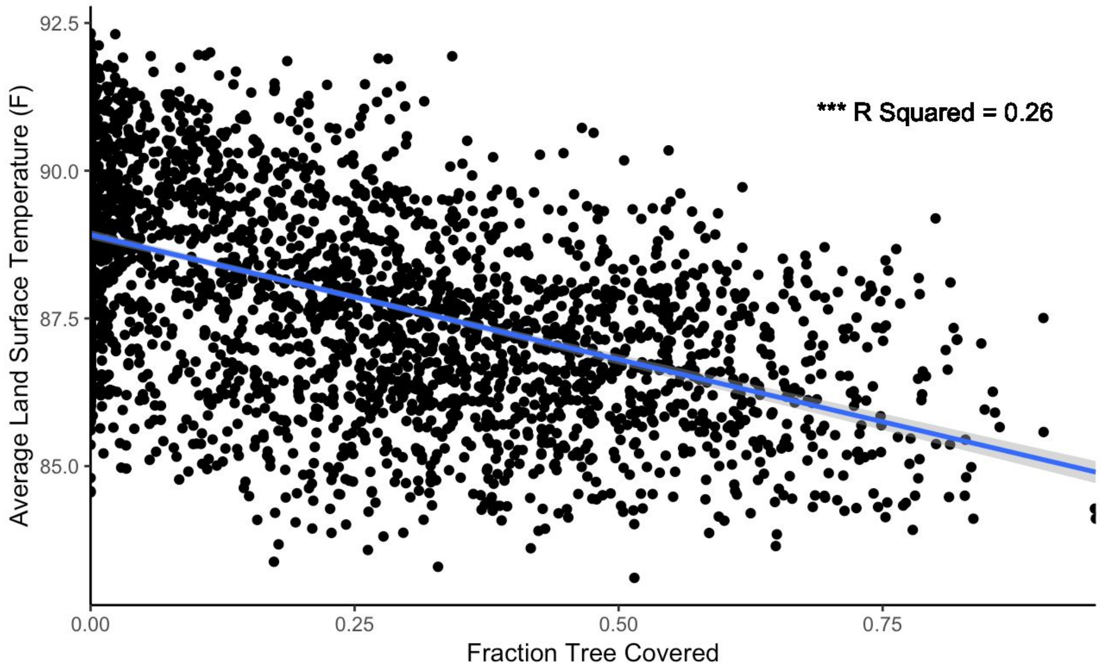

Figure 16. Average land surface temperature showed negative correlation with fraction tree cover. *Four Landsat 8 images taken in the summer of 2014 at 5:00 pm land surface temperatures were averaged in 30x30 meter squares and compared to fraction tree cover data from the city of Austin using linear regression in R.*

The slope coefficient was 4.2℉ (standard error = 0.126). This means a full tree covered parcel would be 4.2℉ cooler during this summer average than a parcel with no tree cover. This relationship is illustrated by a map showing the tree canopy overlain by land surface temperature (Figure 17).

For tree canopy cover, there was a spatial relationship among 30x30 squares using Moran's I (I = 0.63). Land surface temperature also showed a spatial relationship among 30x30 squares (I = 0.94).

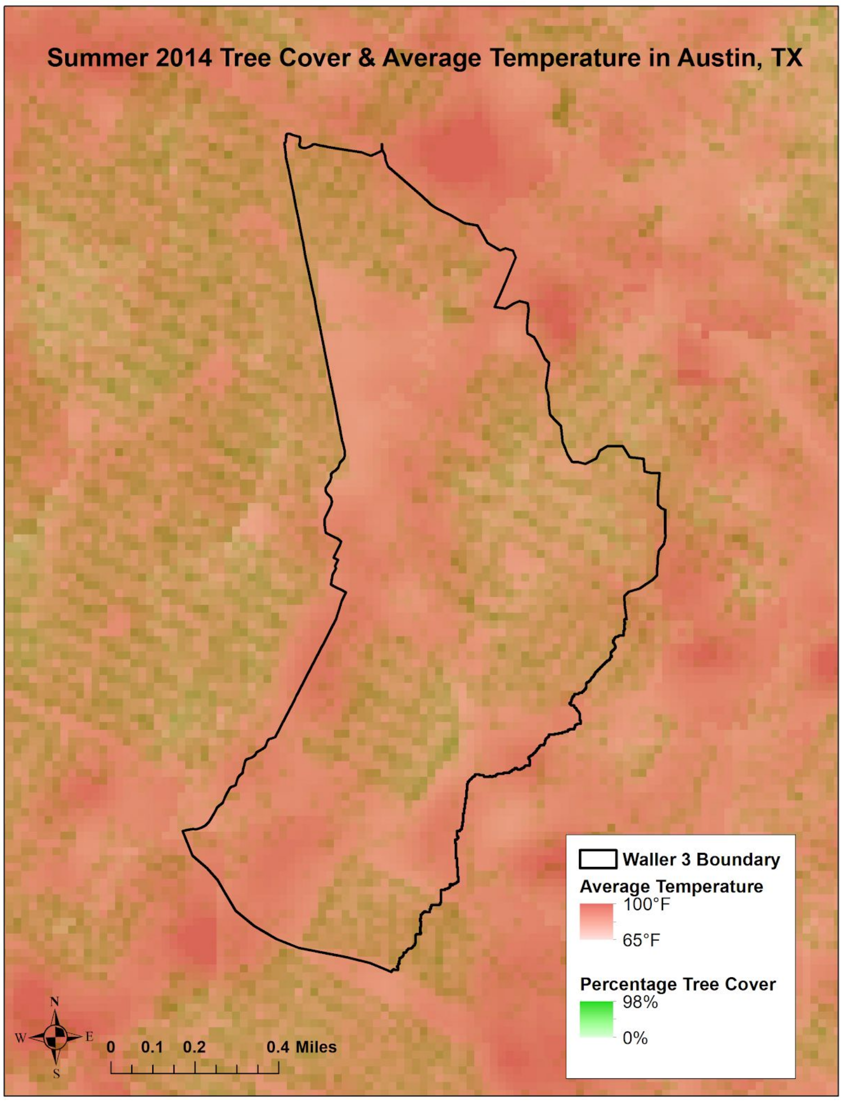

Figure 17. Average land surface temperature and tree canopy cover in Waller-3. *Seven Landsat 8 thermal scans (collected at 5:00 pm in summer 2014) of Austin between April 2014-September 2014 were calculated by the Department of Geography, Texas State University. Tree canopy cover was calculated by the City of Austin using Landsat 8 imagery.*

The RCPP will add one tree, using the palette of trees available for the project and the canopy cover at maturity, the project will cause 4-7% of a 30x30 meter parcel to be covered by trees. Using our regression model, this would lead to 0.17 to 0.33 degrees Fahrenheit cooling.

C. Equity

The RCPP has the potential to affect many aspects of equity in the Waller-3 neighborhood. Two of these include an increase in livability (lower rates of heat stress, heat exhaustion) for residents and an increase in property values. Additionally, the project has the potential to produce co-benefits for downstream communities and for the community as a whole.

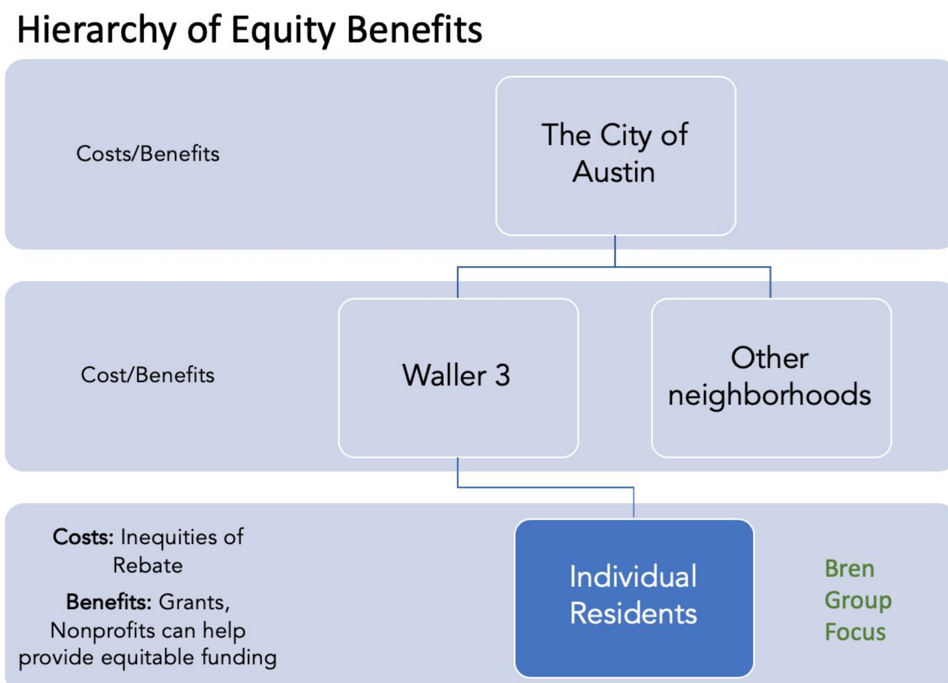

Table 10. Hierarchy of equity benefits. *Equity benefits can be evaluated at multiple scales. This project has quantified costs and benefits to equity within the Waller-3 pilot project area at both the neighborhood-wide level and at the individual resident-level scale.*

While these aforementioned impacts affect a variety of human health indicators and equity parameters, like gentrification, they would be outside the scope of our project timeline. For the purposes of our project, we focused on how to make the RCPP more affordable for residents in Waller 3 so that the benefits of improved stormwater management, reduction in flood risk, and a decrease in energy costs from a reduction in UHI are felt equitably across demographic groups in Waller-3 and for potential future project areas.

1. Current funding options

The City of Austin currently utilizes a rebate program to encourage adoption of green infrastructure on private property, including the Waller-3 rainwater catchment program. While rebates can be an effective strategy for increasing adoption of these types of infrastructure, they can often be unequitable. Rebates rely on residents to have adequate access to upfront capital rebate options and the ability to pay the upfront cost of adoption of green infrastructure. Usually, lower income residents do not have the funds available to pay the upfront costs of adoption, therefore higher income residents tend to benefit most from a rebate structure.

The maximum rebate amount for installing rainwater capture systems on residential properties is $5,000, which is a lifetime limit. Essentially, homeowners get refunded $0.50-1.00 (depending on whether the system has a pump or not) per gallon of capacity, up to half of the equipment cost.[1] This means that a 2,500 gallon cistern with no pump would get a maximum refund of $1,250, and residents would need to finance the other half of the cost themselves. The application and refund process takes about 8 weeks, and residents must get pre approval for tanks that are 500 gallons or larger. So far, 648 tanks have been approved citywide. Additionally, residents must provide an itemized receipt of all material and labor within 30 days.

Citywide data on rebates show that rebates have ranged from $20 to the full amount of $5,000. The overall average rebate is $250, while the most common rebate is $30. If we assume that these rebate amounts remain consistent as the project gets implemented, then the average Waller-3 household will receive $250 worth of financing for their project. However, the planned size of cisterns in the pilot project area are 2,500 gallons and 100 square feet, respectively, and the size of these may require a larger initial outlay.

With this information, it is important to consider whether funds going to support this project could be better allocated. Waller 3 is a middle income community, without an identified disenfranchised community, and a community with fewer resources and greater environmental needs could potentially benefit more from a direct investment of the same size. Additionally, the rebate structure of the program requires program participants to be able to put up ~$2,000 for eight weeks, and coordinate the installation of these projects themselves. This amount of money is likely inconvenient for middle or upper income households, but might be completely prohibitive for lower income households. While these considerations will not change the ongoing implementation of the Waller-3 project, they should be taken into account should the project get expanded.

Table 11. Austin rainwater harvesting rebate benefits and inequalities. *Summary of rebate options available to residents, benefits of the rebate for residents, and potential inequities that relate to affordability.*

Austin Rainwater Harvesting Rebate			
Rebate Options:	Non-pressurized (no pump): $0.50 per gallon up to half of the equipment cost.	Pressurized (has a pump): $1.00 per gallon up to half of the equipment cost.	Up to $5,000 lifetime limit.
Benefits:	Includes costs (materials and labor) for tank, pad screens, filters, first-flush, and selected piping installation.	May apply every 12 months for systems expansions until you reach $5,000.	Can reduce your water bill.
Barriers to Access:	Must intend to keep system in service at least 5-10 years depending on system size. Must pay full system price up-front.	Does not include gutters, irrigation system, shipping or delivery, and auxiliary water source requirements.	Must be property owner or Austin Water account holder. Rebate check takes 6-8 weeks to receive.

We have evaluated alternative financing options for the city of Austin to consider if the project is scaled up to include other neighborhoods in the city. These alternative sources of funding have been detailed below.

2. New sources of funding

Below, we explore potential new sources of funding that the city can use to subsidize GSIs on homeowner projects. Such new funding sources could include philanthropies, grantmaking organizations, partnerships with non-profit organizations and other public agencies, and tax revenue.

Philanthropies

The Austin Community Foundation (ACF) could become interested in funding the RCPP if the project is aligned with their goals. The ACF is dedicated to local community projects, particularly those that have an impact on low income communities. The ACF administers the Urban Forest grant, a grant program that provides funding for urban tree projects in Austin.[36]

Grants

Applying for relevant grants is another opportunity for the City of Austin and local organizations to fund or provide support for urban rainwater catchment projects. The Urban Forest Grant's mission is to make it easier for communities to invest time and energy in planting urban trees. The RCPP's impact on UHI is much greater with the addition of trees. Applying for this grant could potentially allow Austin communities to afford more of the benefits of urban rainwater catchment.[37]

Non-profits

The Texas Living Waters Project focuses on maintaining Texas freshwater resources for wildlife use and economic growth. This organization's goals could benefit from the proposed RCCP in Waller -3 due to the potential reduction in stormwater runoff and therefore decreased pollution of freshwater resources nearby, like Lady Bird Lake and Waller Creek.[38]

Tax revenue

An additional avenue for funding of RCCP implementation is to pass a property tax on homeowners making above the median household income in Austin of $67,462.[39] The revenue generated from this tax could create a citywide assessment district that uses the funds for the construction, maintenance, and improvement of the RCCP in Austin. A similar policy was instituted in Los Angeles, California with the passage of Proposition K. Proposition K created a citywide assessment district which is expected to generate $25,000,000 each year in funds for City parks, recreation facilities, and other projects through an annual real property tax assessment on City residents over a 30-year period.[40]

Partnerships with other city-wide agencies

If the RCPP is able to provide significant co-benefits that align with other agencies' environmental goals, the project could potentially receive funding from these organizations to scale the project. Agencies such as the Watershed Protection Department, and the Office of Sustainability might be interested in providing funding for 'stackable incentives'. Some of this funding should be reserved for grants rather than rebates to ensure that low income households are able to participate in the program.

3. Considering income as a factor when expanding the RCPP

While Waller-3 is not a disenfranchised community, if the rain capture pilot project is expanded to other parts of the city, income should be a consideration for project placement. Low income neighborhoods that are comparable in terms of potential to improve hydrology should be given priority for new projects. Additionally, as has been discussed in this report, income is positively correlated with tree cover, so the addition of income in the equation should align well with the other considerations for project location.

4. Locating ideal locations for RCPP or similar green infrastructure projects

We have developed a tool to be used by decision-makers for visualizing geospatial data relevant to planning "cool" green infrastructure in urban cities. We used the R programming language to create an interactive Shiny application that can be used to visually identify trends and patterns within the Austin, Texas region. For the purposes of our project, we have chosen to visualize current UHI incidence, air quality, water quality, human health, median income and social demographics.

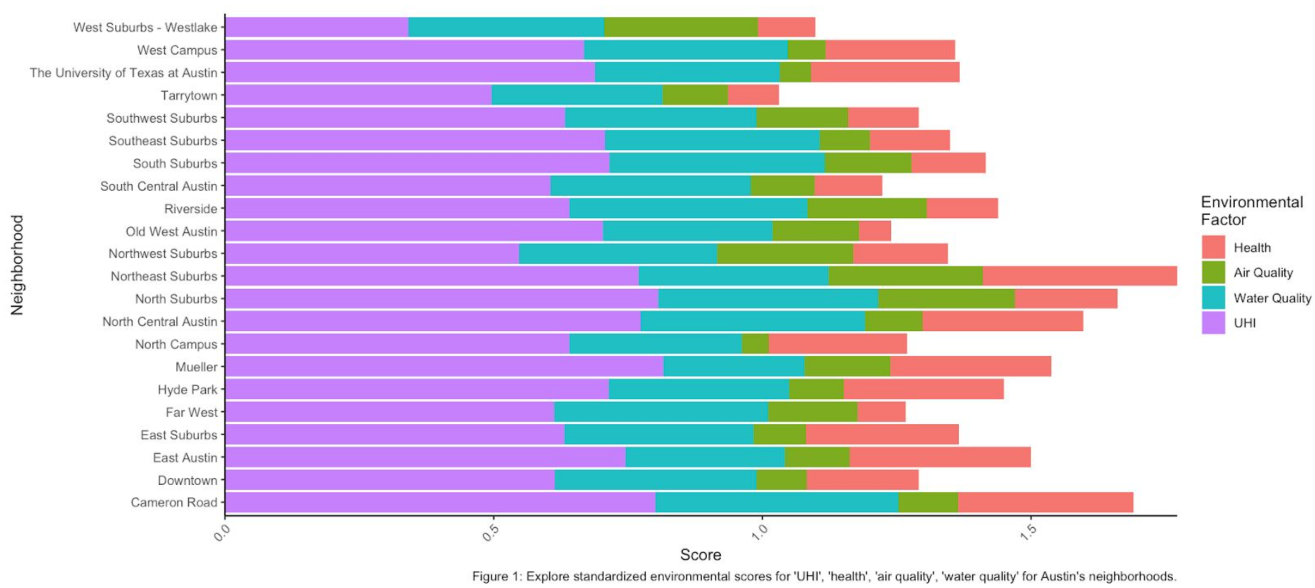

Figure 18. Snapshot of Shiny application environmental factors. *City of Austin neighborhoods scored by current UHI, human health, air quality, and water quality. Each variable was standardized to fit the same unit scale. Higher scores indicate the neighborhood 'does worse' with the environmental factor. This figure was created in the R programming language using the Shiny package.*

V. Discussion & Conclusion

A. Potable water energy offsets

Potable water offsets from implementing the RCPP will result in water conveyance-associated energy savings of 2.2-2.8 kWh per thousand gallons. Additionally, greenhouse gas reductions will result from RCPP implementation: the RCPP is expected to prevent 0.15-0.20% of a ton of CO_2-eq per thousand gallons from being emitted into the atmosphere. Assuming that 2500 gallons are captured in rain cisterns after rain events, 25% of captured water can be used for potable water offsets. When scaled up to 1200 homes, this leads to approximately 1600-2100 kWh or 3.9-4.6 tons CO_2-eq for the entire project area neighborhood. At this scale, the energy and emissions reduced are negligible. According to the U.S. Environmental Protection Agency, the average passenger car emits 4.6 tons of CO_2 each year.[41] As a result, the annual neighborhood savings could at most equal taking one car off the road for the year. However, the RCPP study area is only a small fraction of the overall Austin water system. There are many other suburban areas that could practice rainwater capture for supplemental exterior irrigation. Practiced at the city scale there could be larger impacts on potable water demand.

Other cities could see a larger impact from offsetting potable water demand. Austin's water system has multiple features that allow for a lower energy intensity. The city gets all of its water from the Colorado River and water treatment plants are located adjacent to this river. Many cities have distant, multiple sources of water. For example, in California many cities rely on State Water Project water that can be pumped for hundreds of miles over steep elevation grades. Other cities may rely on groundwater which requires pumping and conveyance to treatment infrastructure. In addition, the post consumer component of Austin's water system has lower energy intensity. Austin does not have a combined stormwater sewage treatment system. Wastewater has high energy intensity, especially if plants do not have the capacity to self generate energy.[42] Cities with combined stormwater systems have to treat stormwater diverted into the wastewater system increasing system energy intensity. As a result, Austin's system energy intensity is not representative of many cities and energy from potable water offsets could be larger in cities with higher water energy intensity.

B. Urban heat island effect

1. Interpretation of results of SUEWS model

The SUEWS model predicted that average daily temperatures in Waller-3 could be reduced by up to 0.51°F for non-climate change scenarios. Additionally, we found that during the hottest time of the day, the RCPP could reduce temperatures by an average of 1.12°F, and on certain days this reduction could be up to 15°F. While 0.51°F may not seem like a significant reduction, it still has implications for energy consumption and CO_2 emissions. Using our daily temperature reduction estimates, we estimated that Waller-3 residents could save a combined 100,233 kWh of energy each year, saving between $5 and $9 on energy bills, for a neighborhood savings of between $5,815 and $10,000 on energy bills. This will reduce CO_2 emissions by almost 200 tons of CO_2 equivalent per year. Additionally, this equates to the annual energy consumption of about 10 homes in Waller-3, and is the equivalent of taking 42 cars off of the road.[41]

Within the context of the other benefits produced by the RCPP, namely energy reductions through reduced potable water demand, we found that energy reductions resulting from a reduction in UHI were much larger. Additionally, UHI provides health benefits. While we did not quantify the potential health benefits that the RCPP produces, it has been found that even one degree Fahrenheit of difference can reduce mortality rates.[43] Additionally, heat-related mortality rates are higher among low income communities and communities with higher proportions of those without a high school diploma.[43]

2. Interpretation of land surface temperature - tree cover analysis

Regression of summer LST and tree canopy covered showed a 4.2℉ decrease in temperature in a 30x30 full tree covered square compared to a 30x30 square with no tree cover. While this gives a better idea of the parcel scale impacts of adding trees, it does not reflect RCPP. Considering the tree species available, the project will only change up to 4-7% of a 30x30 meter parcel once trees mature. As a result, the effects to an individual parcel would be around 0.17-0.33℉. The effect could be larger for properties smaller than the theoretical 30x30 meter "parcel" as a larger fraction of the property would be newly tree covered. Additionally, trees could have a stronger cooling effect during extreme events. A 2019 paper using remote sensing on land surface temperature and fraction tree canopy cover showed an increase in urban tree cooling in heat waves.[44] As the RCPP is implemented, monitoring the temperature on the adopting homes could give a better idea of the parcel scale impacts.

C. RCPP Best Practices

We recommend several "best practices" for enhancing and optimizing the multiple benefits associated with installing rain gardens and rain cisterns in urban neighborhoods.

1. Tree form and placement for optimal shading

As noted by Hwang et al. (2015) and others, trees planted in urban environments can significantly influence ambient air temperatures through increased evapotranspiration and tree canopy shading. Selecting and placing a single tree on a residential parcel influences shading for buildings on the property. Increases in shading can be translated into energy savings resulting from decreases in air conditioning usage.[45] However, tree shading should be used with caution, as it may diminish passive solar heating of buildings. Excessive shading can, potentially, increase home heating costs during colder months.

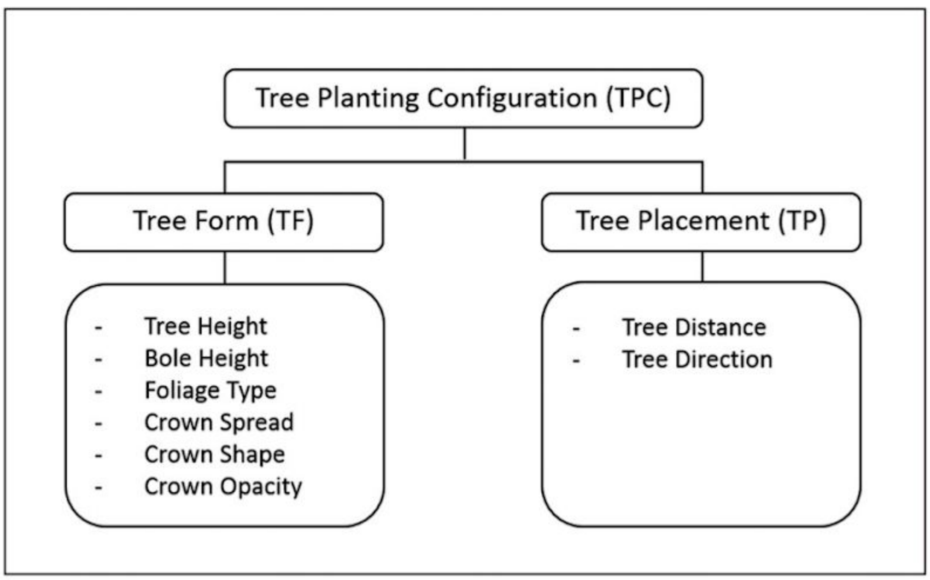

Figure 19. *Integral factors and component variables used to model shade created by single trees onto residential structures in four U.S. cities. Optimal tree planting configurations aim to increase shade provision (shade created by a single tree), which is a function of both tree form (a tree's physical attributes) and tree placement (location relative to a building targeted by shading). Source: Hwang et al (2015).*

While deciduous trees provide the largest amount of shade during times of peak cooling demand, large, coniferous trees provide greater average shade provision. Crowns of coniferous trees are generally highly-opaque tree crowns. These trees remain foliated year-round, and are able to provide large amounts of shade throughout the year. Sun-horizon angles at different latitudes can also impact the effects of tree shading. Trees placed to the south of structures generally produced the most shade at midday during periods of peak cooling demand. However, more shade was generated by southerly-placed trees in northern

U.S. cities than in southern U.S. cities, due to tree crowns intercepting more sunlight at northern latitudes, where the sun does not rise far above the horizon.[45] Tree distance from dwellings also have significant impacts on shade provisions from planted trees. Shade provisions on building surfaces decreased (a) when placed more than five meters away from a structure, and (b) as tree size decreased. Shade provisions generated by larger trees were less influenced by an increase in distance compared to medium-sized and small trees.

Ultimately, Hwang et al (2015) recommends regionally-based university extension guidelines in determining which tree species should be used in GSI projects. Regional tree guides are able to address region-specific interactions between tree forms, tree placement and geographic latitude.

2. Optimizing rainwater cistern efficiency

Within the scope of the RCPP, cisterns are used as rainwater harvesting systems that capture runoff from rooftops of homes and other impermeable surfaces. This rainwater is stored in large, above-ground tanks to be used as irrigation of landscaping on homeowners' properties. While rain cisterns are sometimes used as an alternative potable water source, the cisterns within the Waller-3 project area are intended for non-potable use only.

As determined by Coombes and Barry (2007), the performance of rainwater cisterns is dependent on complex sets of variables, such as climate-dependent water demand, human behavior, unexpected system failures, and consistency of maintenance schedules.[46,47] Within the South and Southeastern United States, harvesting rainwater is largely underutilized in areas that are able to meet most demands for water via extraction from large, regional aquifers or surface water reservoirs.[47] DeBusk, Hunt and Wright (2013) point out that modifications in design can substantially improve the efficiency and rainwater capture potential of cisterns. Potential improvements to rainwater cistern systems could include automation of irrigation, identification and inclusion of anticipated year-round water irrigation demands, and slow release of stored water into irrigated areas outside of the growing season.[47,48]

VI. Resources for Decision-Makers

Characterizing the Waller Creek Watershed

These sources were used to gain general information about the greater Austin, Texas region and Waller Creek Watershed. All sources are free-to-access and open-source.

1. Precipitation and Streamflow Data
   a. LCRA Hydromet - City of Austin Precipitation and Streamflow
      i. https://hydromet.lcra.org/
   b. U.S. Geological Survey
      i. Waller Creek at Koenig Lane: https://waterdata.usgs.gov/nwis/uv?site_no=08156910
      ii. Waller Creek at East 1st Street: https://waterdata.usgs.gov/nwis/uv?site_no=08157560
      iii. Waller Creek at Red River Street: https://waterdata.usgs.gov/tx/nwis/uv?site_no=08157540
   c. U.S. National Oceanic and Atmospheric Administration
      i. Waller Creek at Koenig Lane: https://water.weather.gov/ahps2/hydrograph.php?gage=wlct2&wfo=ewx
   d. Austin Watershed Protection Department
      i. Soil and Water Assessment Tool
         1. https://swat.tamu.edu/
      ii. Maps relevant to water management (e.g. interactive floodplain maps)
         1. http://www.austintexas.gov/department/gis-and-maps
2. Community Demographics
   a. American Community & American Housing Surveys, U.S. Census Bureau
      i. https://www.census.gov/quickfacts/fact/table/austincitytexas/RHI425217
   b. Travis County Tax/Registration Records
      i. https://tax-office.traviscountytx.gov/reports-data
   c. Austin, Texas Data Portal
      i. https://data.austintexas.gov/
3. Development, Housing and Permitting Data
   a. Austin, Texas Development Services Department: http://www.austintexas.gov/department/online-tools
4. Other Austin, Texas Geospatial Data Sources
   a. https://austintexas.app.box.com/s/8ah8itbha7u6lis9eipypnz5ljvwta4t?page=1
   b. http://www.austintexas.gov/department/gis-and-maps/gis-data

c. http://www.austintexas.gov/blog/freezing-urban-heat-island-effect
d. https://data.austintexas.gov/Locations-and-Maps/Tree-Planting-Prioritization-2014/psx7-v95h

Quantifying potable water offsets
We used these data sources for calculating energy savings from potable water offsets.

1. Pacific Institute - WESim Model
   a. https://pacinst.org/publication/wesim/
2. Energy consumption for all water treatment plants in Austin, Texas
   a. https://catalog.data.gov/dataset/austin-water-energy-consumption-for-all-plants

Quantifying urban heat island effects
We used these sources for quantifying, identifying, and visualizing urban heat island effects within the city of Austin, Texas.

1. Documentation for SUEWS model
   a. https://suews.readthedocs.io/en/latest/version-history/v2019a.html
   b. Comparison of SUEWS model with other similar models: http://micromet.reading.ac.uk/lumps-suews-fraise/
2. Incoming shortwave radiation data
   a. https://daymet.ornl.gov/overview
   b. https://disc.gsfc.nasa.gov/datasets/NLDAS_FORA0125_H_002/summary
   c. https://www1.ncdc.noaa.gov/pub/data/uscrn/products/subhourly01/2019/CRNS0101-05-2019-TX_Austin_33_NW.txt
3. Meteorological data
   a. Camp Mabry (Austin, TX) weather data:
      i. https://www.ncdc.noaa.gov/cdo-web/datasets#LCD
      ii. https://www.ncdc.noaa.gov/crn/qcdatasets.html
4. Data used for 2050 climate projections
   a. Regionally-downscaled climate projections: https://toolkit.climate.gov/tool/maca-cmip5-statistically-downscaled-climate-projections
   b. Other useful sources for finding downscaled climate projections:
      i. https://www.data.gov/climate/portals/
      ii. https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html

Calculating reductions in urban energy consumption

These data sources were used to calculate projected reductions in urban energy consumption after planting of shade trees and/or implementation of the RCPP.

1. Energy consumption and energy rates data
   a. https://catalog.data.gov/dataset/austin-energy-rates-cents-per-kilowatt-hour-by-customer-class
2. Average monthly energy bills
   a. https://catalog.data.gov/dataset/residential-average-monthly-kwh-and-bills

Tools for geospatial and statistical analysis, data visualization and data storage

These tools were used for geospatial analysis, statistical analysis, and data visualization throughout the duration of this project.

1. Geospatial data

We used ArcGIS for analyzing, compiling and creating maps of spatial data. QGIS is a popular alternative to ArcGIS that is free, open-source, and relatively easy-to-use.

   a. ArcGIS
   b. QGIS

2. Statistical analysis

For the duration of this project, we primarily used the R programming language for statistical analysis and data visualization. R is a freely available language and environment for statistical computing and graphics, which provides a wide variety of statistical and graphical techniques: linear and nonlinear modelling, statistical tests, time series analysis, classification, clustering, etc.

   a. About the R programming language
      i. https://www.r-project.org/about.html
      ii. Up-to-date packages can be found on CRAN: https://cran.r-project.org/
   b. *R for Data Science* by Hadley Wickham and Garret Grolemund. We strongly recommend that those that are new to the R programming language refer to this free, open-source document written by the creators of the R programming language: https://r4ds.had.co.nz/

3. Data visualization

We primarily used the R programming language for data visualization, such as in the creation of plots, charts, graphs, maps, and interactive applications.

   a. The R Graph Gallery is a helpful compilation of data visualizations, tutorials, and useful code
      i. https://www.r-graph-gallery.com/
   b. We used the Shiny R package for creating interactive web applications.
      i. R Shiny: https://shiny.rstudio.com/
      ii. R Shiny tutorial, created by R Studio: https://shiny.rstudio.com/tutorial/

4. Data repository/storage/sharing

We recommend GitHub as a repository for making data open-source and sharing data with others. If using ArcGIS, we recommend ArcGIS Online, a cloud-based GIS mapping software.

   a. GitHub: https://github.com/
   b. Group Project Data Repository on GitHub: https://github.com/alexbrown922/AustinAgua
      i. The linked Github repository contains essential files that this group project used for analysis.
   c. ArcGIS Online: https://www.esri.com/en-us/arcgis/products/arcgis-online/overview

Other websites and data sources of interest

Group Project Website.
https://austinagua.wixsite.com/website
This website is a digital repository for this group project, and contains links to our interactive Shiny application, GitHub repository, and other useful/relevant background information.

Measuring heat islands, U.S. Environmental Protection Agency.
This resource includes suggested approaches for communities interested in assessing urban heat islands and reducing the risks of high UHI incidence.
https://www.epa.gov/heat-islands/measuring-heat-islands

InVest (Integrated Valuation of Ecosystem Services and Tradeoffs) - Natural Capital Project, Stanford University.
https://naturalcapitalproject.stanford.edu/software/invest
InVEST is a suite of free, open-source software models used to map and value the goods and services from nature that sustain and fulfill human life. InVEST enables decision makers to assess quantified tradeoffs associated with alternative management choices and to identify

areas where investment in natural capital can enhance human development and conservation. The toolset includes distinct ecosystem service models designed for terrestrial, freshwater, marine, and coastal ecosystems, as well as a number of "helper tools" to assist with locating and processing input data and with understanding and visualizing outputs.

Green Values Calculator, Center for Neighborhood Technology.
http://greenvalues.cnt.org/methodology.php
The Green Values® Stormwater Toolbox was originally developed primarily for use by planners, engineers and other municipal staff. The toolbox was created to (a) educate decisionmakers about green infrastructure and its benefits; (b) educate decisionmakers about potential cost savings from green infrastructure projects; (c) help decisionmakers understand the costs and benefits of using green infrastructure to mitigate the need for different types of built water infrastructure, such as sewers and detention basins, and (d) provide comprehensive green infrastructure resources for decisionmakers.

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