2023-08-01

How Active Rainwater Harvesting may help Reduce Nuisance Flooding: Flood Analysis and Social Barriers to Adoption

Isabel Lopez
University of Texas at El Paso

Recommended Citation

Lopez, Isabel, "How Active Rainwater Harvesting may help Reduce Nuisance Flooding: Flood Analysis and Social Barriers to Adoption" (2023). *Open Access Theses & Dissertations*. 3919.
https://scholarworks.utep.edu/open_etd/3919

HOW ACTIVE RAINWATER HARVESTING MAY HELP REDUCE NUISANCE FLOODING: FLOOD ANALYSIS AND SOCIAL BARRIERS TO ADOPTION

ISABEL LOPEZ

Master's Program in Environmental Engineering

APPROVED:

Ivonne Santiago, Ph.D., P.E. Chair

Miguel Velez-Reyes, Ph.D., P.E.

Raed Aldouri, Ph.D.

Stephen L. Crites, Jr., Ph.D.
Dean of the Graduate School

HOW ACTIVE RAINWATER HARVESTING MAY HELP REDUCE NUISANCE FLOODING: FLOOD ANALYSIS AND SOCIAL BARRIERS TO ADOPTION

by

ISABEL LOPEZ, B.S.

THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

Department of Environmental Engineering

THE UNIVERSITY OF TEXAS AT EL PASO

August 2023

Acknowledgments

This study is supported and monitored by The National Oceanic and Atmospheric Administration – Cooperative Science Center for Earth System Sciences and Remote Sensing Technologies under the Cooperative Agreement Grant #: NA16SEC4810008.

The authors would like to thank the NOAA Center for Earth System Sciences and Remote Sensing Technologies, and NOAA Office of Education, Educational Partnership Program for full fellowship support for Isabel Lopez.

Abstract

As urbanization continues to expand, fewer pervious surfaces are available to help reduce stormwater runoff from rainfall. The impacts of urbanization are becoming evident through sunny day flooding – flooding that occurs in areas not designated by the Federal Emergency Management Agency (FEMA) as flood zones. Nevertheless, water accumulates in low-lying areas and compromises street intersections and other parts of neighborhoods. Some methods can help alleviate the impacts of unexpected heavy rains, such as passive and active rainwater harvesting. As a pilot study, in a selected area in the northeast of El Paso, the level of adoption (e.g., what percentage of people may be able to harvest rain), feasibility (appropriate structure, sufficient land), and land cover (e.g., turf, xeriscaping) were evaluated. The GIS approach was employed to generate a land cover map to obtain the necessary parameters for SCS calculations. The SCS curve number was utilized to account for losses due to infiltration. RWH potential of roofs as catchment areas were calculated and in conjunction with the data obtained from GIS, a rainfall-runoff model was developed in HEC-HMS to simulate different volumes for frequency storms ranging from 1-Year to 500-Year. The comparison of the results from the HEC-HMS model and the storage capacity roof indicates that for the most common storms, RWH storage exceeds the volume produced during those storms. In general, the reduction of water that can be kept off the streets is significant even in extreme storm scenarios. Overall, the results are indicative that RWH can help alleviate sunny day flooding. In addition, we explored the community's attitude and understanding of RWH and climate change and their opinions on the impact, if any, they believe has been identified in the region. The views and knowledge of the residents about rainwater harvesting and climate change must be considered to fully gauge the barriers that could present themselves in the case of implementation.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

Nuisance Flooding is temporary inundation when water accumulates in low-lying areas compromising infrastructure [1]. Nuisance flooding is also known as “sunny-day” or "clear-sky" flooding, which refers to quick-to-form flooding scenarios that create public inconvenience by overwhelming existing storm infrastructure, such as storm drains, and cause road closures. The heavy rainfall in a short period is enough to flood intersection points, even in non-designated flood-risk areas. In contrast to extreme flood events, nuisance flooding disrupts daily routine activities and, in some cases, only produces minor property damage. Based on a wide range of literature, including hydrology, transportation, public health risk, and safety impacts, we define sunny-day flooding based on depths larger than 3 cm but less than 10 cm, regardless of the source [1]. The lack of severity associated with sunny-day flooding causes these events to be overlooked, adding to the lack of knowledge, and understanding of the effects of sunny-day flooding.

Even though sunny-day flooding occurs in high-tide areas such as coastal counties, it can happen anywhere where high-intensity rainfall occurs. Highly urbanized sites, such as residential properties, typically have high runoff during rain due to the type of land cover associated with urbanization, such as roofs, paved areas, and streets. In case of a significant rainfall event in a brief period, urban neighborhoods can quickly experience sunny-day flooding that can hinder their ability to use the roads safely and make sidewalks and play areas unusable until the temporary inundation dissipates. Considering feasible and economical solutions to help alleviate short-term flooding is necessary to protect the infrastructure and safety of residents. Identifying sites that experience flooding and are at risk for frequent sunny-day flooding based on location and site properties is necessary to provide some flood control.

Rainwater Harvesting (RWH)

Rainwater harvesting is an alternative option to help lessen the impacts of sunny-day flooding. Rainwater harvesting (RWH) is an umbrella term for methods to capture and utilize rainwater; there are two specific types (1) Active and (2) Passive. Active rainwater harvesting uses catchment areas such as roofs, where rain gutters convey the water into a storage tank. Active rainwater harvesting allows the water to be stored for later use for gardening, outdoor cleaning, and other domestic uses. Passive rainwater harvesting refers to using native vegetation or "xeriscaping." Using native plants, the watering needs may be sufficed by local rainfall. They have high water retention rates, which aid in reducing water that makes it to the streets and contributes to the overall site runoff. The area where the plants are located acts as a storage where water is collected, unlike active RWH that utilizes storage tanks. Passive rainwater harvesting requires "open space" areas with lots of soil/grass coverage to allow native plants to be introduced.

Climate Change

Flooding is the most common natural hazard and the third most damaging behind storms and earthquakes [2]. Climate change alters the average quantities of climatic variables, such as temperature and rainfall, in different regions [3]. Anthropogenic climate change is expected to increase flood risk through more frequent heavy precipitation [4].Urban sprawl has increased flood events that can cause unprecedented damage to residential properties. Thus, climate change can exacerbate the damage in an already vulnerable urbanized area.

While anthropogenic climate change is proven to be an issue affecting us currently, many people do not believe their actions are responsible for the changes we are experiencing today. As the actions of individuals contribute substantially to climate change, identifying factors that underpin environmentally relevant behaviors represents an essential step toward modifying behavior and mitigating climate change impacts [5].

Perceptions of climate change are difficult to detect and assess accurately based on personal experience [6]. We must understand the community's perceptions, knowledge, and opinions of climate change to determine if these affect their willingness to participate in rainwater harvesting.

Goals and objectives

This project examines the relationship between willingness to adopt household RWH technologies in a neighborhood in Northeast El Paso as a case study and how these are related to perceptions of climate change and an environmental assessment of how RWH can help reduce sunny-day flooding. The main goals of the project were to:

1. Develop a framework and a model using Geographic Information Systems (GIS) combined with a hydrological model (HEC-HMS) to analyze how RWH can help mitigate sunny-day flooding in cities located in arid environments like the US Southwest.
2. Understand how opinions, perceptions, and knowledge of RWH and climate change amongst low-income communities can help identify, design, and deploy outreach and educational activities to increase adoption of RWH.

Specifical objectives included:

1. Determine how independent variables (demographic information such as income and ethnicity), perceptions of climate change, and knowledge and exposure about RWH can potentially influence the adoption of RWH. This was done by designing and implementing a survey incorporating questions related to the knowledge of RWH, perceptions of RWH and climate change, and financial and demographic information.
2. Evaluate the impact of active RWH adoption on sunny-day flooding by creating a hydrological simulation using a land cover map of the pilot area in Northeast El Paso using a hydrological model HEC-HMS [7] and a Geographic information system (GIS). method (e.g., Slope, Curve Number, Lag Time, Hydraulic length) [7].

Chapter 2: Literature Review

The continuous urbanization process has resulted in increasing surface runoff and waterflow peaks, reducing evapotranspiration and the groundwater supply, and the deterioration of superficial water quality [8]. Sustainable water management using RWHS involves several aspects, such as a decentralization of public water supply systems and assistance in protection against floods [9]. In this research we focused on the use of RWH for protection against floods, specifically sunny-day flooding as climate change can cause a greater number of intense rain showers and a longer period of consecutive days without rain. Thus, RWHSs can reduce the impacts of climate change by reducing superficial runoff in residential neighborhoods, reducing evapotranspiration, and recharging the groundwater supply. There is increasing interest in utilizing RWH to mitigate the quantity and quality of stormwater runoff, both at a site scale and a community scale [10], [11].

RWH systems can be active or passive. Depending on the characteristic we want to address, either method can be favorable.

Active RWH

Impervious surfaces, surfaces that do not allow for water infiltration, such as roofs, and paved surfaces, such as streets, sidewalks, and driveways, are valuable surfaces to use as catchment surfaces to collect water. Active RWH systems comprise a catchment surface, distribution pipes, rainwater tanks, and complementary devices. In such systems, the building's roof is usually used as a catchment surface [8]. Each RWH technique provides its benefit; using a cistern/tank allows some of the collected water to be used for dry times. In passive rain harvesting, the soil is the storage medium for the rain, and it does not require tanks [12]. When considering how much water could become runoff and be captured for active RWH, the runoff coefficient must be considered. A runoff coefficient can be defined as the ratio of surface runoff to precipitation for any catchment area, in which a more considerable value represents low infiltration and high runoff, and a small value signifies permeable, well vegetated areas [13]; [14]. Another factor to consider is average rainfall; based on this number, a general expectation can be formed of when rain is likely to occur and the amount (inches) that falls, given a reasonable estimate of future rainfall patterns. However, we must consider that rainfall can vary yearly; extreme rainfall events, such as storms with a 1% probability of occurring, must also be considered.

Passive RWH

Passive RWH systems prove an opportunity for small-scale implementation. Planting a low-need tree where water is known to accumulate or pass through allows for some infiltration and can be slightly modified for the site's needs. If the first attempt is successful, one is more likely to continue the implementation of passive RWH at their own pace and based on their site capabilities. Lancaster (2019) states that dozens, hundreds, or even thousands of tiny water harvesting "sponges" are usually far easier to create and more effective than the typical big dam and have the power to capture more water in the long run [15]. Small projects such as Xeriscaping or even larger projects such as active projects provide an alternative to reduce water rather than a costly and time-consuming dam.

Combined Active and Passive RWH

Although presented as two separate options, active and passive RWH systems can be used together. The option to use one or the other is dependent on the landscape and the user's time and monetary capabilities, but if allowed, both strategies can be implemented to spread the harvested water over the total landscape to allow for the water that is not captured in a cistern/tank to be spread throughout for maximum infiltration.

Earthworks (passive) and tanks (active) can capture large volumes of water, reducing the need for municipal water, stormwater drains, and stormwater treatment and decreasing flooding [15]. In that regard, either method could be used; a cistern can be placed near any wall on the outside of the home if sufficient space is left for someone to walk around and provide maintenance and are helpful for individuals with small yards that do not have the area to modify for passive. A cistern would increase the water storage capacity in a small yard.

RWH as a Low-Impact Development (LID)

In urban areas, RWH collects, stores, and treats rainwater from rooftops, terraces, courtyards, and other impervious building surfaces for on-site use [16]. The goal of RWH is to utilize a natural source, in this case, rainwater, to help reduce the demand and consumption of central supply sources. However, even though this is often considered its most notable use, this study aims to investigate how RWH cannot only reduce the demand but also help mitigate sunny-day flooding. The water collected through the method of active rainwater harvesting should reduce the volume of the water that can accumulate during a rainstorm. Once collected and stored, this water can be used as a primary outdoor gardening and cleaning source.

Using RWH to reduce peak floods and volumes is often called Low-Impact Development (LID). As previously mentioned, the most popular reason behind RWH is a way to manage water scarcity and provide an alternate source of water supply. However, over time RWH as a Low Impact Development (LID) approach has been investigated to reduce volumes of urban runoff. The EPA refers to low-impact development (LID) as "systems and practices that use or mimic natural processes that result in the infiltration, evapotranspiration or use of stormwater" the main objective is to preserve but restore green spaces using methods such as rainwater harvest techniques. The motivation of LID is to reduce impervious areas through the implementation of site drainage to allow "stormwater" to be treated as a resource rather than a nuisance. One of the practices of interest as a LID principle is using rain barrels to store water that would otherwise end up on the streets affecting built areas. While full participation of all homes in the area partaking in RWH would keep some of the water off the road, it will not be efficient unless the people who harvest the water use it.

A study in Australia by M.J Burns (2012) focused on the stormwater retention performance of RW tanks; they quantify how the use of those tanks can achieve some retention based on a range of tank volumes along with typical roof sizes [11]. Using computational software and some size assumptions such as two specific roof areas and varied size tanks ranging from 2-15 kL along with a list of water uses for the water collected such as clothes washing or gardening. Regarding the modeling schematic, they utilize a rainfall generator to simulate an event based on actual rainfall data along with internal and external demands to consider a tank model equation that derives a general output from determining the actual retention capacity and the demand supplied from the water collected in the tanks. The results generated from the research showed that the larger the tank, the more runoff was retained. It allowed for the partial restoration of the retention capacity of an average land parcel. Harvesting stormwater using tanks can restore small-scale retention capacity and augment potable water supplies [11]. The tank yield results were substantial, proving their use in retaining rainwater for needs that would otherwise increase their water demand from the city and county. An important note is the variation of the study based on the area of interest, such as a drier area where rainfall might be minute and or a place where rainfall might be more excessive. Considering all rainfall scenarios, even “average” allows for the true capability of rainwater tanks to be investigated and how they can aid in reducing flooding and conserving natural rainwater resources.

Implementation of RWH

The degree of implementation of rainwater harvesting varies by location and available resources. The true potential of rainwater harvesting systems has remained untapped because the benefits have yet to be quantified. According to Zhang (2009), incorporating demands that align with local rainfall patterns can substantially increase the system's efficiency in water conservation and stormwater mitigation [17]. In areas with water scarcity, wide-scale implementation of RWH is increasingly being considered. Further research is still necessary for use as potable water, as it needs treatments and water quality analysis. The ability of household rainwater tanks to reduce peak flows is of particular interest in this case, as stormwater systems are likely to be adversely affected by increased urbanization and climate change [11]. Urbanization increases the imperviousness of areas which in turn increases street runoff.

Use of RWH to reduce flooding.

The primary purpose of active RWH in literature is to alleviate the lack of clean water available and address water scarcity in low-income areas. While this is an everyday use for RWH, our focus is on the use of active RWH systems as a method to reduce street flooding in residential neighborhoods. A large tank (5000 US gallons) is sufficient to reduce peak flows significantly; however, when considering a typical residential parcel, a suitable large enough area for a tank is needed for setup and use [18]. A 5000-gallon tank or cistern would require a large area and a significant investment depending on the income one receives.

A rain barrel that typically stores 50 to 200 gallons is a more inexpensive and viable option for beginners who require much less space to set up and can help eliminate the typical size constraint. Once an overall peak flow is calculated along with the total number of homes participating, and reasonable gallon size estimate becomes much more apparent. A study in the northwest Florida area, Escambia County, focuses on evaluating residential rainwater harvesting to reduce flood discharge. Homes with septic tanks were identified, and different "storage" scenarios and the corresponding percent flood reduction were calculated. Based on the results, they found that flooding could not be mitigated through the small-scale pilot; instead, the results corroborate other studies that require widespread adoption among buildings to reduce peak discharge correctly [19]. Ultimately, more people participating will have a higher impact on alleviating flooding, even at a smaller scale, such as sunny-day flooding.

Feasibility of using RWH to reduce Sunny-Day Flooding

The quantifiable effects of sunny-day flooding have yet to be thoroughly investigated; however, reviewing existing literature and work can aid in the understanding and measurement of the consequences of urbanization. A study in Norfolk, VA, investigates the projected occurrence of sunny-day flooding due to tides and internal climate variability [20]. In this case, the focus is not so much on typical rainstorm scenarios but more on the current and expected increase in sea level rise, which causes more sunny-day flooding events. This minor flood event can cause road closures and affect infrastructure along the coast. Typically, those along the coast have a more significant fear and understanding of major natural disasters such as hurricanes but need to be more aware and concerned with something like sunny-day flooding. Sunny-day flooding could cause comparable, or even more extensive, cumulative property damage compared to infrequent extreme events [1].

Sunny-day flooding might not cause visually impacting damage or make the news, but it does not mean it should be ignored; residents of the area need to understand the risk, and coastal managers must consider how it can affect transportation and surrounding properties and ways to reduce the impact. The study mentioned above creates future sea level rise (SLR) scenarios, equations to calculate the regional SLR, and a tidal analysis. Tides will not be the only factor to consider. It is important to remember that these flooding events generally occur when several processes converge, such as SLR combined with wind-driven events like coastal storms [20]. Burgos's study follows different methods and considers factors not part of sunny-day flooding in land-locked areas. However, it presents the effects of sunny-day flooding and showcases the importance of communities being aware and prepared before a sunny-day flooding event occurs.

Flood events are expected to increase in frequency and acuteness as time progresses, and the effects of climate change will become evident. Much more information and analysis are available on events such as hurricanes or tsunamis, which have caused catastrophic damage, compared to sunny-day flooding that can be perceived as a simply minute inconvenience.

Although this can often be the case, sunny-day flooding can quickly increase in severity as multiple infrastructures become compromised and unusable as water accumulates at low-lying points such as intersections or areas at a low elevation. What is considered “minor” events also require attention as the effects might be anything but minor, especially over time in areas subjected to more than one “minor” event. By analyzing the likelihood of exceedances above mean higher high water and the corresponding property value exposure for minor, major, and extreme coastal floods, sunny-day flooding could generate property value exposure comparable to, or larger than, extreme events [1]. The water collected in active RWH depends on the catchment area’s size, and its usefulness depends on the “active” use. For residential properties, the geography and landscape of the site need to be considered to determine the feasibility of RWH implementation and participation.

Sunny-Day Flooding: Hydrological Analysis

To begin any analysis, the most basic hydrological component is the number and types of watersheds. The first step in the assessment is to find watersheds in the area and observe the water flow. A watershed is a hydrological entity bounded by a ridge line having a single outlet [21]. The highest point to the lowest point of elevation will help determine the specific direction of water flow in the event of rainfall and aid in creating watersheds along with obtaining the slope of the area.

The effects of sunny-day flooding are not included when determining whether a property is in a flood zone—in Moftakhari’s study, using the vulnerability (V) estimation function aids in the verification that the cumulative cost of sunny-day flooding is significant and the notion that it could exceed the cost of extreme not as standard events which are the foundation for flood risk management programs or to determine flood zones [22]. The Cumulative Hazard Index (CHI) was computed, representing a relative measure of coastal community exposure to sunny-day flooding versus infrequent floods [1]. The CHI presents a way for coastal managers/policy managers to view a quantifiable effect for an event such as sunny-day flooding that is not often represented and otherwise not understood or utilized to examine an area's flood risk. Overall, the results of this study highlight the need for a framework that can allow for any flooding event to be investigated and understood. If the effects of sunny-day flooding can be adequately quantified for coastal flooding events due to SLR, it opens the door for the impact of sunny-day flooding in an urban setting to be quantified.

GIS-Based Analysis

The success of RWH systems depends on factors such as rainfall, catchment characteristics, and socio-economic factor [23]. The factors are site-specific and will determine site suitability; an approach where this variability can be easily addressed is necessary. A GIS-based analysis allows for incorporating spatial datasets to evaluate an urban scale to facilitate research [24]. A geographic information system (GIS) approach utilizes location data with all types of descriptive information which provides a foundation for mapping and analysis [25]. Many frameworks use a GIS-based method to analyze the feasibility of rainwater harvesting in countries abroad, such as India, Iraq, Australia, and others. However, regarding existing research on rainwater harvesting, studies are abundant on using rainwater harvesting to aid in water scarcity. Notably, applying GIS to optimize the analysis has been investigated to compare methodologies and the reasoning behind rainwater harvesting. GIS can assist in large-scale RWH by identifying significant areas of rainwater collection and storage [26]. Methodology varies across the spectrum for selecting appropriate sites and techniques for rainwater harvesting. The methods in recent times have an increased focus on the use of GIS and remote sensing. The success of RWH systems depends heavily on their technical design and the identification of suitable sites [27], [28].

The site suitability criteria for Adham's study included annual rainfall, soil water conservation (SCS) parameters such as curve number (CN), land use classification, and area slope. The land cover analysis was developed using satellite imagery (Landsat 8-2013), and the land cover classification focused on bare soil, urban space, moist soil, and farmland [27].

Adham uses a similar methodology for hydrologic parameters with the SCS method as our study; however, the focal point of rainwater harvesting in their research is the utilization of dams as catchment systems [27]. The suitability map generated in the study is meant as a tool for planners to identify areas with the potential for rainwater harvesting.

A case study in Wollert, Victoria, quantified the potential of water captured by rooftop rainwater harvesting using GIS techniques. The images were digitized considering rooftops, roads, and open space topography [29]. The catchment area was calculated through ArcGIS and by summing the Annual Rainwater Harvesting Potential using a runoff coefficient representing any losses that were not retained. This study considers the potential of "road catchments" from roads between the houses and main roads apart from roof potential. The study focuses on the roof rainwater harvesting method to reduce water scarcity by collecting water to be used as a drinking alternative and for other domestic needs. The main advantage of GIS is that the digital database developed at any stage can also be used in the future, and any related information can conveniently and effectively be retrieved [30].

HEC-HMS

Location-specific studies are needed to evaluate the potential feasibility of RWH in a specific area [23]. In Ndeketeya study, a municipality in South Africa is investigated for RWH success. A simulation to observe the rainfall-runoff relationship is created in HEC-HMS. The simulation in HEC-HMS was composed of various algorithms and processes to obtain different parameters, such as runoff and infiltration along with river flow for the study area. The suitability of the site was calculated using the Analytical Hierarchy Process (AHP). They consider various factors ranging from household income to property owners to determine potential suitability, and only those deemed "suitable" were used in the HEC-HMS model. The monthly harvestable runoff (RWHQ) was estimated using (1) Runoff, (2) Catchment Area, and (3) Harvest Efficiency. The modeling approach allowed rainfall variability to be captured across various seasons and over the years, which is useful in long-term planning [23]. Its use of socio-economic variables needs adjustment based on site characteristics since this variable will vary by site.

Perception of Climate Change and Willingness to Modify Lifestyle

Rainwater harvesting has been deemed a viable option to help mitigate sunny-day flooding, as presented by research in the literature. For the successful adoption and implementation of alternative and innovative technologies, it is imperative to understand public perceptions towards them and the causes of their agreement-disagreement [31]. The understanding of a community's willingness as well as identifying misconceptions they might have allows for proper education and accurate information to be distributed to help with adoption of new technologies. Additionally, water resources management, specifically in highly urbanized areas, is critical due to the increase of surface flooding, groundwater depletion and water scarcity caused by population growth, urbanization sprawl, and climate change [31]. However, it is essential to consider how views on climate change can affect the population’s willingness to participate in a community effort to alleviate flooding conditions that were once not the norm.

Climate change in recent years has been more evident, more commonly through temperature shifts, since it is the most apparent change that communities can detect. It is crucial to understand the community’s perceptions and understanding of climate change to know their disposition to make personal changes that can help decrease the effects of climate change. To do so, we must understand what baseline considers weather as either normal or abnormal; this can be affected by age and cognitive biases. Age represents how long an individual has been around to observe and notice climate changes. Personal characteristics such as relationship status, socio-economic status, and culture can increase an individual's vulnerability in addition to their gender. Climate change is a health threat multiplier through a multifactorial framework of direct and indirect mechanisms while increasing health inequalities [32].

Gender-based health disparities concerning the effects of climate change vary primarily due to different vulnerability levels and needs of individuals. The impact of climate change on health determinants such as food security, clean water, disease vectors, and air quality [33]. Often climate change is thought of as extreme weather events and or increased frequency of such events. However, “smaller-scale events” such as heavy rainfall, resulting flood events, and increased temperatures can create the same climate change effects as “extreme weather events”. Overall, the impact of climate change can fluctuate, affecting the population's health by causing heat stress or even death in extreme cases. The range of climate change can often cause smaller events to be overlooked as everyday events instead of instances of climate change and are often attributed to natural causes.

To further understand these misconceptions, it is vital to consider the type of public understanding of the effects of climate change as their source of information. If their misunderstanding grows, it will likely delay any actions to mitigate climate change. Scientists repeatedly present new findings that correspond to how harmful the effect of climate change is and how if they continue, it will only worsen. However, despite the results that explain the causes and hazards of climate change, the public seems unwilling to participate in actions that could help reduce the effects of climate change. When dealing with climate change and addressing its effects, there is a wait-and-see preference where many prefer to, in a sense, wait till it becomes what they consider a "real problem" where it is evident that there is an issue. However, as pointed out by multiple authors, it can be problematic due to the long delays between detecting a problem and implementing corrective actions [34]. In the end, disciplinary action might not be enough if implemented when climate change has progressed past the mitigation point.

As all barriers and misconceptions are identified, a proper strategy using education and outreach activities is needed to address them and help reduce the effects of climate change. Early implementation in education could be the key to helping increase understanding and spread information to future generations who will likely have to deal with the consequences of the current lack of action. Engineers now and future engineers are the basis to help solve the effects of climate change on the current population and the answer to developing solutions that can become the basis for the prevention of consequences of climate change. If engineering students or students, in general, are provided with an education that can address climate change, it can give a foundation to help prevent misconceptions early on or at least deter misconceptions from continuing to grow, thus hindering climate change action. Milovanic, Shealy, & Goodwin (2022) surveyed engineering students and determined that only 30 percent understood climate change's specific causes and methods. However, they did not wholly erase misconceptions; college courses and scientific publications positively affected students' knowledge [35].

Additionally, the sources of information, such as social media and family/friends' opinions, negatively impacted the understanding of climate change compared to literature, courses, and information presented by scientists. Compared to the older generation, young people often consume all their news from social media, which shapes who they are, what they believe, and how they identify themselves. Introducing a climate change curriculum early on can help provide them with additional credited sources that help shape their knowledge and understanding. As engineers, if they choose to focus on addressing the climate change effects, it is essential they fully understand and gets rid of misconceptions to not only develop solution but be able to present the information they find to the community and be able to teach and provide them with information that will allow individuals to become adequately educated so they can take preventive actions to address the effects of climate change. To obtain a picture of the needs and wants of a community, we need to hear from the community. This can be achieved through survey distribution, one-on-one communication, or focus groups. A survey for this study allowed for the investigation of perceptions, knowledge, and possible willingness to participate.

Chapter 3. Methodology

In this study there was a combination of methods to create a hydrological model along with a questionnaire. Each part of this study's method was selected to obtain missing parameters and aid in the building of a model that provided volumes of water generated in the area. The methods included a GIS-based approach seen in previous studies [27], [30], [36] a HEC-HMS model [23], [37] and a mixed-methods survey.

Soil Conservation Service- Curve Number (SCS-CN) Land Cover Method

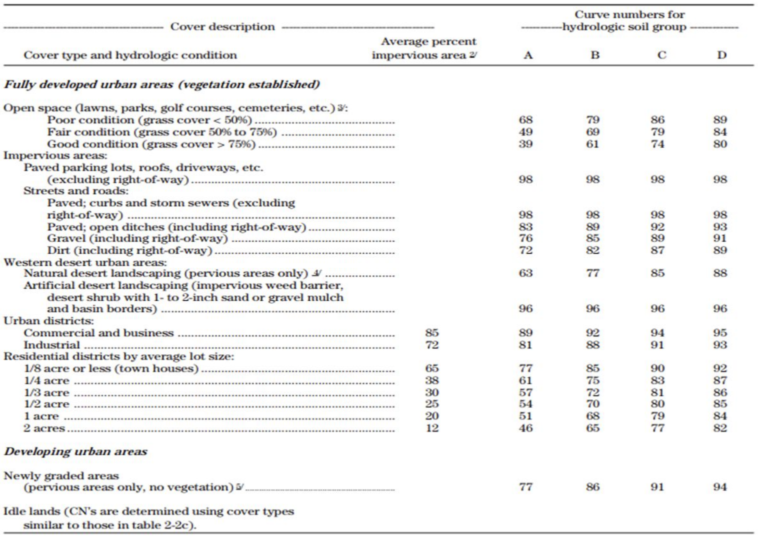
The United States Department of Agriculture's Natural Resources Conservation (NRC) has a designated manual for urban hydrology for smaller watersheds known as SCS-CN [38]. to the NRC, SCS-CN is a simplified procedure to calculate storm runoff volume as well as peak rate of discharge. Utilizing the information generated from the land cover analysis in GIS, some variables are obtained to start calculations.

The USDA refers to an "urban watershed" as a watershed where impervious surfaces primarily cover the area. From a residential standpoint, we are referring to the impervious areas such as roads, sidewalks, and parking lots. Typically, records are hard to find and even harder to generate for smaller drainage areas such as residential properties. By considering urbanization, we become aware of standard behavior expected during a storm. This project aims to quantify the volume of water generated during various rainfall scenarios. The most common behavior for highly urbanized areas is a slow infiltration rate; the lack of grassy areas or open space sections heavily hinders the rate of infiltration and when the water accumulates, the runoff has nowhere to travel to, and it can aid in sunny-day flooding.

The SCS-CN land cover uses the curve number (CN) to estimate runoff from storm rainfall. The curve number is dependent on land characteristics, depending on the cover type, and hydrologic conditions; there are two categories (1) Fully Developed Urban Areas (Vegetation established) and (2) Developing Urban Areas. Each class will have a corresponding curve number for a hydrologic soil group (A-D). The "SCS Urban Hydrology" provides existing flow charts for Small Watersheds (See Appendix)," which will help determine the correct method to develop the Composite CN. To calculate the CN, it is necessary to know the hydrologic soil group in the area. Hydrologic soil groups are based on estimates of runoff potential. Soils are assigned to one of four groups according to the water infiltration rate (A, B, C, or D).

Each weighed CN is calculated using Equation 1, using the data obtained from the Web Soil Survey and area information for each land type. The corresponding CNs will be used to obtain the weighed CN once the area for each sub-basin is calculated during the GIS- based analysis as seen in Figure 3.1.

$$CN = \frac{\sum CN_i \times A_i}{\sum A_i} \tag{1}$$



Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area [2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

Figure 3. 1 Runoff Curve Number for urban areas (Source: SCS Manual pg. 2-5)

From the CN, the maximum retention can also be calculated. Maximum Retention (S) relates to soil and cover properties of the watershed and the relationship with the curve number; CN is evaluated as follows:

$$S = \frac{1000}{CN} - 10 \tag{2}$$

Potential maximum retention represents infiltration after runoff has started in an area of interest. Since the slope of each site was obtained in ArcGIS, the remaining variable to be calculated to get lag time is hydraulic length. Hydraulic or flow length refers to the flow path that "runoff" would take from the most distant point in the watershed to the watershed outlet. The travel time for the water to move along the hydraulic path will be calculated using equation (3) for lag time.

$$T_{LAG} = \frac{L^{0.8}(S+1)^{0.7}}{1900Y^{0.5}} \tag{3}$$

Where:

L= Hydraulic Length (ft)

S=Maximum Retention (in.)

Y= Watershed Slope (%)

GIS-Based Approach

It is a very tedious process to calculate the area and type of catchment along with the corresponding parameters for hydraulic calculations; hence, the GIS approach was adopted. The outlined steps followed can be observed in Figure 3.2. The resolution type and spatial extent must allow for the digitization of an image where land cover type in a residential area can be visually examined, the imagery for this analysis was obtained from the NOAA National Agriculture Imagery Program (NAIP). The specification of the imagery has a total of four bands with a radiometric resolution (bit) of 8- and 1-meter resolution. The size of interest was outlined and was found to lie within two separate rasters from the NOAA database; creating a mosaic of the raster dataset was necessary. This will be useful as the analysis proceeds to ensure a single raster dataset when generating the land cover map. The next step was to use the "Extract by Mask," which extracts the cells of a raster that correspond to the areas defined by a mask, in this case, the overall AOI. The purpose of doing so is only to have information for the region within the environment mask an input mask; this is useful to ensure the analysis is only completed for the study area.

Once the specific area of interest is imported into the ArcGIS interface, the next step is to determine what land cover classes will be of interest; in this case, since we are interested in the analysis of a primarily residential area, the general land cover classes are (1) open space, (2) roof area and (3) paved areas. This specific breakdown was selected due to the need for a record of the roof areas as a type of surface for the land cover map. For the rainwater harvesting analysis, the open space will help get an idea of areas of greenery that infiltrate some water. At the same time, the paved areas are also needed for the land cover method analysis.

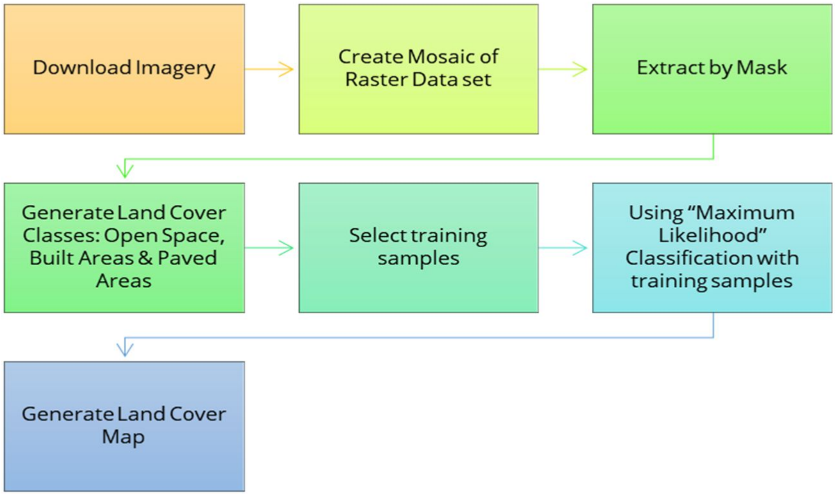


Figure 3.2 Steps to create a land cover map in ArcGIS.

Two main classification methods can be used, supervised or unsupervised. Supervised is a machine learning approach using labeled datasets (training samples) to classify data accurately by selecting sample pixels in images of specific classes. Unsupervised classification in which the "computer" or ArcGIS, in this analytical case, is allowed to determine which classes are presently based on statistical differences in the pixel's spectral characteristics.

The study area is relatively large; thus, the supervised method was selected to obtain higher accuracy in the classification process, in which the training sites are the basis for accuracy. Based on the land cover breakdown (ex. open space or roof) a schema was created to serve as the classes in the training samples manager. The class breakdown starts with two parent classes: Impervious and Pervious. The impervious parent class refers to all land cover that doesn't retain any water and includes the following classes: (1) Roof Areas, (2) Paved Areas (Sidewalks/Driveways), (3) Streets and (4) Pools. The pervious parent class pertains to all land types that allow for infiltration, such as (1) Bare Earth, (2) Greenery (Trees/Grass) and (3) Open Space. For each class created, various drawing tools can be used to generate polygons over bodies in a study related to each class; the more samples are collected, the higher the accuracy will be during the classification process. Once training samples have been collected, each land cover type can be saved as a shape file for later classification.

The designated method for classification will be pixel-based using the Maximum Likelihood classifier. This classification method assumes statistical information for the classes in each raster band is "normally distributed" and then calculates where a pixel belongs from the specified categories based on probability. Ultimately, the pixel is classified as the class with the highest chance. Once the classification process was complete, a land cover map was generated. There are various tools available to revise a classified raster, such as the "Reclassifier Tool", which allows for the visual inspection of the pixels in each class, based on the pictorial review, to view any incorrect pixels in each class, in which they can be reclassified and included in the correct land class. Additionally, similar classes can be grouped into a generalized class. As specified earlier, each class was designated a parent class, either pervious or impervious. This tool will generate a new map with two primary classes where areas considered pervious or impervious areas would be visible and aid in the land cover assessment using hydrological formulas.

From the maps created, connecting the generalized land cover map to the 22 watersheds was necessary to quantify how much area in each basin falls into any of the six specified classes. A cross-tabulated area table between two datasets (Land Cover Classification and Watersheds) is created by tabulating areas in the Spatial Analyst toolbox. This method was also followed to tabulate the area at a parcel level to determine the total size of each class at an individual level for each home in the area. A secondary tool to join raster datasets, such as elevation or slope raster zonal statistics, was performed to summarize a raster's values within the zone of another dataset.

Impervious and Pervious Classification

As previously mentioned, impervious surfaces are any surface that prevents infiltration, leading to an overall increase of water flow on land and can increase peak floods. On the other hand, pervious surfaces refer to any surface that allows water percolation into the underlying soil. In the initial land classification, the parent classes were designated as such from the start, so a secondary map was created using the tool to merge categories. The land cover classification into the two categories can be observed in Figure 3.3. Apart from the map generated, it was also essential to determine how much impervious percentage was present in each parcel and each watershed. Using similar methods to tabulate area for the individual classes, the total size of the impervious and pervious surface was obtained then the percentage was calculated by dividing the impervious area over the entire region.

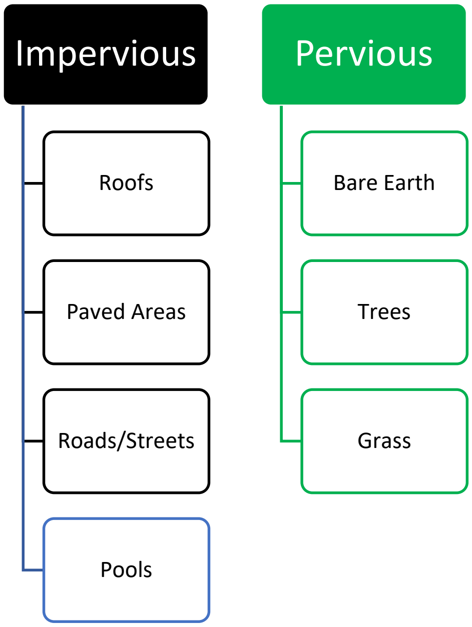


Figure 3.3 Impervious and pervious classification of land classes.

Accuracy Assessment

Once the classification was completed, an accuracy assessment was created using that raster dataset of the classified image to further validate the accuracy. The validation method was done in the following sampling strategies: (1) Equalized Stratified Random, and (2) Random. Once each evaluation was completed, a confusion matrix was generated for each sampling strategy. A confusion matrix presents a summary of the prediction results of classification results, including U_Accuracy and P_Accuracy [39]. The U_Accuracy represents users' accuracy which is errors of commission that represent a fraction of values that were predicted to be a part of the class selected but are not part of the class and is calculated by dividing the total number of classified points that agree with the reference date by total classified points. The P_Accuracy represents producers' accuracy or errors of omission where the fraction is of values that belong to a class but were predicted to be a part of a different class. Equalized Stratified Random, where points are randomly generated but, the same points are generated for each class and the Random assessment type where points are just randomly generated. A Kappa coefficient is also calculated, a ratio of the agreement between the classification and the truth values. The coefficient ranges from 0 to 1 with the value of 1 being representative of a perfect agreement [39]. Completing the accuracy assessment and results from confusion matrix helps verify that the land cover map generated accurately represents the actual raster and the accuracy of the parameters calculated using that information.

HEC-HMS Modeling

HEC-HMS allows for hydrological simulation, using different specifications to quantify the volume generated in various scenarios. Using the information generated during the land cover analysis to calculate the hydrologic parameters, a model was created in HEC-HMS. In the ArcGIS process, 22 watersheds were delineated; in HEC-HMS, these will be the "sub-basins." Each sub-basin requires parameters previously calculated using formulas from the Soil Conservation Service- Curve Number Method (SCS-CN), also previously referred to as the TR-55 Method. The parameters needed will depend on the Loss and Transform method specified; in this case, since all calculations were done following the SCS-CN procedure, the SCS Curve Number will be selected as the Loss Method, while the Transform method will be denoted as "SCS Unit Hydrograph. Once these changes have been made, the Curve Number and the Lag

Time (min) will be inputted. This process was repeated for all 22 subbasins until all information was included. Additionally, the outline of all the watersheds created was imported into the program to aid in creating a schematic that visually represents each sub-basin.

Once the basis of the model was created, it was necessary to utilize other tools within the program to run a simulation. The junction tool within the system allows for the combination of multiple basins, enabling the accumulation of flows from each subbasin to be quantified at a point in common. Depending on the basin and the junction assigned to it, it was noted where the "water" would be headed by stating the junction's name in the sub-basins downstream section.

Once the basin model was finalized, a meteorological model called "Met 1" was created. The type of precipitation that can be implemented in the model includes frequency storms, gage weights, or even a hypothetical storm; the data for this project is obtained from the El Paso Drainage Manual [40], so for this case, Frequency Storm was selected. To connect the meteorological event to the previously developed basin model, it was necessary to include all subbasins in the model for the meteorological analysis. In the frequency format option, the following parameters need to be included: (1) Storm Duration, (2) Intensity Duration, and (3) Depth (in). Depending on the storm duration, how many depths (in.) values need to be inputted in the program; in the case of a 1 Day storm duration, depth values would need to be implemented during that length. The intensity duration specifies when the depth values need to start.

In the El Paso Drainage Design Manual (DDM) [40] the Intensity-Duration-Frequency Data depends on the AOI within the Drainage Regions. The AOI falls within the Central drainage region. Thus, the Total Rainfall Depth (inches, as well as Central Intensity Equations, will be used for this project. The corresponding values of total rainfall depth for the city were recorded for the following storms: 1-Year, 2-Year, 5-Year, 10-Year, 25-Year,50-Year,100-Year, 250-Year, and 500-Year storms.

The last model needed to run a simulation is Control Specifications, in which a start date, end date, start time, and end time are added for the model to run. This date can be any; it is just needed for the storm scenario to run. When each component, basin model, meteorologic and control specs are created, the simulation manager can be added to make "runs" or calculations for the area. A run will be completed for each frequency storm since only one type of meteorological data is allowed per run. Still, the same basin model and control specification will be used for all runs. In the event of an error, when "compute" is selected, the simulation will not run, and a window will display any errors preventing the model. If the model runs smoothly in this case, a global summary table of the results will be created; in this summary table, the elements of the basin model are displayed by hydrological placement, which means details are listed based on their place from top to bottom and depending on their downstream connections. In this model, the last element, where all basins are connected, should have the highest value to quantify the total volume generated.

RWH Survey and Deployment

A 37-question survey was crafted to help understand the perception and understanding of Rainwater harvesting and El Pasoans' opinions on climate change and how that affects their opinions and willingness to participate. The IRB-approved survey was deployed in English and Spanish to ensure the language was not a barrier when distributing the study due to El Paso's predominantly Hispanic population. The target population was residents within the Area of Interest in El Paso, meaning anyone living in one of the residential properties. The questionnaire was distributed primarily online with some in-person distribution. There was a total of 32 closed-ended questions and 5 open-ended questions.

The survey was designed to gauge a particular community's perceptions and opinions on RWH and their willingness to participate in adoption. Variations in public perception in different geographical locations are considerable; a perception study is one of the most effective tools for eliciting public opinion [41]. The survey is composed of six main sections (1) perception of RWH, (2) usefulness of RWH, (3) willingness to participate and pay, (4) demographic background, (5) climate change perception, and (6) site properties.

The introductory section of the survey deals with knowledge of RWH, such as prior experience and how important they consider RWH to be when dealing with local issues such as street flooding. The following section deals with the possible use of collecting rainwater in their daily lives. Next is their willingness to participate and the range they are willing to pay for an RWH system, along with their preferred method in which they participate (e.g., Passive, or active). Apart from the perception and willingness to participate, we wanted to investigate the participants' demographic background and how it affected their answers; parameters such as income, household size, education level, ethnicity, and age were also recorded. The next survey sections entail climate change perception and considerations/modifications they make due to climate change concerns. Lastly, the survey concludes with a qualitative, open-ended section regarding the site and home properties to determine the feasibility of RWH implementation.

Chapter 4. Results

The area of interest was in a northeast El Paso, Texas, neighborhood. El Paso is considered a high desert with high temperatures and receives, on average, 9 inches of rain annually. Summer monsoons bring heavy rains from June through September. The inundation caused by rains during, and outside monsoon season can put communities at risk of flooding, especially in highly urbanized sections where large amounts of runoff are generated. Following the methodology described above and the results are described below.

Soil Conservation Service: Curve Number (SCS-CN) Land Cover Method

Based on information from the Web Soil Survey, the AOI falls directly on Hydrologic Soil Group A or B. Group A soils have a high infiltration rate, are characterized by their low runoff potential, and are composed of well-drained to excessively drained sands or gravelly sands. Group B. soils have a moderate infiltration rate when thoroughly wet, moderately deep, profound, moderately well-drained, or well-drained soils with a reasonable water transmission rate (see Figure 3. 1)

The first step was to verify if we could use the SCS method for calculations. We utilized a flow chart and table from the SCS manual to determine the curve numbers for our areas (See Appendix). The appropriate information was selected to calculate the pervious CN (Figure 3. 1). Each subbasin will have a corresponding Curve Number (CN) to characterize its runoff potential based on soil group classification and land cover type. Runoff Curve Numbers for urban areas were chosen, then depending on the land classification of the site, such as open space (e.g., poor condition, fair condition, and good condition) or other cover types such as paved areas (e.g., parking lots, roofs, driveways, or streets) along with the corresponding hydrologic soil group a curve number was selected. This analysis only focused on CN for soil groups A or B (Figure 4.1).

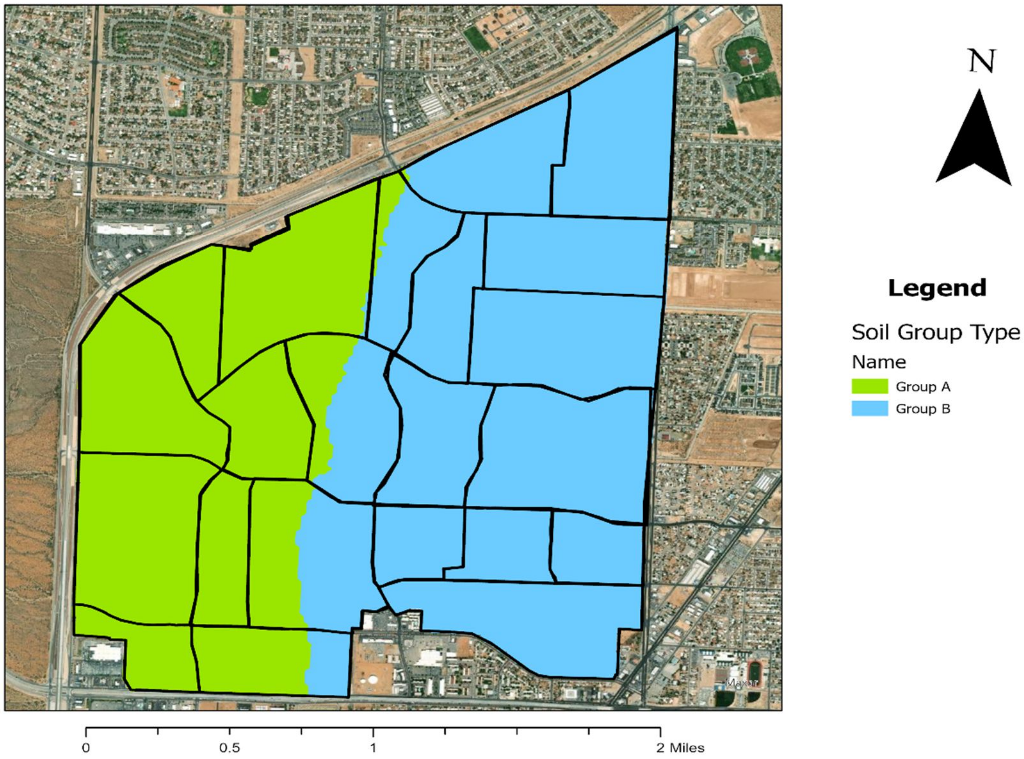


Figure 4.1 Hydrologic Group classification based on Web Soil Survey data.

GIS-Based Approach

Once the data was imported into a GIS program, various methods were applied to obtain the remaining parameters necessary to complete the hydrological calculations. We obtained each watershed's total area and made a distinction of either pervious or impervious.

The typical range for curve number is from approximately 30 (representative of permeable area with high infiltration rates) to 100 (for a pervious high impervious area with minimal to no infiltration). For the sites in AOI, the CN would be represented by a value ranging from 52 to 72 depending on the hydrological group for the site and if there is an impervious site it would be represented by a value of 98 signifying paved areas such as parking lots or driveways or roofs. The results obtained can be observed in Table 4.1.

Table 4.1 Hydrological Soil Group and Weighted CN for each Sub-basin.

Subbasin Name	HYDROLOGIC SOIL GROUP	Pervious (OP) CN	Impervious (Paved) CN	Open Space Area (sq. meters)	Paved Areas (sq. meters)	Total Subbasin (sq. meters)	Weighed CN
A-1	GROUP A	52	98	82668	138690	221358	81
A-2	GROUP A	52	98	250990	505323	756313	83
A-3	GROUP A/B	61	98	133891	245193	379084	85
A-4	GROUP A	52	98	96775	187431	284206	82
A-5	GROUP A/B	61	98	286470	367428	653898	82
A-6	GROUP A	52	98	201689	397068	598757	83
A-7	GROUP A	52	98	169558	204396	373954	77
A-8	GROUP A/B	61	98	234380	299596	533976	82
A-9	GROUP A	52	98	113948	198740	312688	81
A-10	GROUP A	52	98	293680	422602	716282	79
A-11	GROUP B	70	98	116368	208966	325334	88
A-12	GROUP B	70	98	223681	408346	632027	88
A-14	GROUP B	70	98	94908	146948	241856	87
A-15	GROUP B	70	98	123284	121968	245252	84
A-16	GROUP B	70	98	91309	134356	225665	87
A-17	GROUP B	70	98	248587	404140	652727	87
A-18	GROUP B	70	98	181740	284608	466348	87
A-19	GROUP B	70	98	194671	324609	519280	88
A-20	GROUP B	70	98	230750	110127	340877	79
A-21	GROUP B	70	98	315416	366229	681645	85
A-22	GROUP B	70	98	151937	277062	428999	88
A-23	GROUP A/B	61	98	309353	473314	782667	83
AO1						10388446	

Areas composed of higher pervious area, with a lower CN, generated an overall lower weighted curve number. The lower values correspond to an increased ability of the soil to retain rainfall, thus producing less runoff. The higher CN signifies more runoff as most rain will become runoff due to minimal losses. This was attributed to the many impervious areas that accumulate water and have little infiltration. As observed in Figure 4.2, places in the northeast corner and southeast side have the basins with the highest CN (86-88), while areas in the southwest side and middle of the AOI have lower CN (77-79).

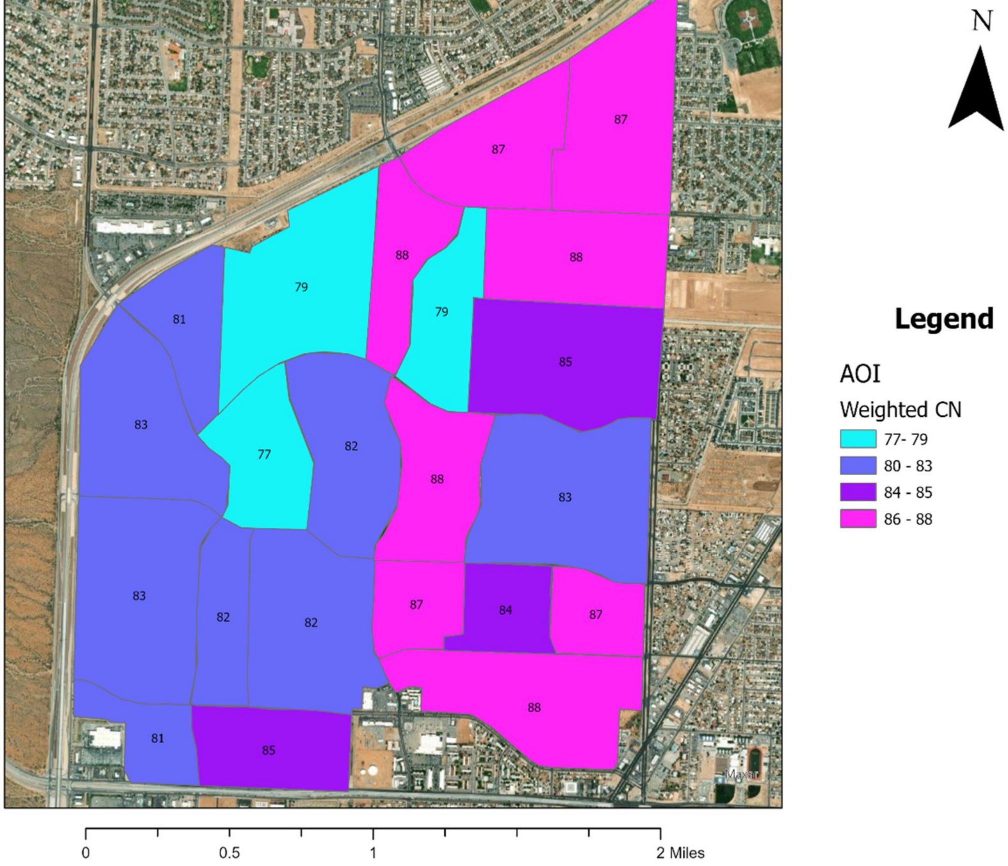


Figure 4.2 Weighted CN for each Sub-basin.

Maximum retention (S) was calculated using the CN obtained from the GIS analysis using equation (2). The results can be seen in Figure 4.3, where the areas in yellow represent the highest maximum retention. This means the potential infiltration after runoff will be anywhere from 2-3 inches. It is important to note that the same area with the highest S values is the same area with the lowest CN.

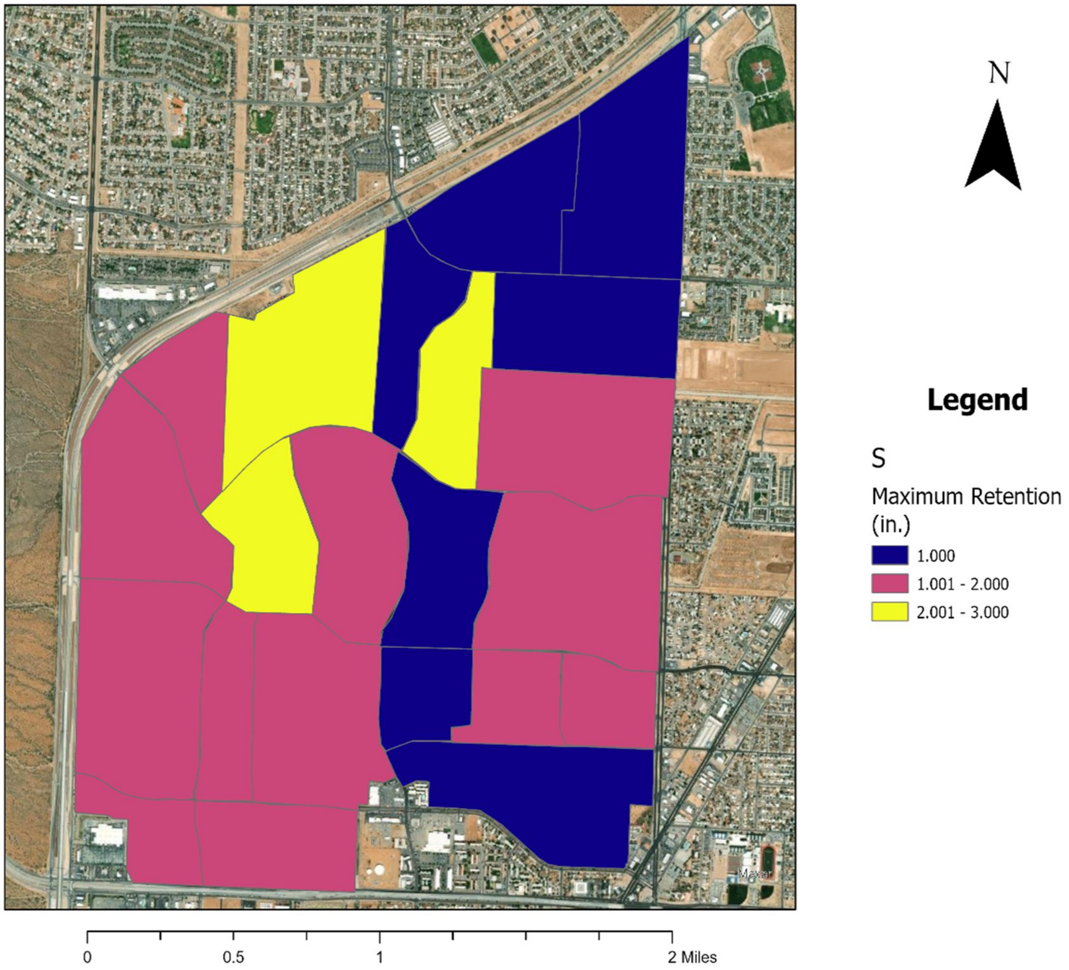


Figure 4.3 Maximum Retention (in.).

An elevation map was generated, and it was observed that it sloped downwards towards the southeast area, with the highest elevation coming in at 4,108 ft on the southwest side of the study area (Figure 4.4). Additionally, from the elevation, the slope (percent rise) was calculated, the percent rise shows areas with steeper slopes and will be used when calculating the slope % for the hydrological parameters (Figure 4.5). Zonal statistics were used to obtain the values of the raster within the zone of the parcels (See Appendix). The slope obtained was averaged for each individual sub-basin, as seen in Figure 4.6, to get the watershed slope % (Y) for lag time calculation.

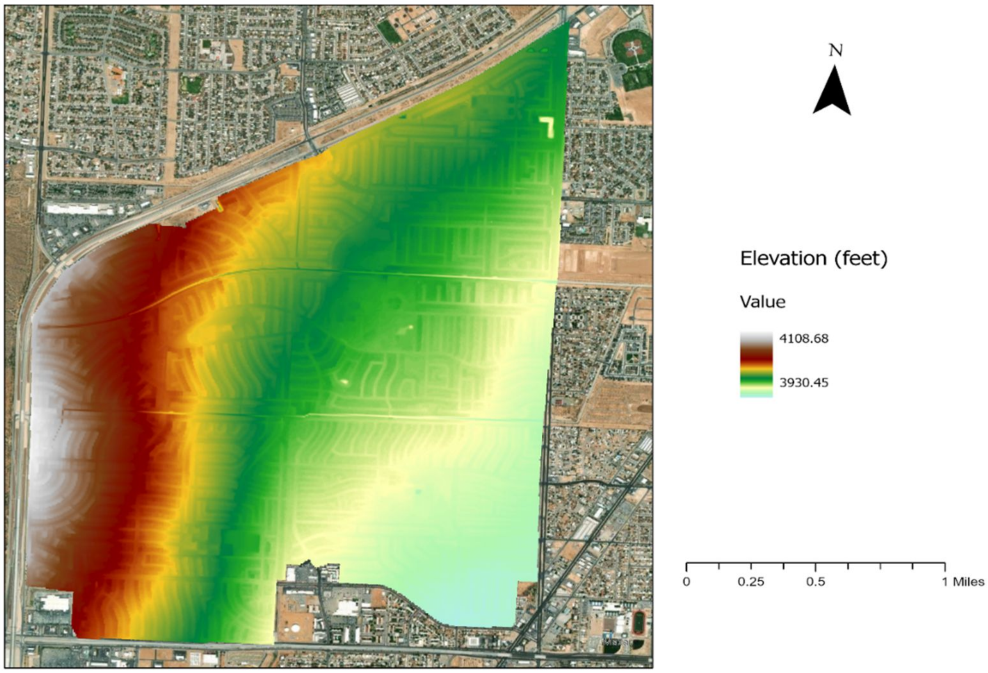


Figure 4.4 Elevation Map of Study Area.

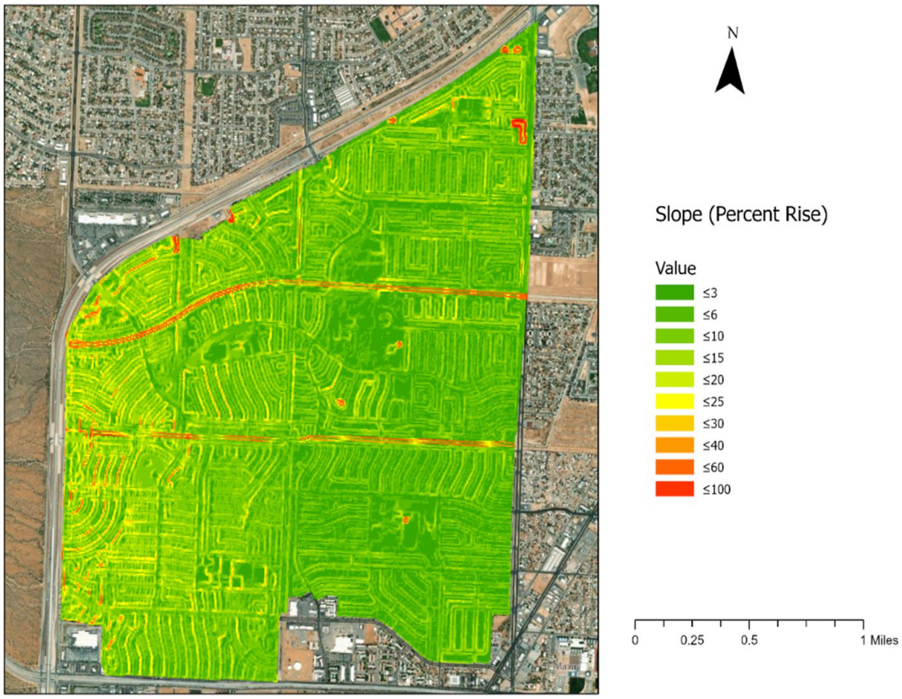


Figure 4.5 Slope (Percent Rise) of the study area.

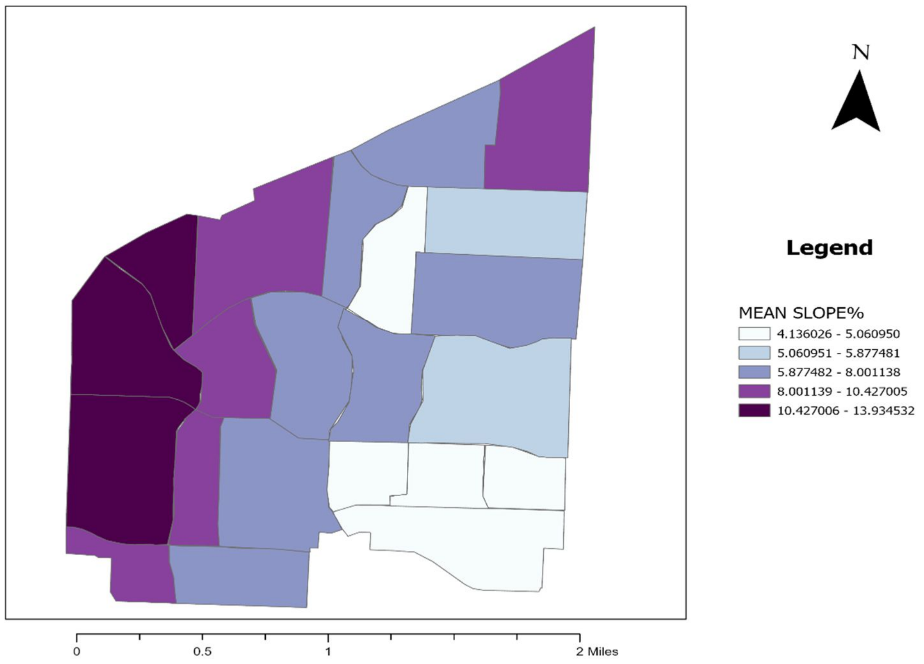


Figure 4.6 Mean Slope of Each Subbasin.

Another parameter needed for calculating lag time is the longest flow path or hydraulic length. The hydraulic length represents the most extended path water can take once it enters until the water exits. This was obtained from GIS and recorded in Table 4.2. Once all three parameters were obtained: hydraulic length, maximum retention, and slope, the lag time was calculated using equation 3.

Table 4.2 Hydrological Parameters obtained from GIS and Calculated Parameters.

Sub basin Name	**Mean Slope (%)**	**Maximum Retention (inches)**	**Hydraulic Length (meters)**	**Hydraulic Length (feet)**	**Lag Time (Hours)**	**Lag Time (Minutes)**
A-1	10.43	1.77	941	3086.86	0.21	12.35
A-2	12.35	1.53	1572	5156.79	0.27	16.08
A-3	7.55	1.23	1021	3349.29	0.22	13.30
A-4	9.86	1.53	1154	3785.58	0.23	14.04

Sub basin Name	Mean Slope (%)	Maximum Retention (inches)	Hydraulic Length (meters)	Hydraulic Length (feet)	Lag Time (Hours)	Lag Time (Minutes)
A-5	7.45	1.79	1335	4379.33	0.32	19.41
A-6	13.93	1.64	1333	4372.77	0.23	13.66
A-7	8.94	2.45	1013	3323.05	0.27	16.49
A-8	7.27	1.79	1206	3956.16	0.30	18.11
A-9	12.73	1.67	1375	4510.55	0.25	14.76
A-10	9.34	2.16	1712	5616.04	0.39	23.12
A-11	7.52	1.03	1252	4107.06	0.25	14.71
A-12	5.06	0.98	1567	5140.39	0.35	21.09
A-14	4.46	1.08	668	2191.31	0.20	11.76
A-15	4.14	1.25	795	2607.92	0.25	14.82
A-16	4.48	1.19	853	2798.18	0.25	14.79
A-17	8.47	0.88	1606	5268.32	0.27	15.99
A-18	7.39	1.01	1567	5140.39	0.29	17.59
A-19	5.79	0.94	1281	4202.19	0.28	16.53
A-20	4.77	2.29	1228	4028.33	0.43	25.51
A-21	6.91	1.35	1345	4412.14	0.30	17.97
A-22	6.77	1.06	1147	3762.62	0.24	14.59
A-23	5.88	1.64	1387	4549.91	0.36	21.72

Apart from SCS parameters that were obtained using GIS, the landcover map (Figure 4.7) was generated using the steps in in Figure 3.. The land cover map was created using trained datasets (training samples) that were representative of each class (1) Roof, (2) Open Space, (3) Roads, (4) Greenery, (5) Pools and (6) Paved.

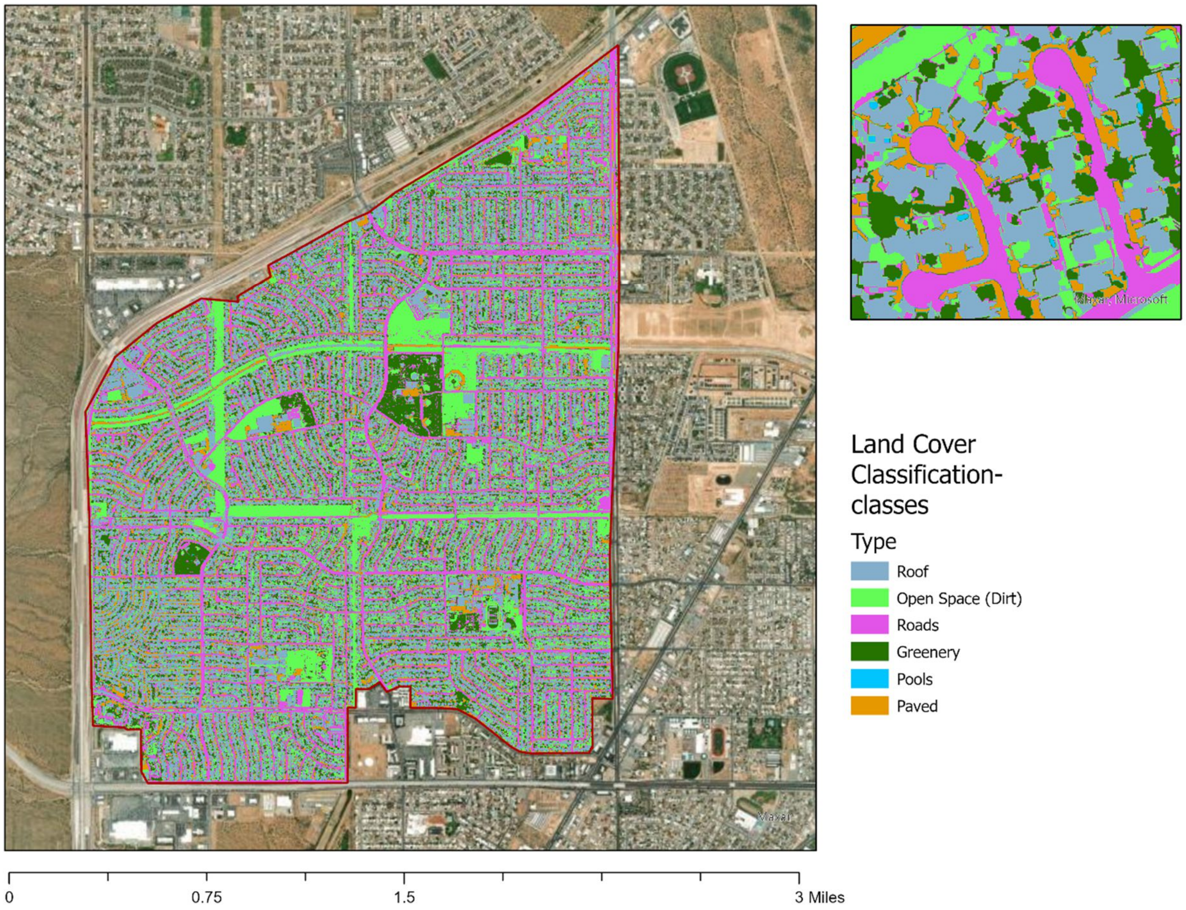


Figure 4.7 Land cover map.

Impervious and Pervious Classification

The area of each land type was recorded ex. roof, paved surfaces, and open space were classified as pervious or impervious. Then the total area of impervious percent was obtained then divided by the total area of the parcel (Figure 4.8) or the total watershed area (Figure 4.9)

Based on the results generated in Figure 4.8 it is difficult to visualize where the higher impervious percentage properties lie; upon closer inspection through zooming in, there is a range in which most properties have anywhere between 36-60%, which means that over 30% of land in most parcels is impervious which will generate more runoff than areas with a lower impervious percentage. Figure 4.9 is a more generalized map in which the impervious ratio is calculated for a larger size, such as the 22 watersheds. It paints a much clearer picture of areas with a higher impervious percentage. More specifically, places in the south/southwest region near the Franklin Mountains will have more water runoff due to a higher impervious rate of 60%-75%. In Figure 4.10 the % pervious is also calculated, the map along with Figure 4.9 shows a correlation with the high % impervious areas being the same area that have low % pervious. Apart from the visual product's benefit, obtaining those impervious percentages is necessary to conduct SCS calculations.

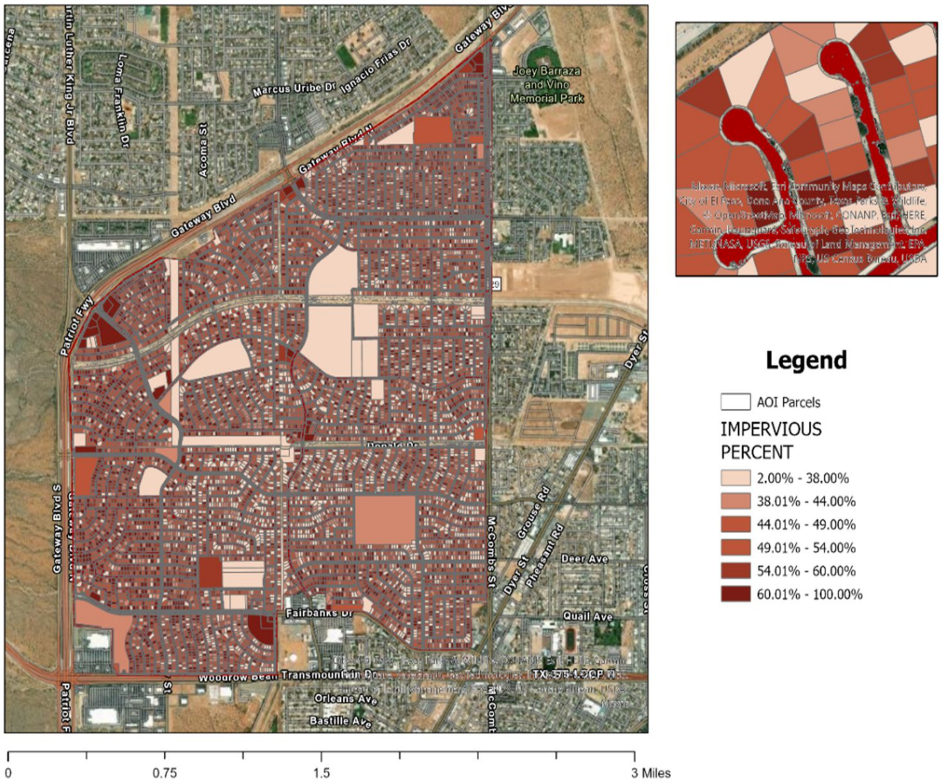


Figure 4.8 Impervious % by Land Parcel.

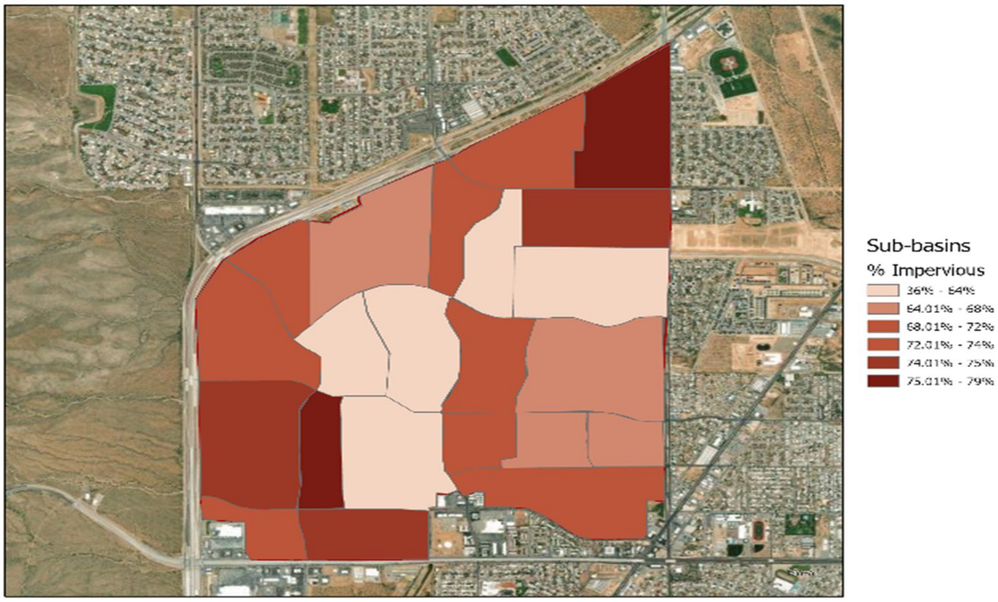


Figure 4.9 % Impervious by Subbasin

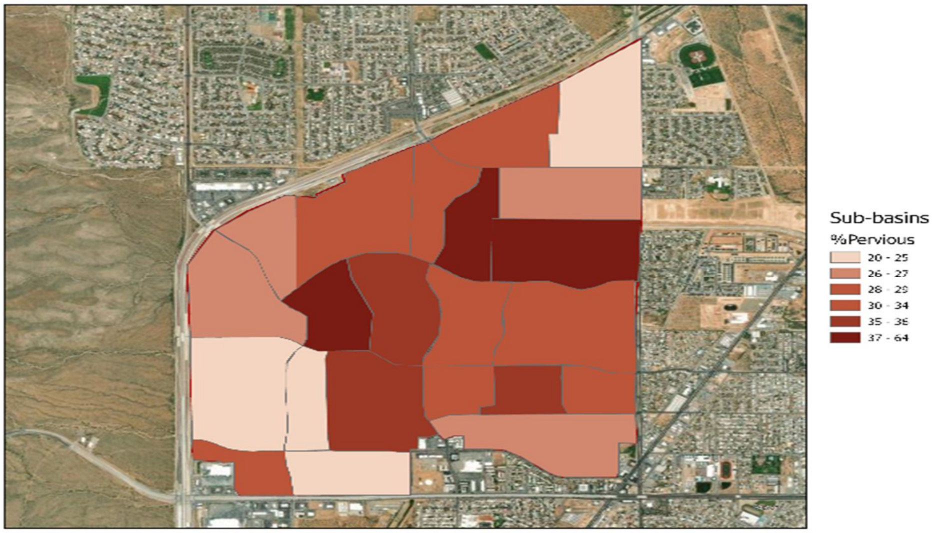


Figure 4.10 % Pervious by Subbasin.

Accuracy Assessment

Once the remote sensed data was finalized, such as the assessment of pixels to determine what pixel belonged to each class (1) Roof, (2) Open Space, (3) Roads, (4) Greenery, (5) Pools, and (6) Paved, it was also necessary to determine the accuracy of the algorithm in the classification. An accuracy assessment was performed to verify the quality of the information in this case, the category of the land types that were then utilized to complete the calculation and further analysis.

Completing the accuracy assessment and the results from confusion matrix help verify that the land cover map was generated accurately and is representative of the actual raster and allows for the continuation onto the land cover analysis. The following verification methods were completed to observe users' and producers' accuracy: (1) equalized stratified random and (2) random. Equalized stratified random is where after random points are created, they are randomly distributed in each class, each class will have the same number of points.

An initial analysis was conducted to determine the validity of the training samples selected as seen Table 4.3, where all the values for user's accuracy and producer's accuracy were 1 as well as the kappa coefficient showcasing the accuracy of the training samples selected during the land cover classification. An analysis using random points using the raster dataset to obtain accuracy parameters was conducted to understand how well they represent the study area through statistical analysis (Table 4.4). As per the equalized stratifies random sampling the user accuracy ranges from 0.915 to 1, with the paved class having the lowest accuracy. In this case, the producer's accuracy was obtained by dividing the number of classified points that agree with reference data by the total number of reference points for each class. For the producer's accuracy the ranges are from 0.884 to 1. The value of the kappa coefficient is 0.93.

The random classification of the points generated where randomly distributed throughout the image, meaning each class had a different number of points unlike equalized stratified random. Following the same steps as for the equalized stratified random sampling, an initial analysis was conducted employing the random sampling for just the training samples where the user's accuracy and producers' accuracy along with the kappa coefficient were calculate to be 1, solidifying the accuracy of the training samples. To compare the classification of the classified image to the actual raster another analysis was completed. Through this sampling strategy the user accuracy ranges from 0.943 to 1 and producer accuracy values range from 0.82 to 1 and the Kappa coefficient is also found to be around 0.93 (Table 4.6). Both sampling strategies help assert the accuracy of the land cover classes and to utilize the data provided for other calculations.

Table 4.3 Accuracy Assessment (Equalized Stratified Random) of Training Samples

Class Name	**Roof**	**Open Space**	**Roads**	**Greenery**	**Pools**	**Paved**	**Total**	**User Accuracy**	**Kappa**
Roof	83						83	1	0
Opens Space		83					83	1	0
Roads			83				83	1	0
Greenery				83			83	1	0
Pools					83		83	1	0
Paved						83	83	1	0
Total	83	83	83	83	83	83	498	0	0
Producer Accuracy	1	1	1	1	1	1	0	1	0
Kappa	0	0	0	0	0	0	0	0	1

Table 4.4 Accuracy Assessment (Equalized Stratified Random) of Random Points

Class Name	**Roof**	**Open Space**	**Roads**	**Greenery**	**Pools**	**Paved**	**Total**	**User Accuracy**	**Kappa**
Roof	77	0	1	0	0	5	83	0.927711	0
Open Space	1	79	2	1	0	0	83	0.951807	0
Roads	0	1	76	1	0	5	83	0.915663	0
Greenery	0	3	1	79	0	0	83	0.951807	0
Pools	0	0	0	0	83	0	83	1	0
Paved	2	0	5	0		76	83	0.915663	0

Class Name	Roof	Open Space	Roads	Greenery	Pools	Paved	Total	User Accuracy	Kappa
Total	80	83	85	81	83	86	498	0	0
Producer Accuracy	0.9625	0.951897	0.894118	0.9735089	1	0.883721	0	0.943775	0
Kappa	0	0	0	0	0	0	0	0	0.93253

Table 4.5 Accuracy Assessment (Random) of Training Samples

Class Name	Roof	Open Space	Roads	Greenery	Pools	Paved	Total	User Accuracy	Kappa
Roof	142						142	1	0
Open Space		89					89	1	0
Roads			98				98	1	0
Greenery				67			67	1	0
Pools					10		10	1	0
Paved						96	96	1	0
Total	142	89	98	67	10	96	502	0	0
Producer Accuracy	1	1	1	1	1	1	0	1	0
Kappa	0	0	0	0	0	0	0	0	1

Table 4.6 Accuracy Assessment (Random) of Random points

Class Name	Roof	Open Space	Roads	Greenery	Pools	Paved	Total	User Accuracy	Kappa
Roof	150	0	0	0	0	0	159	0.943396	0
Open Space	0	93	1	0	0	0	96	0.966937	0
Roads	3	1	104	0	0	0	111	0.952381	0
Greenery	1	1	0	60	0	0	63	0.951807	0
Pools	0	0	0	0	83	1	1	1	0
Paved	2	0	1	0		0	70	0.957143	0
Total	156	95	106	60	83	1	500	0	0
Producer Accuracy	0.961538	0.978947	0.981132	1	1	0.817	0	0.95	0
Kappa	0	0	0	0	0	0	0	0	0.935828

HEC-HMS Modeling

The model will reflect all 22 basins, five junctions were implemented into the design (Figure 4.11). Each intersection can quantify the flow of about 2-5 subbasins, where the last junction in the model is connected to all the junctions to quantify the total amount of volume generated.

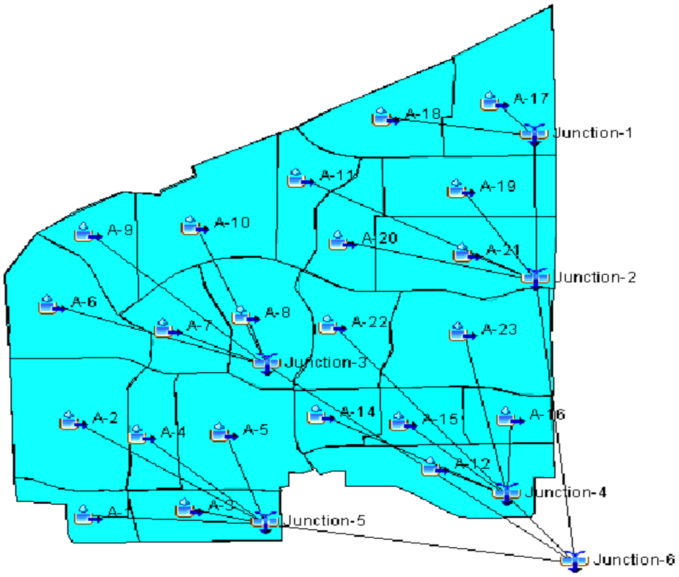
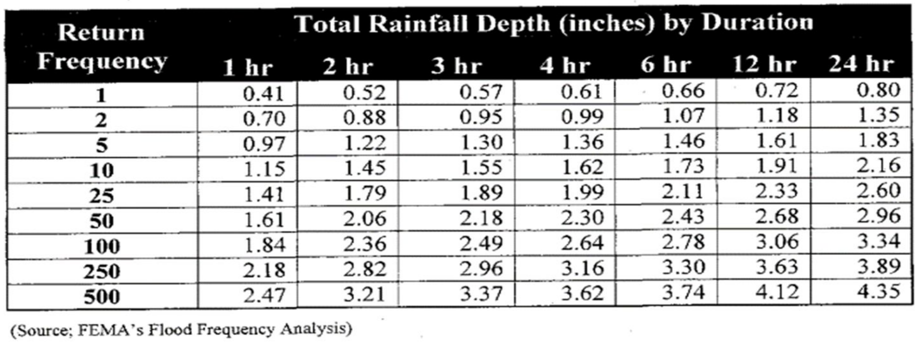


Figure 4.11 HEC-HMS Hydrological Model Schematic.

The computation process can be started once the basin model, meteorological, and control specifications are created and completed. Using the simulation manager allows for a “run” to be made. The only change in each run designed is the frequency of storm used, which will vary from 8 different storm frequencies (Table 4.7). The global summary table from each run generated will provide each element’s volume and peak flow.

Table 4.7 Central Duration Depth Frequency (Source: El Paso Drainage Manual June 2008 pg.11).



Return Frequency	Total Rainfall Depth (inches) by Duration						
	1 hr	2 hr	3 hr	4 hr	6 hr	12 hr	24 hr
1	0.41	0.52	0.57	0.61	0.66	0.72	0.80
2	0.70	0.88	0.95	0.99	1.07	1.18	1.35
5	0.97	1.22	1.30	1.36	1.46	1.61	1.83
10	1.15	1.45	1.55	1.62	1.73	1.91	2.16
25	1.41	1.79	1.89	1.99	2.11	2.33	2.60
50	1.61	2.06	2.18	2.30	2.43	2.68	2.96
100	1.84	2.36	2.49	2.64	2.78	3.06	3.34
250	2.18	2.82	2.96	3.16	3.30	3.63	3.89
500	2.47	3.21	3.37	3.62	3.74	4.12	4.35

(Source; FEMA's Flood Frequency Analysis)

Active Rainwater Harvesting Roof Catchment

In an urban setting, a neighborhood-sized watershed in which a home is to be considered a watershed, different home areas such as (1) Roof, (2) Grass/Open space, and (3) Driveways all make part of more extensive watersheds. The calculation of the area for each watershed was implemented into HEC-HMS. We also determined the number of homes in each sub-basin and recorded them in Table 4.8. For the implementation of active rainwater harvesting, the focus was shifted to the roof footprint area that was also individually obtained for each home that was part of each subbasin or watershed.

Table 4.8 Homes to be Considered in each subbasin.

Watershed	No. of Homes
A-1	139
A-2	643
A-3	396
A-4	293
A-5	579
A-6	407
A-7	275
A-8	436
A-9	264
A-10	624

Watershed	No. of Homes
A-11	276
A-12	694
A-14	282
A-15	113
A-16	273
A-17	690
A-18	560
A-19	579
A-20	37
A-21	554
A-22	442
A-23	779

For the initial analysis, each run uses the same basin model and its characteristics and control specifications. The only change made is the depth data included in the meteorological model. Each run generated using each of the eight frequency storms yielded the results in

Table 4.9. The smaller range of frequency storms such as 1- Year, 2- Year, and 5- Year are storms more likely to occur due to their high probability; the rainfall depths for a 5-year storm have a 20% probability of occurring. The rainfall depth from storms such as the 100- Year and 500-Year have a 1% and 0.2 % respectively of occurring. However, we want to quantify and determine the feasibility of using RWH even in the case of intense storm scenarios with a low probability of occurring. The peak discharge generated in a 1-Year storm is 23.2 cubic foot per second (cfs) compared to the peak discharge of 479.8 cfs for a 500-year storm. While the peak discharge for a 1-Year storm is much more manageable, the peak discharge for a 500-Year storm allows for the worst-case scenario to be considered.

Table 4.9 HEC-HMS Peak Discharge and Volume Results.

Frequency Storm	Peak Discharge (CFS)	Volume (AC-FT)
1-Year Storm	23.2	11.5
2-Year Storm	74.0	36.7
5-Year Storm	129.3	64.1

Frequency Storm	Peak Discharge (CFS)	Volume (AC-FT)
10-Year Storm	170.7	84.8
25-Year Storm	229.0	113.8
50-Year Storm	278.5	138.5
100-Year Storm	332.2	165.1
250-Year Storm	411.9	204.5
500-Year Storm	479.8	238.0

With the data obtained from including the area's characteristics, with no modifications for RWH implementation. We can utilize the data to determine the change if the RWH catchment would be implemented. To do so, it was necessary to consider the roof areas along with the average rainfall of the site.

The calculation of rainfall volumes is achieved through the following equation:

$$Total\ Rainwater = Catchment\ Area\ \times Avg. Rainfall\ \times\ 7.48\ \frac{gal}{ft^3} \tag{4}$$

The average rainfall typically reported in inches will be converted to feet and gallons to obtain the total rainfall volume collected. The catchment area will be used as the individual roof area for all the homes in each watershed. In the case of comparing the volume generated from storms that will be analyzed in HEC-HMS, analysis can be performed using the rainfall from a specific event in substitution to average annual rainfall. The volume being considered will be collected from a sloped roof surface; based on the material, a runoff coefficient is also included in the calculation. The more impervious an area and the higher the rain intensity, the higher the coefficient will be a material such as grass will have a coefficient as low as anywhere between 0.05 to about 0.35. The variation in numbers is significantly due to the quality of the soil and is dependent on location, as previously mentioned. Because the study area is in Texas, data from the TXDOT manual will be used to classify roofs with a coefficient of 0.75 to 0.95.

If 100% of the homes participated, all 9,335 roof areas would be considered for the catchment. Using the equation above, the amount of available harvested rainwater in gallons was calculated and then converted to ac-ft to compare and subtract from the total volume of water generated during the storm (Table 4.10). The same rainfall depth used in HEC-HMS was used to find the amount of harvested water in the equation. As the depth increases, the frequency of storm range increases, and the larger the subbasin area, the more rainfall can be captured.

Table 4.10 Total Rainfall Captured by Roof Areas by Sub-basin using Rainfall Depth from El Paso Drainage Manual.

SUB_BASIN NAME	1-YR (AC-FT)	2-YR AC-FT)	5-YR (AC-FT)	10-YR (AC-FT)	25-YR (AC-FT)	50-YR (AC-FT)	100-YR (AC-FT)	250-YR (AC-FT)	500-YR (AC-FT)
A-1	0.782	1.319	1.788	2.111	2.541	2.892	3.264	3.801	4.251
A-2	2.775	4.682	6.347	7.492	9.018	10.266	11.584	13.492	15.087
A-3	1.555	2.623	3.556	4.198	5.053	5.752	6.491	7.559	8.453
A-4	1.090	1.839	2.493	2.942	3.541	4.032	4.549	5.298	5.925
A-5	2.146	3.621	4.909	5.794	6.975	7.940	8.960	10.435	11.669
A-6	2.269	3.829	5.191	6.127	7.375	8.396	9.474	11.034	12.339
A-7	1.253	2.115	2.867	3.384	4.074	4.638	5.233	6.095	6.816
A-8	1.614	2.724	3.693	4.359	5.247	5.973	6.740	7.850	8.778
A-9	1.196	2.017	2.735	3.228	3.885	4.423	4.991	5.813	6.501
A-10	2.476	4.178	5.663	6.684	8.046	9.160	10.336	12.038	13.461
A-11	1.177	1.986	2.692	3.177	3.825	4.354	4.913	5.722	6.399
A-12	2.552	4.306	5.837	6.890	8.293	9.442	10.654	12.408	13.876
A-14	0.904	1.525	2.068	2.441	2.938	3.344	3.774	4.395	4.915
A-15	0.877	1.480	2.006	2.368	2.850	3.245	3.662	4.265	4.769
A-16	0.827	1.395	1.891	2.232	2.687	3.059	3.452	4.020	4.495
A-17	2.375	4.007	5.432	6.412	7.718	8.786	9.914	11.547	12.912
A-18	1.869	3.154	4.276	5.047	6.075	6.916	7.804	9.089	10.163
A-19	1.905	3.215	4.359	5.145	6.193	7.050	7.955	9.265	10.361
A-20	0.504	0.851	1.153	1.361	1.638	1.865	2.105	2.451	2.741
A-21	2.085	3.518	4.768	5.628	6.775	7.713	8.703	10.136	11.334
A-22	1.527	2.577	3.493	4.123	4.962	5.650	6.375	7.425	8.303
A-23	2.641	4.457	6.042	7.131	8.584	9.772	11.027	12.843	14.362

Degree of Implementation

Approximately 10-20% of rainwater is assumed to be lost due to evaporation; thus, it needs to be accounted for when considering the amount of water collected (Table 4.9). Assuming 100% of participation from all homes in this study, the volume of possible rainwater collected ranges from 29.118 ac-ft for the most typical storm (1-YR) and in the case of a 100-YR storm approximately 158.327 ac-ft of water can be collected through roof catchments **(**Table 4.11**).**

Table 4.11 Total Rainfall Captured By all roofs.

Frequency Storm	**Calculated Volume (AC-FT)**	**Volume Collected (Evaporation/travel) considered (AC-FT)**
1	36.397	29.118
2	61.420	49.136
5	83.258	66.607
10	98.272	78.618
25	118.291	94.632
50	134.669	107.735
100	151.958	121.566
250	176.981	141.585
500	197.909	158.327

When comparing the volume generated during each storm as well as the capacity of rainwater captured through roof catchment 100% of it can be captured for the volume of rainwater calculated to occur in the 1-Year, 2-Year and 5-Year storm scenarios. For the frequency storms with more substantial rain the percentage of rain kept off the streets decreased, for the storms with less likelihood to occur the 100-Year,250-Year and 500- Year storm the probability is 73.63%, 69.23% and 66.52 % respectively under the assumption that all 9,335 homes in the area participated (Table 4.12)

Table 4.12 Volume Kept off the streets (100% Participation).

Frequency Storm	Runoff Volume Generated (HEC-HMS Model) (AC-FT)	Storage Capacity of Roof Areas Considering Abstractions (AC-FT)	% Kept off the Streets
1-YR	11.5	29.118	100.00%
2-YR	36.7	49.136	100.00%
5-YR	64.1	66.606	100.00%
10-YR	84.8	78.618	92.71%
25-YR	113.8	94.633	83.16%
50-YR	138.5	107.735	77.79%
100-YR	165.1	121.566	73.63%
250-YR	204.5	141.585	69.23%
500-YR	238	158.327	66.52%

Ideally, complete participation would be the best-case scenario for the capturing of rainwater to minimize sunny-day flooding. However, it is important to consider that not all residents will have an interest in participating, which is why it is necessary to compare the volume of water that could be captured based on the degree of implementation. The volume of water captured on roof decreases proportionally as the level of participation decreases. In the case of severe storm scenarios, compared to the volume capture with 100% participation, 158.327 ac-ft, the volume captured with 10% participation decreases to 15.833 ac-ft (Figure 4.13).

Table 4.13 Volume of Water Collected through Roof Catchment based on different levels of adoption.

	Volume Captured on Roofs (AC-FT) by level of Participation									
Frequency Storm	**100%**	**90%**	**80%**	**70%**	**60%**	**50%**	**40%**	**30%**	**20%**	**10%**
1-YR	29.118	26.206	23.294	20.382	17.471	14.559	11.647	8.735	5.824	2.912
2-YR	49.136	44.222	39.309	34.395	29.482	24.568	19.654	14.741	9.827	4.914
5-YR	66.607	59.946	53.285	46.625	39.964	33.303	26.643	19.982	13.321	6.661
10-YR	78.618	70.756	62.894	55.032	47.171	39.309	31.447	23.585	15.724	7.862
25-YR	94.632	85.169	75.706	66.243	56.779	47.316	37.853	28.390	18.926	9.463
50-YR	107.735	96.962	86.188	75.415	64.641	53.868	43.094	32.321	21.547	10.774
100-YR	121.566	109.410	97.253	85.096	72.940	60.783	48.627	36.470	24.313	12.157
250-YR	141.585	127.426	113.268	99.109	84.951	70.792	56.634	42.475	28.317	14.158
500-YR	158.327	142.495	126.662	110.829	94.996	79.164	63.331	47.498	31.665	15.833

The last analysis performed was the calculation of percentage of water captured and kept off the streets based on the degree of participation. Considering the volume generated per storm scenario over the total amount of potential water captured using roofs as catchment areas the results can be observed in Table 4.14. For 1-Year storms 100% can be captured for 40% to 100% level of participation. However, as the Frequency Storm occurrences decrease the amount of water kept off the streets even with high participation rates decreases. Because the volume of water generated by a 500- YR storm is much larger than that of a 1-YR or 10-YR storm the amount of water that can be captured using roof areas decreases. The 500-YR storm has a probability of 0.2%, but at 100% participation roughly 60% can be prevented from flooding the streets in the rare event it occurs.

Table 4.14 % of Volume off the Streets by Level of Participation

Frequency Storm	% Kept off the Streets (90% Participation)	% Kept off the Streets (80% Participation)	% Kept off the Streets (70% Participation)	% Kept off the Streets (60% Participation)	% Kept off the Streets (50% Participation)	% Kept off the Streets (40% Participation)	% Kept off the Streets (30% Participation)	% Kept off the Streets (20% Participation)	% Kept off the Streets (10% Participation)
1-YR	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	75.96%	50.64%	25.32%
2-YR	100.0%	100.0%	93.72%	80.33%	66.94%	53.55%	40.17%	26.78%	13.39%
5-YR	93.52%	83.13%	72.74%	62.35%	51.96%	41.56%	31.17%	20.78%	10.39%
10-YR	83.44%	74.17%	64.90%	55.63%	46.35%	37.08%	27.81%	18.54%	9.27%
25-YR	74.84%	66.53%	58.21%	49.89%	41.58%	33.26%	24.95%	16.63%	8.32%
50-YR	70.01%	62.23%	54.45%	46.67%	38.89%	31.11%	23.34%	15.56%	7.78%
100-YR	66.27%	58.91%	51.54%	44.18%	36.82%	29.45%	22.09%	14.73%	7.36%
250-YR	62.31%	55.39%	48.46%	41.54%	34.62%	27.69%	20.77%	13.85%	6.92%
500-YR	59.87%	53.22%	46.57%	39.91%	33.26%	26.61%	19.96%	13.30%	6.65%

RWH Survey and Deployment

Barriers can cause social and economic implications, to advance RWH all factors must be considered to develop outreach education programs. Engaging a Hispanic community is important not just in El Paso but at a national level as the Hispanic population is the nation’s second-largest racial or ethnic group behind white American and ahead of Black Americans, according to the US Census Bureau [42].

A 37-question survey was designed to help understand the perceptions, opinions, and understanding of RWH and climate change and what are the barriers to the adoption of RWH practices. The IRB-approved survey was deployed in English and Spanish due to the predominantly Hispanic (81%) and Spanish-speaking population of the survey area in Northeast El Paso.

The participation rate was 66.9%, with 105 responses received. We determined the adequate sample size to obtain statistically significant data to be 96 responses, with a confidence level of 95% and a margin of error of 8%. Additionally, the survey language in Spanish was not validated externally. Operating under the assumption that not everyone will know RWH practices, each section was prefaced with a brief introduction about what RWH meant and the two methods, active and passive. Method 1 (active) is above the ground by installing rainwater barrels on the side of the home. Method 2 (passive) is adding plants and trees to retain some water.

Section 1: Demographic Information

It is essential to understand the demographic of the survey pool, as well as their socio-economic status. About half of the participants made an annual income of about $30,000-$40,000, while about 25% of the applicants made about $40,000-$50,000 (Figure 4.12). The level of education observed of the participants mainly was "Highschool diploma or higher," with 34.5%, and about 28.6% had some college education with no diploma. In terms of upper-level education completion, about 18% fell into that category.

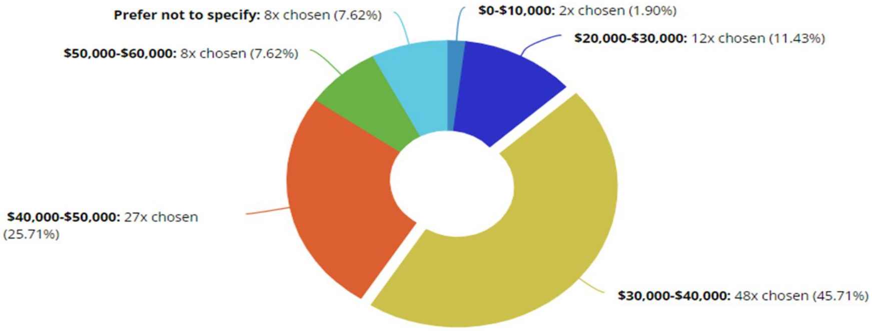


Figure 4.12 Household Incomes of survey participants.

This parameter will help us understand how different age groups feel about climate change and RWH. The preliminary analysis of ages showed that 46% fell in the 30-39 age group while 30% were in the youngest age bracket of 20-29 (Figure 4.13). Only 9% of the participants were 50 and older, while 15% were in the 40-49 category. Therefore, the majority demographic of the participants ranged from 20-39 years of age.

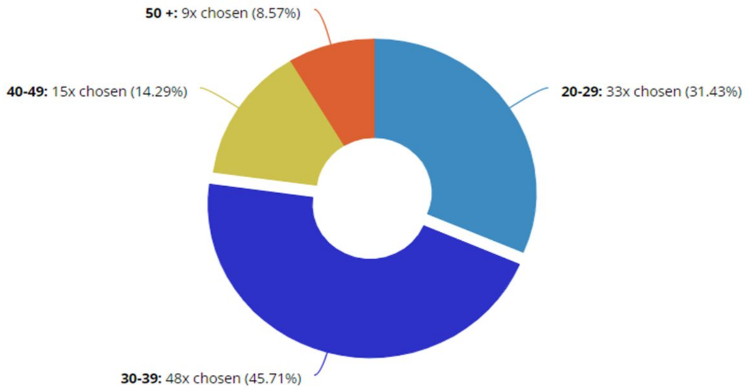


Figure 4.13 Age breakdown of survey participants.

El Paso, Texas, has a prominent Hispanic population, so it was predicted that it would be the majority in the breakdown of the ethnicity of those who participated. About 42% of the participants identified as Hispanic, Latino, or Spanish, 36% were white, and 22% identified as other minorities such as Black, Asian, or American Indian (Figure 4.14).

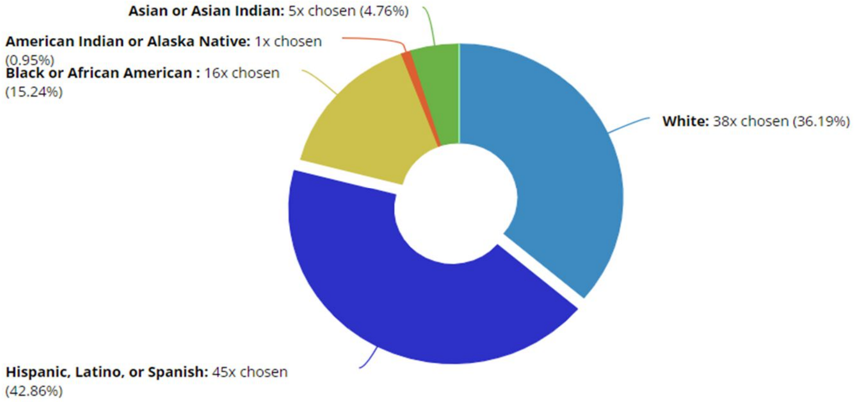


Figure 4.14 Ethnicity breakdown of survey participants.

According to the census, $51,325 is the median annual income in El Paso; the categories of revenues of participants ranging from $0-$10,000, $20,000-30,000, and $30,000- $40,000 will be grouped to observe how their responses defer from those participants with higher income. About 62 participants out of a total of 105 (59%) fall into the lowest-income group of ($0-$40,000).

Section 2: Perceptions, Opinions, and Knowledge about Rainwater Harvesting

The second survey category included questions to determine existing perceptions, opinions, and knowledge of Rainwater Harvesting. Once the initial data was obtained, it was further analyzed by income range and other parameters.

To the question: "Have you ever had any experiences with rainwater harvesting at your home, either at your home, apartment complex or with relatives or friends" before any income classification, 79 out of 105 participants selected that they had never seen any RWH systems in their own home or home of their parents. Only 26 out of 105 participants had seen an RWH system in the house of someone they know (Figure 4.15).

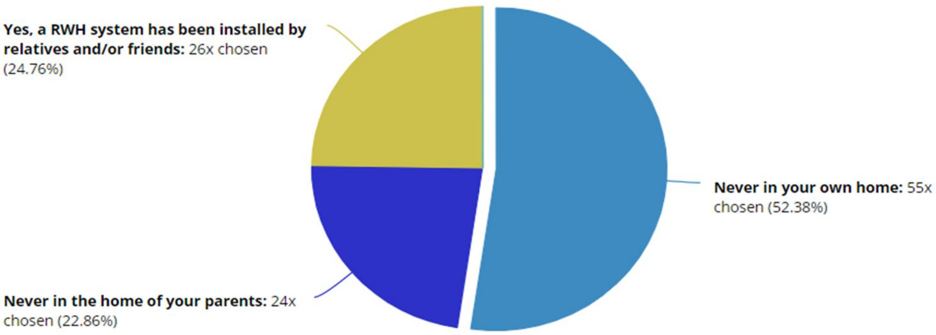


Figure 4.15 RWH Prior Exposure.

Once the classification of low-income and high-income was completed, approximately half of the participants (29%) had yet to gain experience with RWH in their home or their parent's home, with only 19% having experienced it first-hand in the house of relatives or friends (Figure 4.16). A primary difference was the increase in the number of people who have seen RWH. In the high-income group ($40,000-$60,000), 33% of participants have visited an RWH system installed in someone else's home (Figure 4.17). Consequently, for all participants that had observed RWH in real life, 12 participants from the low-income category and 14 from the high-income group were all willing to participate in RWH initiatives.

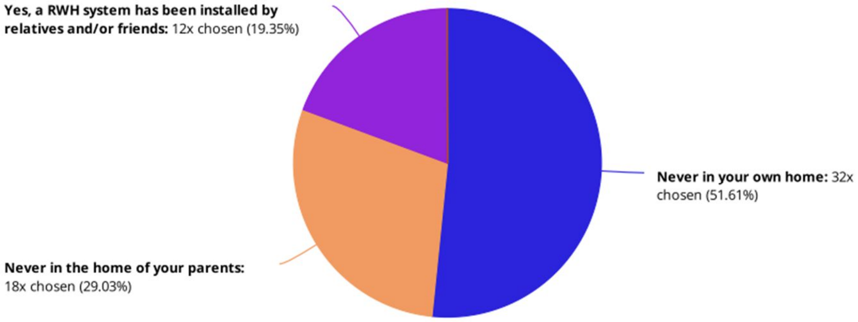


Figure 4.16 Low-Income ($0-$40,000) RWH Prior Exposure.

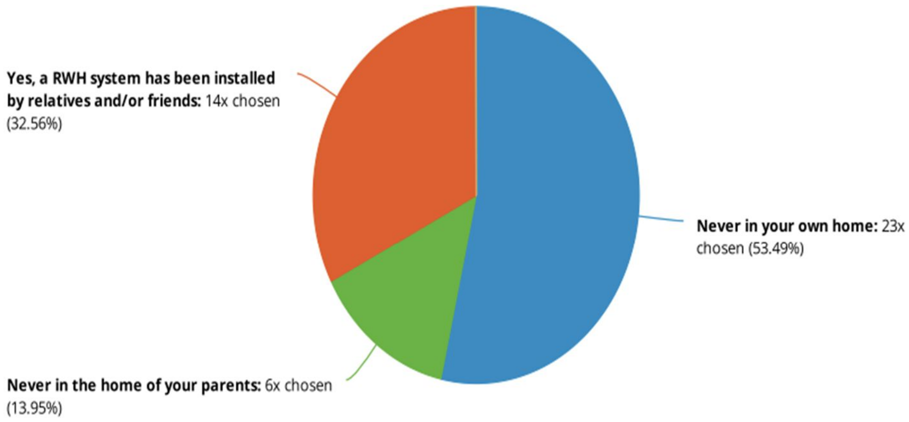


Figure 4.17 High-Income ($40,000-$60,000) RWH Prior Experience.

To the question: “What method would you be interested in having at your home,” 19 out of 43 participants (44%) of the high-income group would prefer to put a barrel down compared to 34 out of 62 participants (55%) of the low-income groups (Figure 4.18-Figure 4.19). Method 1 refers to using a tank or rain barrel on their property where the water captured is conveyed from an impervious surface. In contrast, Method 2 uses “below the ground” methods, such as planting local vegetation and modifying the landscape to help capture some of the water from a rainfall event. There was a difference in the type of methods of RWH- each income group would be inclined to implement. Higher-income groups seem to slightly prefer Method 2 over Method 1, while the opposite is true for the lower-income category (Figure 4.18-Figure 4.19)

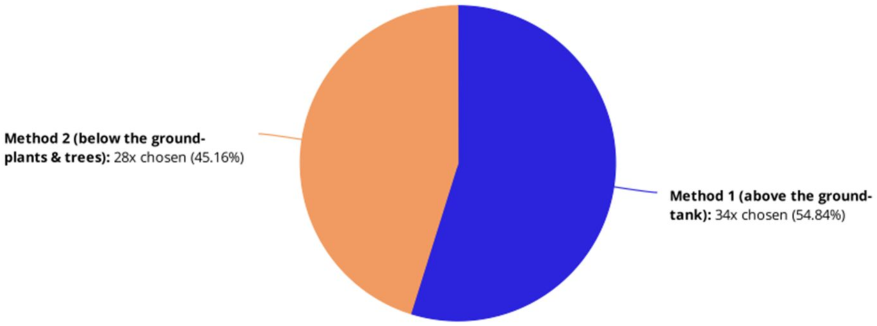


Figure 4.18 Low-income Bracket ($0-$40,000) preferred RWH method 1.

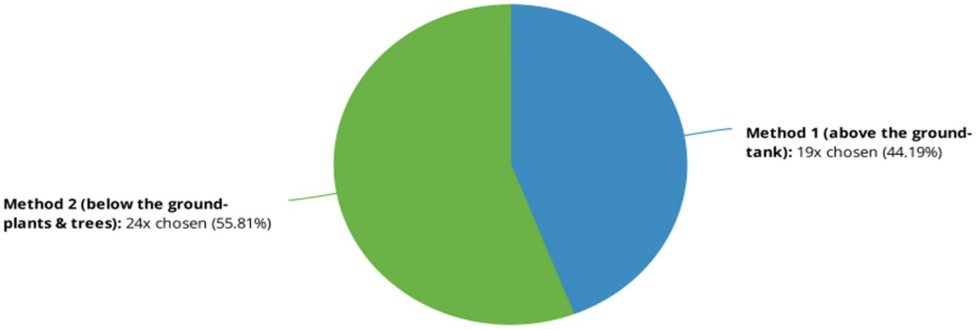


Figure 4.19 High-income interest ($40,000-$60,000) preferred RWH method 2.

As we continued to investigate the differences, we wanted to understand the reasons for a change in preference among both groups. For the lower-income groups, 97% experienced flooding conditions. Of the higher-income groups, 88% have experienced flooding. Since lower-income groups have experienced flooding, this makes them much more likely to look for some type of resolution, such as RWH using a barrel.

The amount of money the participants are willing to spend differs among the low-income and high-income groups. In the low-income group ($0-$40,000), the most they are willing to pay is $0-$50 to participate in implementing RWH, with 30% not willing to pay. The high-income group has a more comprehensive range of variance; about the same percentage (10-15%) are willing to pay either $0-$50, $50-$100, $100-$150, or $150-200, while about 32% are not willing to pay at all.

These results from the survey will help us understand the willingness to adopt RWH and pay for water harvesting of participants. Combined with technical information on areas more likely to experience sunny day flooding, the results will help us identify the areas where adopting RWH practices would be successful. In other words, when the willingness to pay and implement RWH and the need to control sunny-day flooding are aligned, we can prioritize areas of likely successful implementation of RWH practices.

Section 3: Climate Change

There are no comprehensive studies about the perceptions, opinions, and knowledge of climate change of residents of El Paso. Our study targeted the population in Northeast El Paso, a typical middle-class, predominantly Hispanic neighborhood of El Paso. The questions in the survey allowed us to find the relationship between climate change opinions and their willingness to partake in RWH.

An initial analysis was completed to compare how different income groups perceive climate change. The exact breakdown of high and low-income groups was conducted in Section 2, where the low-income bracket was from 0- $40,000, and the high-income bracket was from $40,000-60,000. Although both groups in the majority believe that climate change is "Caused mostly or entirely by humans," there is a higher percentage of participants in the low-income bracket, 35 out of 61 (57%) that selected this option (Figure 4.20). The second most preferred option was the "caused equally by humans and natural causes," while there are 7 out of 61 participants (11%) in the high-income bracket and 7 out of 43 (21%) in the low-income bracket who believe that "natural causes" entirely cause climate change (Figure 4.20-Figure 4.21). The perceptions of this sample showcase a population that does attribute human actions, their own included, to climate change; those that believe their actions do not contribute to climate change are the minority.

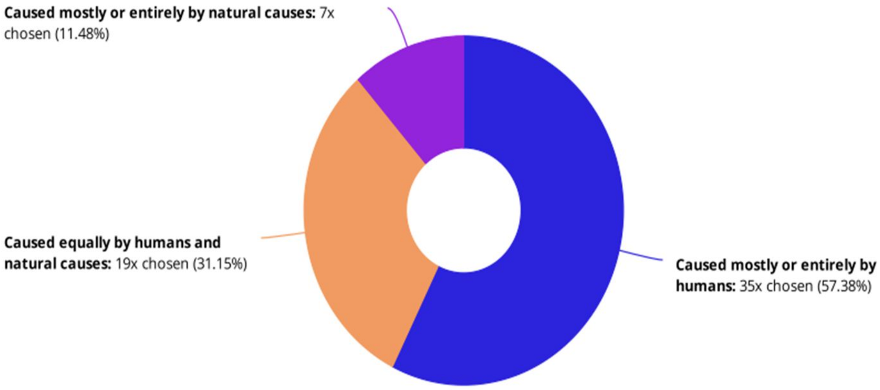


Figure 4.20 Low-income Bracket ($0-$40,000) belief of cause of climate change.

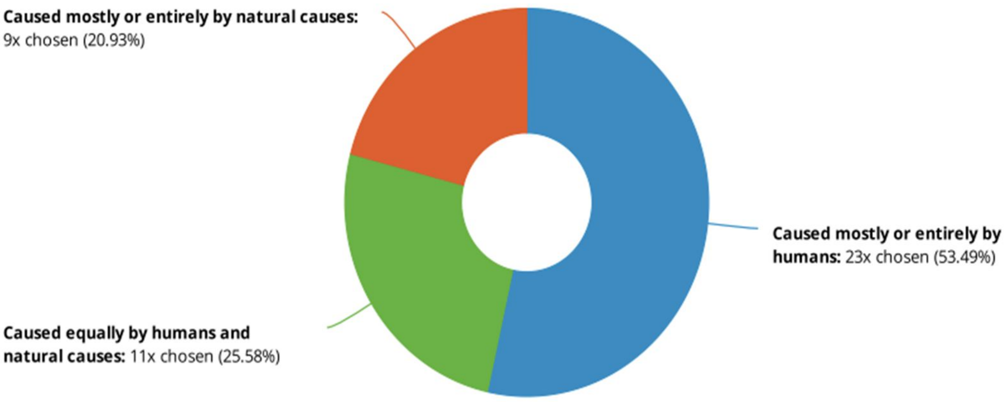


Figure 4.21 High-income interest ($40,000-$60,000) belief of cause of climate change.

To the question: “Have you personally noticed the following changes in the environment (climate) in the past ten years in your region?” 70 % of participants said they had noticed a temperature change. Approximately 44% responded that they had seen a difference in the rain, 39% noticed floods, 35% noticed season shifts, and 18% noticed an increase in droughts. Most participants have noticed a regional change, and 11% have not seen any climate changes (Figure 4.22). Based on these responses, it can be determined that the community is aware of changes in the climate that are not the norm, and any changes are severe enough to be noticed.

Based on these responses, participants have noticed an increase or decrease in weather events enough to be aware of climate changes. The community is the most knowledgeable of temperature as a sign of climate change and rain.

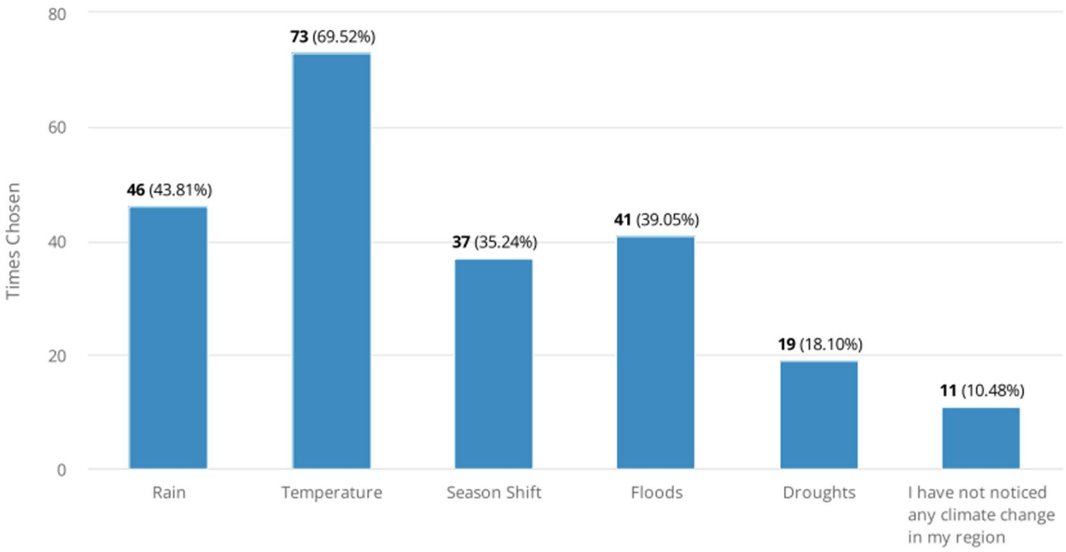


Figure 4.22 Climate changes observed in the community.

Although most participants have observed some change in climate change, we also wanted to observe if participants actively followed that type of information. To the question: "Do you follow climate change-related activities or policies?", 39 out of 105 participants (37%) followed climate change-related activities or policies, 48 participants (46%) selected no, and 18 (17%) chose not to specify. The low-income bracket does not follow climate change policies only 17 out of 62 (27%), as much as the high-income bracket 22 out of 43 (52%) (Figure 4.23-Figure 4.24).

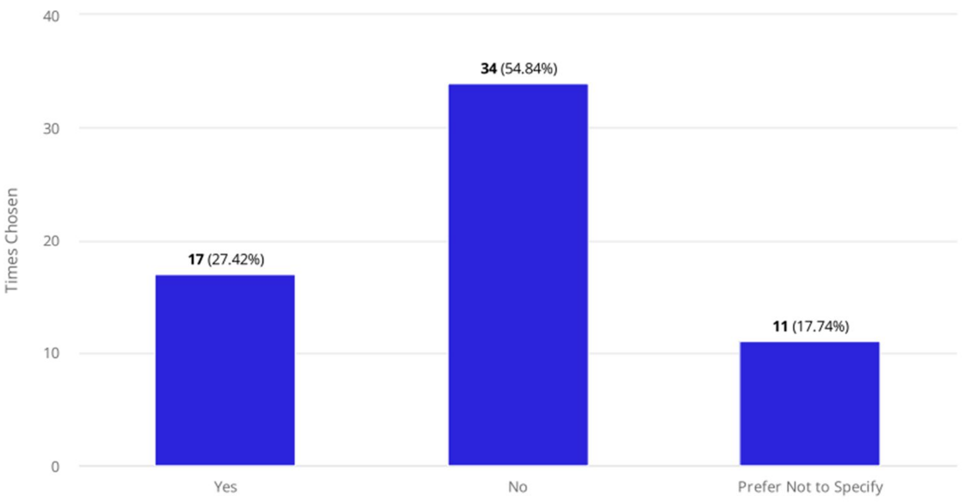


Figure 4.23 Participants in the low-income bracket ($0-$40,000) who follow climate change.

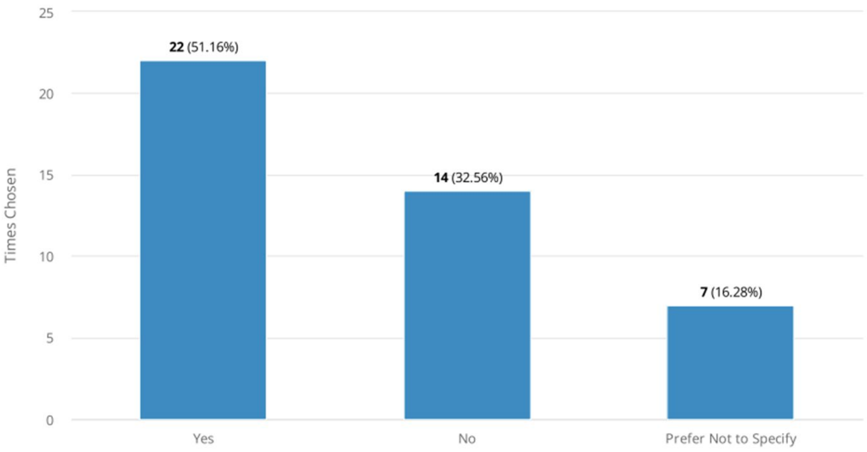


Figure 4.24 Participants in the high-income bracket ($40,000-$60,000) who follow climate change.

We wanted to determine if the participants considered climate change when making decisions about their household, such as reducing energy and water consumption, waste recycling, choosing alternative transportation methods to reduce air emissions, or insulating their homes. The question allowed users to select multiple options. To the question: “Do you consider the environment and subsequent climate change when making decisions of….", the most popular choice was waste recycling, with 64% of participants implementing recycling. Residents of the city of El Paso are provided with a blue receptacle for recycling. Other options like reduction in water consumption (55%) and energy consumption (43%) were also selected by most participants (Figure 4.25). Options that require additional expenses were not chosen as often, such as "buying environmentally friendly products (31%)", "buying a car that consumes less fuel and is eco-friendly (17%)", "alternative transport (11%)", and "insulating a home (36%)" as observed in Figure 4.25.

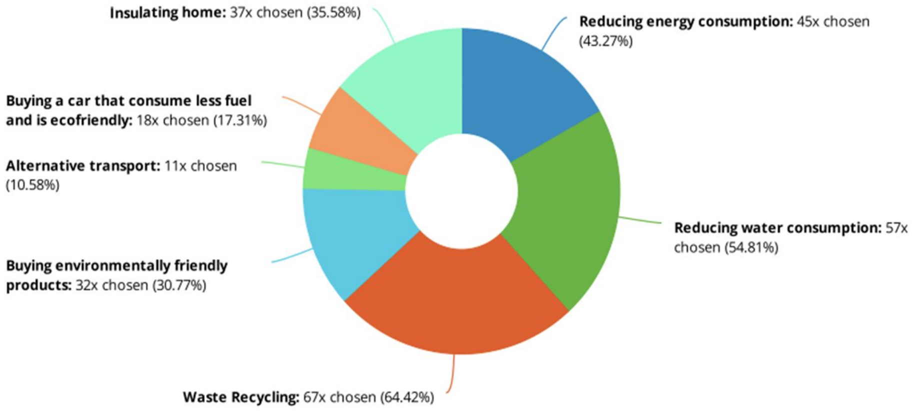


Figure 4.25 Household modification because of climate change.

To the question: "How worried are you about climate change?", approximately half of the participants expressed concern about climate change. We wanted to observe how that concern manifested in the rest of their responses regarding other information about climate change and other considerations. As previously mentioned, the questions included perceptions of climate change, sources of information, and knowledge of existing policies.

To the question: “How worried are you about climate change?” both the low-income and high-income group consensus is that there is some concern about climate change. About 70% of participants in each category, 43 out of 61 participants, and 29 out of 42 participants for the low-income and high-income groups, respectively, express some worry. However, only 7 out of 61 (11%) and 12 out of 61 (20%) say they are “very worried (Figure 4.26-Figure 4.27).” Based on the statistical analysis, Pearson’s coefficient was found to be 0.749, which is close to 1 thus suggesting that there is a relation between income and the level of worry about climate change. They are inversely proportional as the income level increases and the worry about climate change decreases.

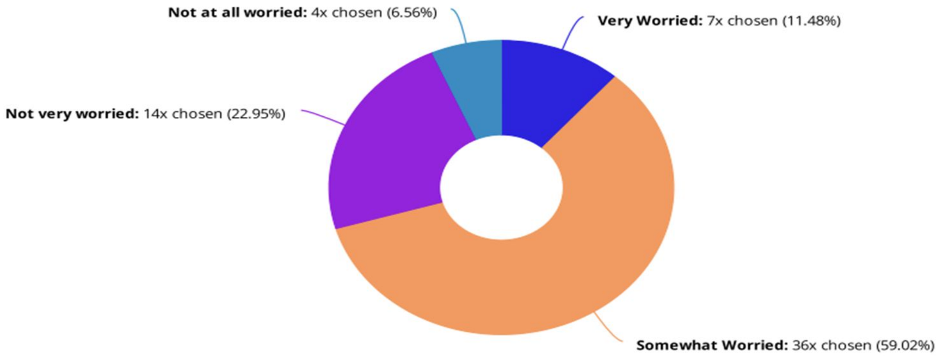


Figure 4.26 Low-income bracket ($0-$40,000) concern regarding climate change.

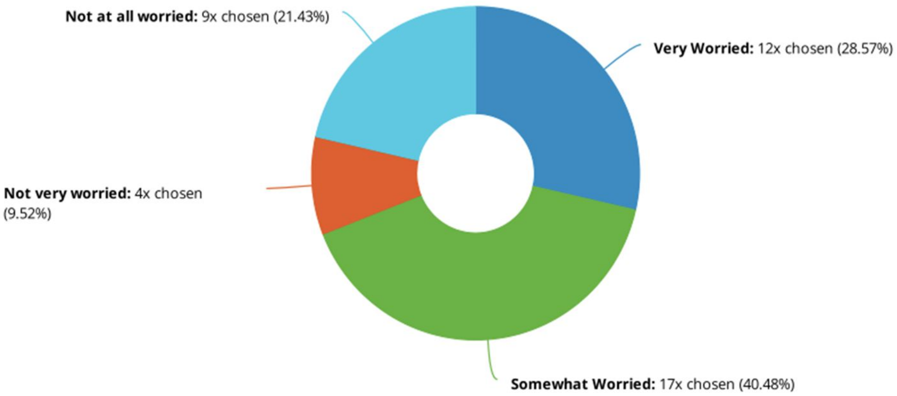


Figure 4.27 High-income bracket ($40,000-$60,000) concern regarding climate change.

To the question: “Which is the primary source of information that helps you understand climate change?” of the participants who expressed concern over climate change, 64% obtained information from the internet, and 49% received information from television (Figure 4.28). The same is true of the total survey sample, where most participants obtained information from the Internet (47%) and television (51%). A significant difference is that of those participants that expressed some degree of concern, only 3% did not use any source of information to help them in their knowledge/understanding of climate change compared to 14% of the total survey pool who did not use any external sources of information (Figure 4.29).

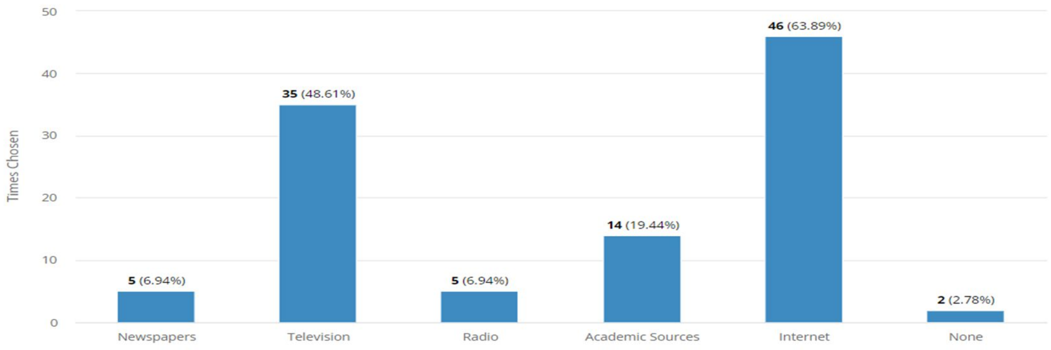


Figure 4.28 Sources of Information about climate change used by participants who expressed concern over climate change.

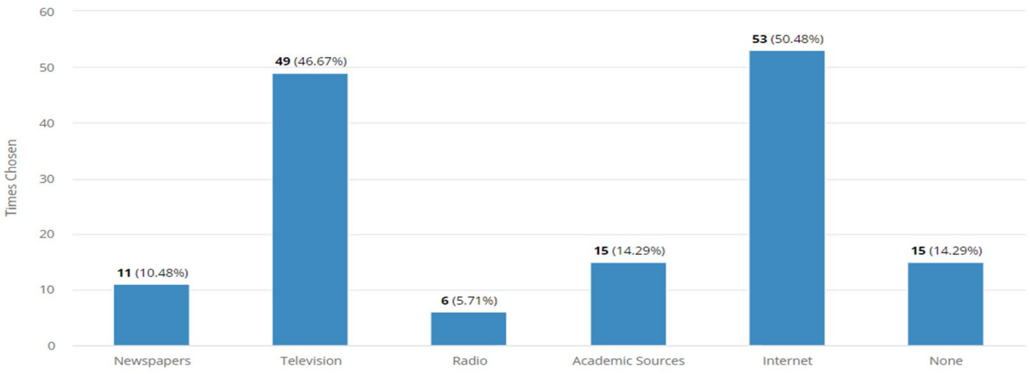


Figure 4.29 Sources of Information about climate change used by all participants.

Relationship between Perceptions of Climate Change and Willingness to Participate in Rainwater Harvesting

A closer look was taken at the willingness of the participants to partake in RWH based on their opinions about climate change. Specifically, if someone is concerned with the effects of climate change on the environment, will the individual be more likely to participate in alternatives that can alleviate some of the concerns posed by flooding?

76 out of 105 participants (72%) were considered to observe any relationship between interest and climate change concern. The cross-tabulation of the participant's responses to the question "How worried are you about climate change" was completed along with people who were interested in RWH and selected Yes to the question "In this case, are you interested in participating in RWH?", 65 out of 76 participants (86%) expressed some worry about climate change (Figure 4.30). For participants not interested in RWH, 20 out of 26 (77%) were not worried about climate change (Figure 4.31). A statistical analysis was performed to determine how much correlation exists between the interest in participation in RWH to climate change concerns. The correlation was evaluated using the Pearson correlation (r), measuring the strength and direction between two variables. A r-value of 0.60 was calculated, signifying that the strength of the association is moderate and strong. A positive correlation is indicated when one variable, in this case, the climate change concern, influences the other variable, willingness to participate, with both changing in the same direction.

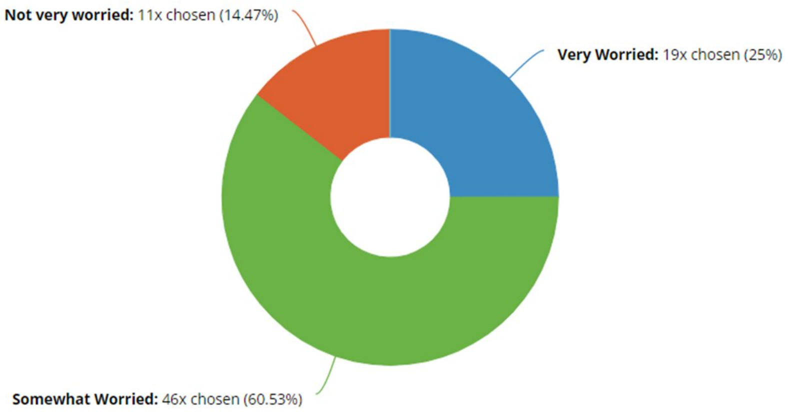


Figure 4.30 Concern about climate change by participants interested in partaking in RWH.

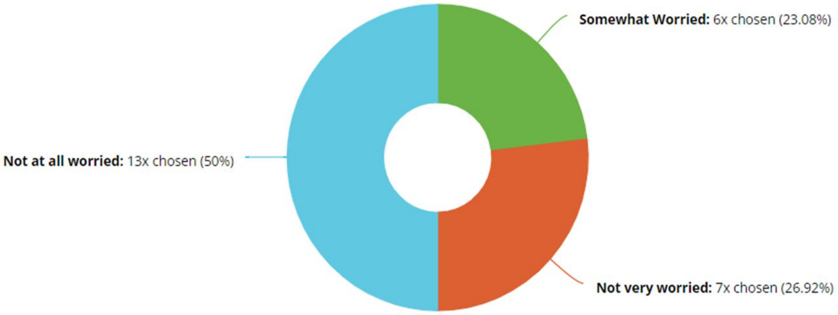


Figure 4.31 Concern about climate change by participants not interested in partaking in RWH.

The cross-tabulation of the participant's responses to the questions: "How much do you know about collecting rainwater for future use?" and "How worried are you about climate change?" were completed and shown in Figure 4.31. Most participants worried about climate change also had some knowledge about RWH, 58 out of 72 (81%).

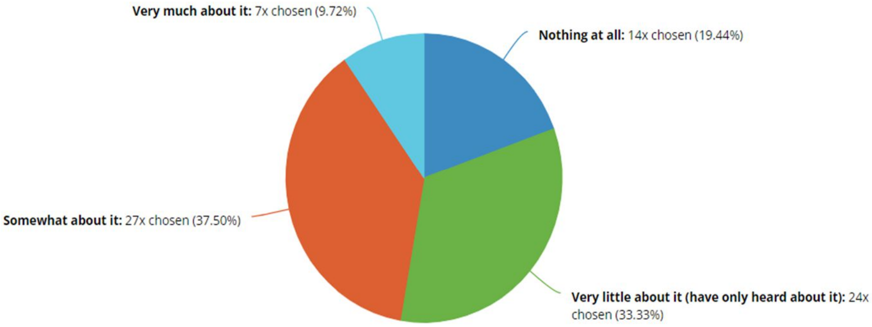


Figure 4.32 Rainwater harvesting degree of knowledge of participants who expressed concern over climate change.

The cross-tabulation of participants’ responses regarding the questions: “What issue in your community do you believe rainwater harvesting can help minimize?” and “How worried are you about climate change?” were completed and shown in Figure 4.33. Of most participants, 67 out of 105 (64%) are concerned about flash floods, and 48 out of those 72 (67%) are concerned about climate change (Figure 4.33). Pertaining to other issues, such as global warming and the water crisis, the people most concerned are the participants worried about climate change.

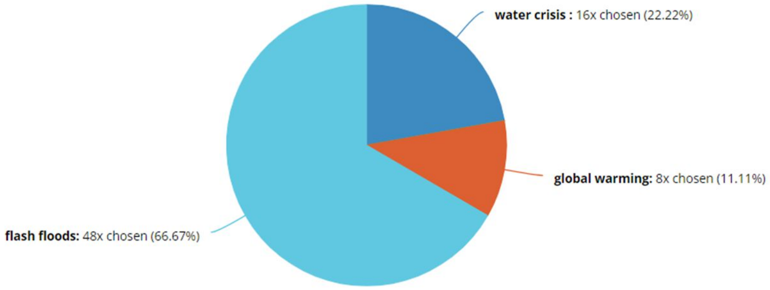


Figure 4.33 Climate change issues believed to be reduced by RWH of participants who expressed concern over climate change.

The final analysis was completed to gauge the importance of using RWH to meet gardening needs or flood reduction. The cross-tabulation of “How important would it be for you to collect rainwater in your house for your garden or other uses in your home?” and “How worried are you about climate change?” was completed in Figure 4.34. The range of importance from “Only a bit” to “very important” has the most responses from participants worried about climate change, with 62 out of 72 participants (87%) finding the importance of RWH to meet gardening needs.

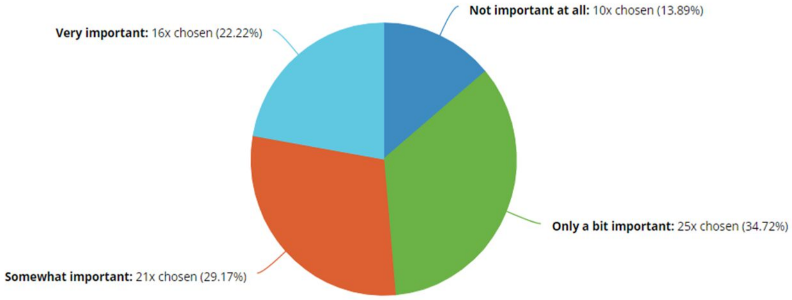


Figure 4.34 Importance of RWH to meet gardening needs for participants who expressed concern over climate change.

To the question: "How important would it be to collect rainwater in your home to prevent flooding on the streets you drive, and your children play?", 67 out of 72 participants (93%) who worry about climate change think using RWH to keep water off the streets is essential to some degree (Figure 4.35).

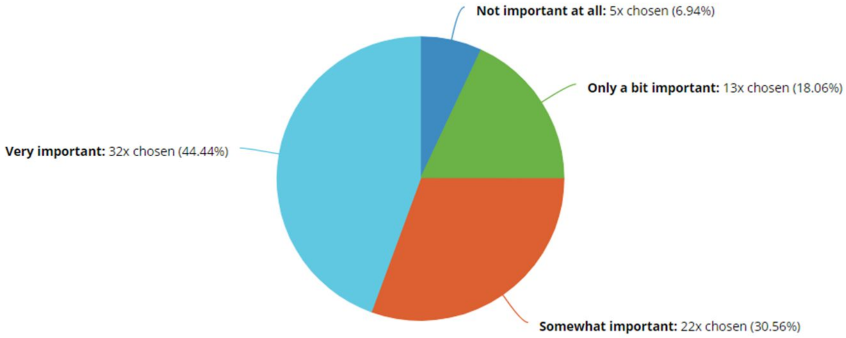


Figure 4.35 The importance of RWH to prevent flooding for participants who expressed concern over climate change.

Open-ended Questions

When left with the question of placement, participants specified possible locations for the rain barrel to be placed. Based on the size of the word in the word cloud, participants indicated that the best place for the barrel in their property would be in their backyard or anywhere outside of their property such as near their garden beds or the edge (Figure 4.35).

Figure 4.35. Word cloud for placement of barrel.

Participants were also asked about their size of household, ranging from a single household to about a 5-person household. Concurrently participants live most commonly in a 3-bedroom household. With most commonly most participants identifying themselves as part of 2 or 3- person household. Regarding where they were born all participants indicated either the United States or Mexico as their place of birth. Participants were also asked to describe their property's terrain to determine the property's characteristics where a barrel might be installed. Of the participants surveyed, the consensus was that they had either a flat or highly sloped property. Lastly, we wanted to allow participants to voice any opinions or concerns that were not addressed during the duration of the questionnaire through a final open-ended question. Their concerns ranged from flooding at intersections and the sentiments that the issue of flooding is up to the city to fix.

Chapter 5: Conclusions

RHW showed potential to reduce sunny-day flooding in arid environments. However, its success is dependent on participants willingness to adopt active RWH at an urban scale. The potential amount of water captured by roof catchment exceeded the amount of water that was generated in several storm scenarios. With the adoption of active RWH by some or all the residents within a community, the volume of water from a rainstorm that often would have nowhere to go but to low elevation points and inundate the area, can be stored in tanks, and be kept off the streets. The more people adopt active RWH the less impact sunny-day flooding will have in the area.

Overall, the technical part of the research provided a framework to evaluate and assess how RWH can help mitigate sunny-day flooding. Specifically, the project focused on volumetric calculations based on different percentages of active RWH adoption. These calculations were then analyzed and compared against the potential catchment of the residential properties in the area. Along with the socioeconomic criteria it provided a preview of potential barriers that could hinder widespread adoption. Furthermore, our findings showed that opinions, knowledge, and perception of RWH may be influenced by social and economic considerations. Thus, this was an example of how social science must be incorporated into the deployment of technology and engineering practices if the adoption of these technologies is to be successfully accepted and embraced by communities. Our results suggested that barriers to adopting RHW can be reduced through education and outreach activities that include hands-on demonstrations. If we do not understand the desires and concerns of the communities that will decide whether they partake in RWH initiatives, we cannot be successful as Engineers with the technical skills to provide an alternative solution to alleviate sunny-day flooding.

Hydrologic Modeling for RWH

1. The study showed the effectiveness of GIS in the analysis of RWH. GIS allowed for the process to be streamlined to include the characteristics of over 9000 residential properties- using the Maximum Likelihood method to not only identify homes in the area but also to identify all land cover classes to complete hydrological calculations.
2. The quality of the information was dependent on the accuracy of the parameters found using the GIS-based approach. An accuracy assessment helped validate the information to ensure reliability further down the calculation process.
3. For the most common storm types: 1-Year, 2-Year and 5-Year the storage potential of roof exceeded the volume of water produced in the HEC-HMS model for 100% adoption in the case of the other storm scenarios the volume of captured on the roof ranged from 60 to 90%
4. Varying degrees of adoption affected the amount of water that was captured, with 100% participation capturing the most volume, however even in cases of minimal participation about 6% to 25% of water was calculated to be kept off the streets to reduce nuisance flooding.

Survey about Perceptions, Opinions, and Knowledge on RWH and Climate Change

Sunny-day flooding can often interrupt and inconvenience a community. The survey results provided an initial snapshot of the perception, knowledge, and opinions of a sample of residents of a low-income Hispanic neighborhood in El Paso. Therefore, it may not represent the large metropolitan city and county of El Paso as different areas have different breakdowns of ethnicities and income ranges. However, the average income of residents of this area is lower than other areas of east or west of El Paso. The results from this study helped us understand what can be done to influence the willingness to participate in RWH initiatives for a low-income Hispanic neighborhood and what can be done to increase the adoption of RWH practices to reduce sunny-day flooding in their neighborhoods.

1. The willingness to participate in an RWH initiative was investigated by analyzing not only the socio-economic information of the participants but also their preconceived notions on the topic of RWH and climate change. Our results showed that these can influence their willingness to participate in RWH practices:
2. Adoption of RWH requires technical competence and an understanding of perceptions, opinions, and knowledge to recognize the barriers to adoption. In general, participants showed a genuine interest in learning about RWH practices that can help provide water for gardening purposes, and keep water off the streets, to ensure the safety of drivers and pedestrians.
3. An introductory understanding of RWH is necessary for some participants to be willing to engage in RWH practices. Of those with prior RWH knowledge, 100% were willing to adopt RHW. Based on the survey results, those who had witnessed active RWH using a tank at someone's house or firsthand were almost always willing to participate. Educational workshops at a more significant level can help bridge the knowledge gap of many participants. In addition, community events that allow for the demonstration of water catchment and its path to a tank can educate a community and encourage them to partake in such initiatives. This

emphasizes the need to provide pilot and hands-on demonstrations to engage and increase the adoption of RWH practices. Misconceptions or lack of knowledge are the leading cause of apprehension in active participation in RWH.

4. Participants indicated they would be willing to pay $50 for an RWH project in their homes. This can present an opportunity to incentivize participation in RWH initiatives.
5. The differing opinions on climate change, such as the belief that humans do not affect climate change, decrease the desire to participate in RWH practices. Of the 76 participants (72%) that expressed interest in RWH, 65 (85%) had some level of concern about climate change. Considering the results for 70% adoption of RWH, it can be observed that it can produce a significant amount of roof catchment to (Table 4.13) minimize sunny-day flooding.
6. The most appealing reason for engaging in RWH practices was water availability for gardening. Of those who expressed climate change concern, 62 out of 72 participants (87%) expressed an interest in the use of RWH to meet their gardening needs. It is common knowledge that rainwater benefits plant life and creates better-growing conditions for trees and plants. However, if proven, people who do not own a garden may be willing to participate in RWH to mitigate sunny-day flooding. This emphasizes the need to articulate to the public the benefits of RWH, not only to reduce flooding risks.
7. If someone believes that climate change effects cannot be attributed to human actions, then they will not see any benefit to RWH. Dissemination of accurate climate information through reliable sources is needed to sway opinions. Early in

> education, in grade school, and throughout the curriculum, along with visual demonstrations of the effects, can help diminish the misconceptions about climate change. Understanding climate change is the first step to helping connect people to available options to help reduce or prevent the results of climate events, such as sunny-day flooding.

Overall, the process developed for this thesis provided a framework that can be replicated to analyze other sites for RWH suitability. By streamlining the process to create a land cover map and obtaining the roof areas necessary for active RWH analysis, it is also possible to obtain parameters necessary for hydrological calculations and simulation. The use of GIS to complete this task created a seamless use of both GIS and HEC-HMS to be used in conjunction and developed an output that can be used to calculate storage potential of roofs vs. amount of volume of rainfall. Additionally, the degrees of adoption implemented in this study provide an idea of the amount of water that can be captured for each individual scenario. The use of a mixed-method survey provided insight to this specific community of what options the participants would be open to as well as the identification of barriers such as lack of understanding of RWH and money that need to be addressed to ensure successful implementation.

Chapter 6: Future Work

Perceptions, opinions, and knowledge of RWH practices and climate change were evaluated in a northeast neighborhood of El Paso. The same analysis will be conducted for the city, including a much fuller picture of the sociodemographic breakdown, including a hydrologic/hydraulic analysis that will identify the areas prone to sunny-day flooding.

When all catchment space is utilized, that amount of water captured can be enough to capture all water to minimize sunny-day flooding. The next step of this work is to calculate the size of the cistern and tank residents will need if it is not provided for them. Beginner water harvesters start with a tank that does not exceed 1500-gallon capacity [15]. When starting, you can size a tank to capture some of the runoff from at least one roof section. This means that while not all the "catchment" will be utilized, some of it will be to capture some of the water, reducing the amount that makes it to the street.

A 55-gallon rain barrel is what participants in this study would be most inclined to purchase based on the monetary limits specified. If all homes had a tank at this minimum size, approximately 513,370 gallons (1.57 ac-ft) could be collected. Now if people had a 1500-gallon installed in their home, there would be the potential to collect 14,000,000 gallons (42.96 ac-ft). The degree of implementation in this estimate is assumed to be 100%, but it is more likely that there will be a lower degree of implementation for the 1500-gallon tank, which can range anywhere from $1,200 to $1,500. Additionally, the feasibility of applying this method to various urban neighborhoods needs to be explored through a cost-benefit analysis and exploring local incentives that could be used to encourage participation further.

References

[1] H. R. Moftakhari *et al*, "Cumulative hazard: The case of nuisance flooding," *Earth's Future,* vol. 5, *(2),* pp. 214-223, 2017. Available: https://doi.org/10.1002/2016EF000494. DOI: 10.1002/2016EF000494.

[2] (). *Floods*. Available: https://www.who.int/health-topics/floods.

[3] B. Khazaei *et al*, "Climatic or regionally induced by humans? Tracing hydro-climatic and land-use changes to better understand the Lake Urmia tragedy," *Journal of Hydrology,* vol. 569, pp. 203-217, 2019. Available: https://www.sciencedirect.com/science/article/pii/S002216941830934X. DOI: 10.1016/j.jhydrol.2018.12.004.

[4] R. L. Wilby and R. Keenan, "Adapting to flood risk under climate change," *Prog. Phys. Geogr.,* vol. 36, *(3),* pp. 348-378, 2012.

[5] G. L. Bradley *et al*, "The role of climate change risk perception, response efficacy, and psychological adaptation in pro-environmental behavior: A two nation study," *J. Environ. Psychol.,* vol. 68, pp. 101410, 2020.

[6] E. U. Weber, "What shapes perceptions of climate change? New research since 2010," *Wiley Interdisciplinary Reviews. Climate Change,* vol. 7, *(1),* pp. 125-134, 2016. Available: https://api.istex.fr/ark:/67375/WNG-8J47WF69-3/fulltext.pdf. DOI: 10.1002/wcc.377.

[7] (). *HEC-HMS*. Available: https://www.hec.usace.army.mil/software/hec-hms/.

[8] A. Teston *et al*, "Comprehensive Environmental Assessment of Rainwater Harvesting Systems: A Literature Review," *Water,* vol. 14, *(17),* 2022. . DOI: 10.3390/w14172716.

[9] A. Stephan and L. Stephan, "Life cycle water, energy and cost analysis of multiple water harvesting and management measures for apartment buildings in a Mediterranean climate," *Sustainable Cities and Society,* vol. 32, pp. 584-603, 2017. Available: https://www.sciencedirect.com/science/article/pii/S221067071730015X. DOI: 10.1016/j.scs.2017.05.004.

[10] J. Kim and H. Furumai, "Assessment of Rainwater Availability by Building Type and Water Use Through GIS-based Scenario Analysis," *Water Resour Manage,* vol. 26, *(6),* pp. 1499-1511, 2012. Available: https://link.springer.com/article/10.1007/s11269-011-9969-9. DOI: 10.1007/s11269-011-9969-9.

[11] M. Burns *et al*, *The Stormwater Retention Performance of Rainwater Tanks at the Land-Parcel Scale.* 2012.

[12] (). *Harvesting the Rain Part 1: Passive rainwater harvesting*. Available: https://tucson.com/lifestyles/home-and-garden/harvesting-the-rain-part-1-passive-rainwater-harvesting/article_bf86a31e-4ac5-11eb-abd5-ff9729f748fb.html.

[13] P. B. Bedient, W. C. Huber and B. E. Vieux, *Hydrology and Floodplain Analysis.* (5th ed.) Upper Saddle River, NJ: Pearson Education Limited, 2008.

[14] (). *Runoff Coefficient (C)* . Available: https://www.waterboards.ca.gov/water_issues/programs/swamp/docs/cwt/guidance/513.pdf.

[15] B. Lancaster, *Rainwater Harvesting for Drylands and Beyond.* (Third ed.) Tucson, AZ: Rainsource Press, 2019.

[16] A. Rahman, "Recent Advances in Modelling and Implementation of Rainwater Harvesting Systems towards Sustainable Development," *Water,* vol. 9, *(12),* 2017. . DOI: 10.3390/w9120959.

[17] S. Zhang *et al*, "Water saving efficiency and reliability of rainwater harvesting systems in the context of climate change," *J. Clean. Prod.,* vol. 196, pp. 1341-1355, 2018. Available: https://www.sciencedirect.com/science/article/pii/S0959652618317839. DOI: 10.1016/j.jclepro.2018.06.133.

[18] A. Palla, I. Gnecco and P. La Barbera, "The impact of domestic rainwater harvesting systems in storm water runoff mitigation at the urban block scale," *J. Environ. Manage.,* vol. 191, pp. 297-305, 2017. Available: https://www.sciencedirect.com/science/article/pii/S0301479717300439. DOI: 10.1016/j.jenvman.2017.01.025.

[19] M. J. Deitch and S. T. Feirer, "Cumulative impacts of residential rainwater harvesting on stormwater discharge through a peri-urban drainage network," *J. Environ. Manage.,* vol. 243, pp. 127-136, 2019. Available: https://www.sciencedirect.com/science/article/pii/S0301479719306164. DOI: https://doi.org/10.1016/j.jenvman.2019.05.018.

[20] A. G. Burgos *et al*, "Future Nuisance Flooding in Norfolk, VA, From Astronomical Tides and Annual to Decadal Internal Climate Variability," *Geophys. Res. Lett.,* vol. 45, *(22),* pp. 12,432-12,439, 2018. Available: https://doi.org/10.1029/2018GL079572. DOI: 10.1029/2018GL079572.

[21] B. Gavit *et al*, "Rainwater harvesting structure site suitability using remote sensing and GIS," in Anonymous 2018, . DOI: 10.1007/978-981-10-5801-1_23.

[22] J. Hinkel *et al*, "Coastal flood damage and adaptation cost under 21st century sea-level rise," *Proc. Natl. Acad. Sci. U. S. A.,* vol. 111, pp. 3292-7, 2014. . DOI: 10.1073/pnas.1222469111.

[23] A. Ndeketeya and M. Dundu, "Application of HEC-HMS Model for Evaluation of Rainwater Harvesting Potential in a Semi-arid City," *Water Resour. Manage.,* vol. 35, *(12),* pp. 4217-4232, 2021. Available: https://doi.org/10.1007/s11269-021-02941-0. DOI: 10.1007/s11269-021-02941-0.

[24] Q. Zhong *et al*, "A GIS-based approach to assessing the capacity of rainwater harvesting for addressing outdoor irrigation," *Landscape Urban Plann.,* vol. 223, pp. 104416, 2022. Available: https://www.sciencedirect.com/science/article/pii/S0169204622000652. DOI: https://doi.org/10.1016/j.landurbplan.2022.104416.

[25] (). *What is GIS?*. Available: https://www.esri.com/.

[26] K. S. Balkhair and K. Ur Rahman, "Development and assessment of rainwater harvesting suitability map using analytical hierarchy process, GIS and RS techniques," *Geocarto Int.,* vol. 36, *(4),* pp. 421-448, 2021. Available: https://utep.idm.oclc.org/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=148626975&site=ehost-live&scope=site. DOI: 10.1080/10106049.2019.1608591.

[27] A. Adham *et al*, "A GIS-based approach for identifying potential sites for harvesting rainwater in the Western Desert of Iraq," *International Soil and Water Conservation Research,* vol. 6, *(4),* pp. 297-304, 2018. Available: https://www.sciencedirect.com/science/article/pii/S209563391830114X. DOI: https://doi.org/10.1016/j.iswcr.2018.07.003.

[28] R. Al-Adamat *et al*, "The Combination of Indigenous Knowledge and Geo-Informatics for Water Harvesting Siting in the Jordanian Badia," *Journal of Geographic Information System,* vol. 4, *(4),* pp. 366-376, 2012. Available: https://search.proquest.com/docview/1718948915. DOI: 10.4236/jgis.2012.44042.

[29] S. Baby, C. Arrowsmith and N. Al-Ansari, "Application of GIS for Mapping Rainwater-Harvesting Potential: Case Study Wollert, Victoria," *Engineering,* vol. 11, pp. 14-21, 2019. . DOI: 10.4236/eng.2019.111002.

[30] P. Preeti and A. Rahman, "Application of GIS in Rainwater Harvesting Research: A Scoping Review," *Asian Journal of Water, Environment and Pollution,* vol. 18, pp. 29–35, 2021. . DOI: 10.3233/AJW210040.

[31] V. Sheikh, "Perception of domestic rainwater harvesting by Iranian citizens," *Sustainable Cities and Society,* vol. 60, pp. 102278, 2020.

[32] K. van Daalen *et al*, "Climate change and gender-based health disparities," *The Lancet Planetary Health,* vol. 4, *(2),* pp. e44-e45, 2020. Available: https://doi.org/10.1016/S2542-5196(20)30001-2. DOI: 10.1016/S2542-5196(20)30001-2.

[33] P. Preeti and A. Rahman, "A Case Study on Reliability, Water Demand and Economic Analysis of Rainwater Harvesting in Australian Capital Cities," *Water,* vol. 13, *(19),* 2021. . DOI: 10.3390/w13192606.

[34] V. Dutt and C. Gonzalez, "Decisions from experience reduce misconceptions about climate change," *J. Environ. Psychol.,* vol. 32, *(1),* pp. 19-29, 2012. Available: https://www.sciencedirect.com/science/article/pii/S0272494411000764. DOI: 10.1016/j.jenvp.2011.10.003.

[35] J. Milovanovic, T. Shealy and A. Godwin, "Senior engineering students in the USA carry misconceptions about climate change: Implications for engineering education," *J. Clean. Prod.,* vol. 345, pp. 131129, 2022. Available: https://www.sciencedirect.com/science/article/pii/S0959652622007612. DOI: 10.1016/j.jclepro.2022.131129.

[36] Q. Zhong *et al*, "A GIS-based approach to assessing the capacity of rainwater harvesting for addressing outdoor irrigation," *Landscape Urban Plann.,* vol. 223, pp. 104416, 2022. Available: https://www.sciencedirect.com/science/article/pii/S0169204622000652. DOI: 10.1016/j.landurbplan.2022.104416.

[37] U. Saddle *et al*, "Hydrology and Floodplain Analysis International Edition contributions by," .

[38] United States Department of Agriculture Soll Conservation Service Engineering Division, "Urban Hydrology
for Small Watersheds," Available: https://www.nrc.gov/docs/ML1421/ML14219A437.pdf.

[39] S. Basheer *et al*, "Comparison of Land Use Land Cover Classifiers Using Different Satellite Imagery and Machine Learning Techniques," *Remote Sensing,* vol. 14, *(19),* 2022. . DOI: 10.3390/rs14194978.

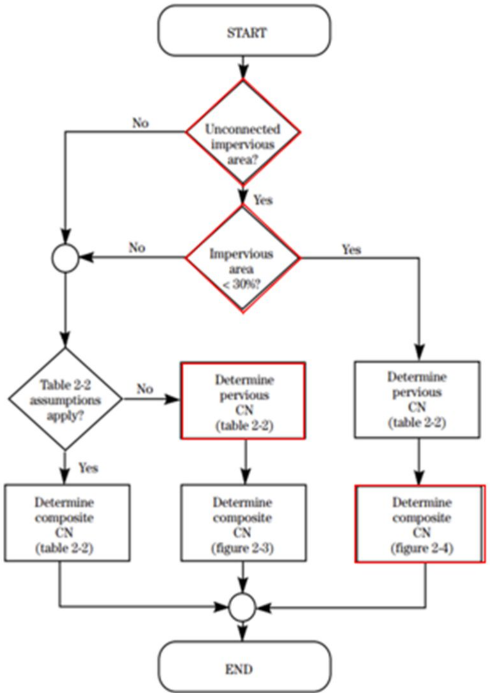
[40] (June). *Drainage Design Manual* . Available: http://legacy.elpasotexas.gov/muni_clerk/agenda/06-03-08/06030815B.pdf.

[41] V. Sheikh, "Perception of domestic rainwater harvesting by Iranian citizens," *Sustainable Cities and Society,* vol. 60, pp. 102278, 2020. Available: https://www.sciencedirect.com/science/article/pii/S2210670720304996. DOI: 10.1016/j.scs.2020.102278.

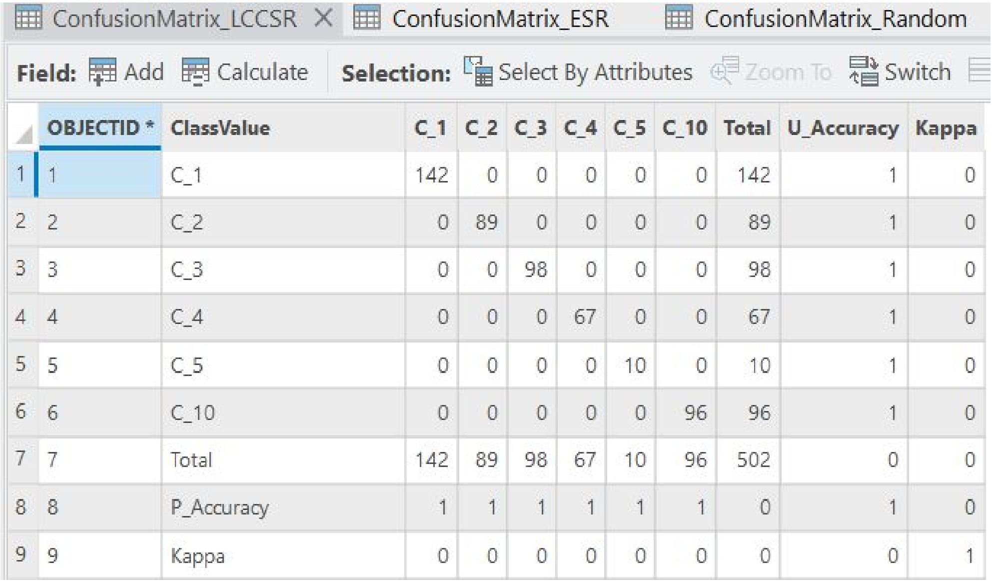
[42] (). *A brief statistical portrait of U.S. Hispanics*. Available: https://www.pewresearch.org/science/2022/06/14/a-brief-statistical-portrait-of-u-s-hispanics/.

Appendix

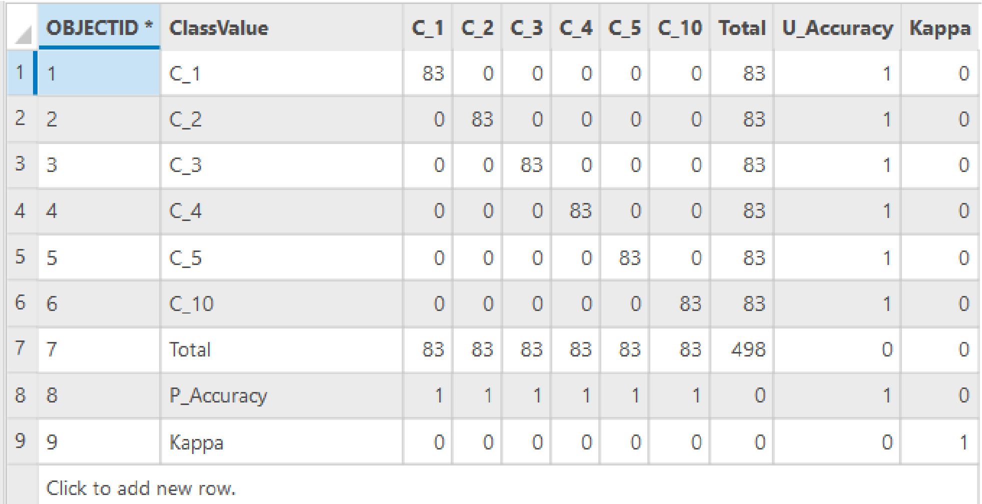
SCS Flow Chart



Accuracy Assessments (Original Data)

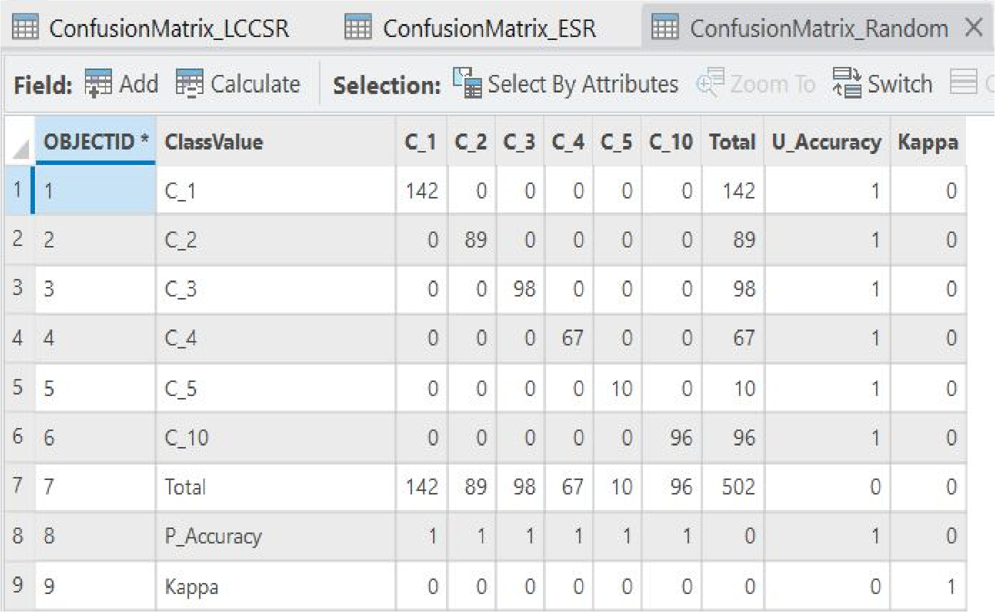


	OBJECTID *	ClassValue	C_1	C_2	C_3	C_4	C_5	C_10	Total	U_Accuracy	Kappa
1	1	C_1	142	0	0	0	0	0	142	1	0
2	2	C_2	0	89	0	0	0	0	89	1	0
3	3	C_3	0	0	98	0	0	0	98	1	0
4	4	C_4	0	0	0	67	0	0	67	1	0
5	5	C_5	0	0	0	0	10	0	10	1	0
6	6	C_10	0	0	0	0	0	96	96	1	0
7	7	Total	142	89	98	67	10	96	502	0	0
8	8	P_Accuracy	1	1	1	1	1	1	0	1	0
9	9	Kappa	0	0	0	0	0	0	0	0	1

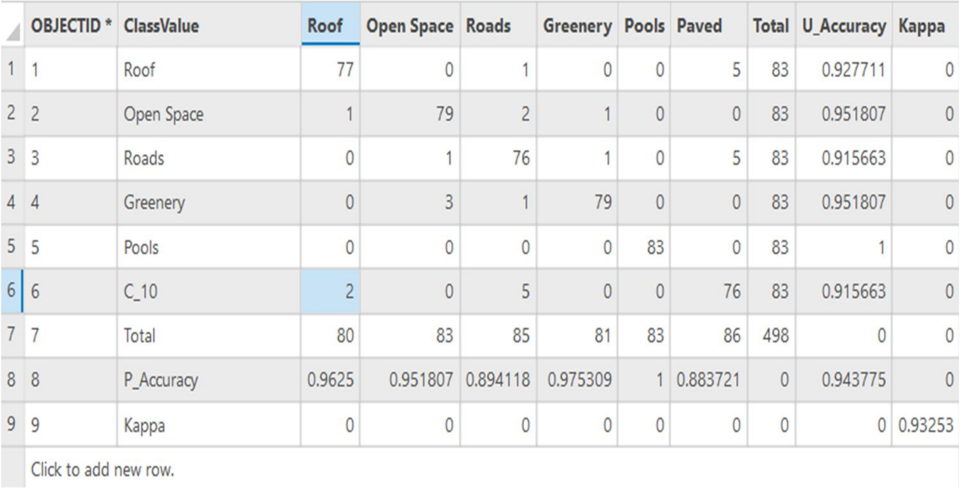


	OBJECTID *	ClassValue	C_1	C_2	C_3	C_4	C_5	C_10	Total	U_Accuracy	Kappa
1	1	C_1	83	0	0	0	0	0	83	1	0
2	2	C_2	0	83	0	0	0	0	83	1	0
3	3	C_3	0	0	83	0	0	0	83	1	0
4	4	C_4	0	0	0	83	0	0	83	1	0
5	5	C_5	0	0	0	0	83	0	83	1	0
6	6	C_10	0	0	0	0	0	83	83	1	0
7	7	Total	83	83	83	83	83	83	498	0	0
8	8	P_Accuracy	1	1	1	1	1	1	0	1	0
9	9	Kappa	0	0	0	0	0	0	0	0	1

Click to add new row.

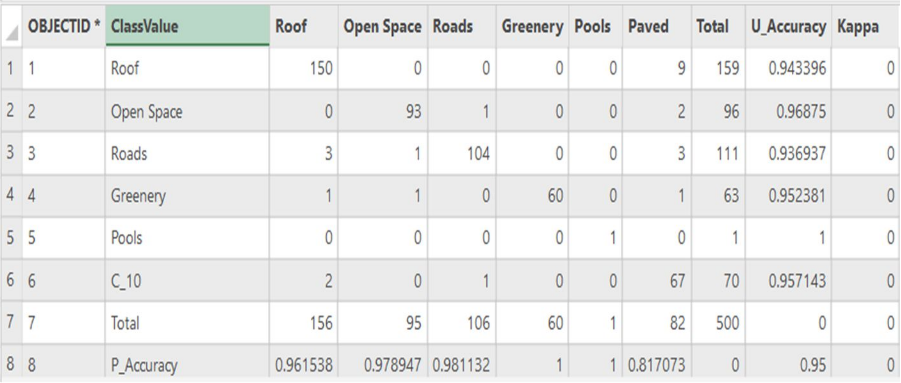


	OBJECTID *	ClassValue	C_1	C_2	C_3	C_4	C_5	C_10	Total	U_Accuracy	Kappa
1	1	C_1	142	0	0	0	0	0	142	1	0
2	2	C_2	0	89	0	0	0	0	89	1	0
3	3	C_3	0	0	98	0	0	0	98	1	0
4	4	C_4	0	0	0	67	0	0	67	1	0
5	5	C_5	0	0	0	0	10	0	10	1	0
6	6	C_10	0	0	0	0	0	96	96	1	0
7	7	Total	142	89	98	67	10	96	502	0	0
8	8	P_Accuracy	1	1	1	1	1	1	0	1	0
9	9	Kappa	0	0	0	0	0	0	0	0	1



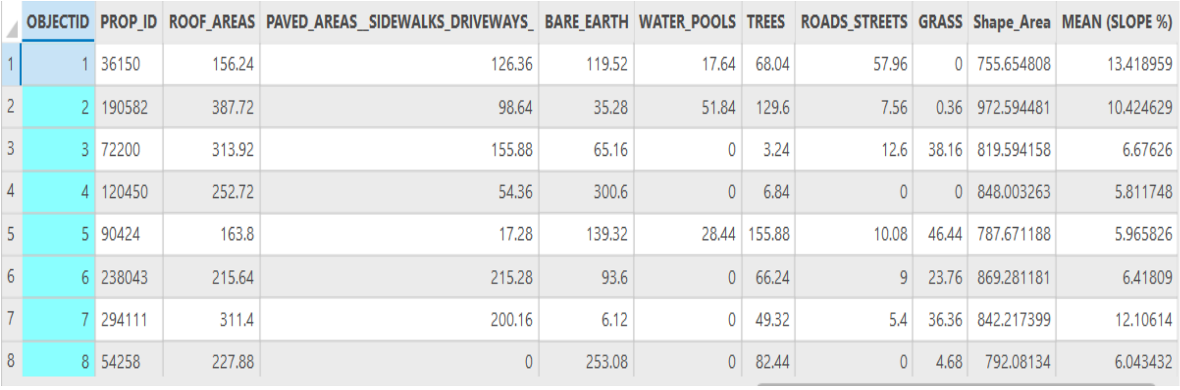
	OBJECTID *	ClassValue	Roof	Open Space	Roads	Greenery	Pools	Paved	Total	U_Accuracy	Kappa
1	1	Roof	77	0	1	0	0	5	83	0.927711	0
2	2	Open Space	1	79	2	1	0	0	83	0.951807	0
3	3	Roads	0	1	76	1	0	5	83	0.915663	0
4	4	Greenery	0	3	1	79	0	0	83	0.951807	0
5	5	Pools	0	0	0	0	83	0	83	1	0
6	6	C_10	2	0	5	0	0	76	83	0.915663	0
7	7	Total	80	83	85	81	83	86	498	0	0
8	8	P_Accuracy	0.9625	0.951807	0.894118	0.975309	1	0.883721	0	0.943775	0
9	9	Kappa	0	0	0	0	0	0	0	0	0.93253

Click to add new row.



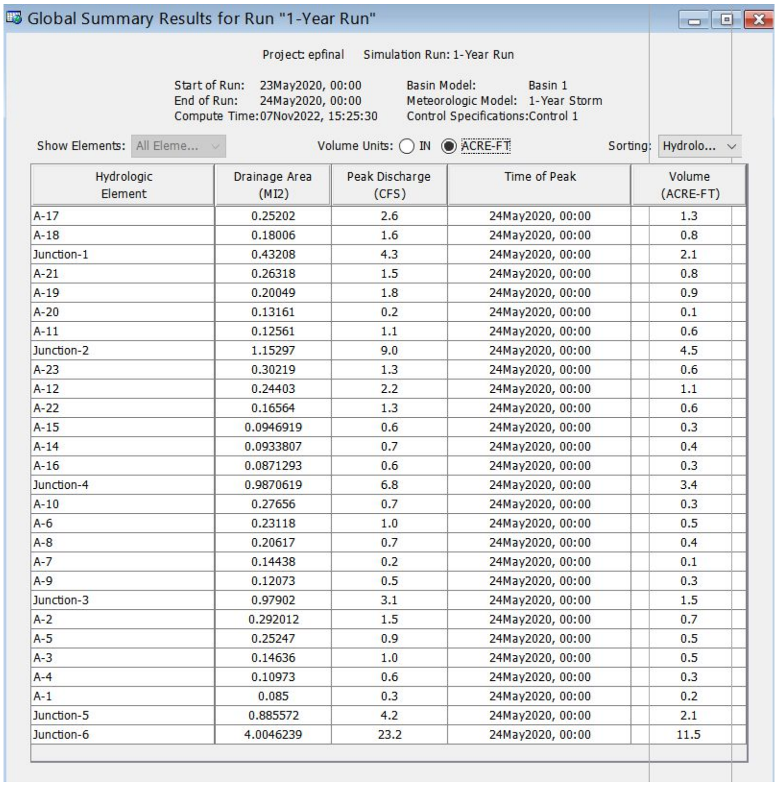
	OBJECTID *	ClassValue	Roof	Open Space	Roads	Greenery	Pools	Paved	Total	U_Accuracy	Kappa
1	1	Roof	150	0	0	0	0	9	159	0.943396	0
2	2	Open Space	0	93	1	0	0	2	96	0.96875	0
3	3	Roads	3	1	104	0	0	3	111	0.936937	0
4	4	Greenery	1	1	0	60	0	1	63	0.952381	0
5	5	Pools	0	0	0	0	1	0	1	1	0
6	6	C_10	2	0	1	0	0	67	70	0.957143	0
7	7	Total	156	95	106	60	1	82	500	0	0
8	8	P_Accuracy	0.961538	0.978947	0.981132	1	1	0.817073	0	0.95	0

Zonal Statistics



	OBJECTID	PROP_ID	ROOF_AREAS	PAVED_AREAS__SIDEWALKS_DRIVEWAYS_	BARE_EARTH	WATER_POOLS	TREES	ROADS_STREETS	GRASS	Shape_Area	MEAN (SLOPE %)
1	1	36150	156.24	126.36	119.52	17.64	68.04	57.96	0	755.654808	13.418959
2	2	190582	387.72	98.64	35.28	51.84	129.6	7.56	0.36	972.594481	10.424629
3	3	72200	313.92	155.88	65.16	0	3.24	12.6	38.16	819.594158	6.67626
4	4	120450	252.72	54.36	300.6	0	6.84	0	0	848.003263	5.811748
5	5	90424	163.8	17.28	139.32	28.44	155.88	10.08	46.44	787.671188	5.965826
6	6	238043	215.64	215.28	93.6	0	66.24	9	23.76	869.281181	6.41809
7	7	294111	311.4	200.16	6.12	0	49.32	5.4	36.36	842.217399	12.10614
8	8	54258	227.88	0	253.08	0	82.44	0	4.68	792.08134	6.043432

HEC-HMS Original data



Global Summary Results for Run "1-Year Run"

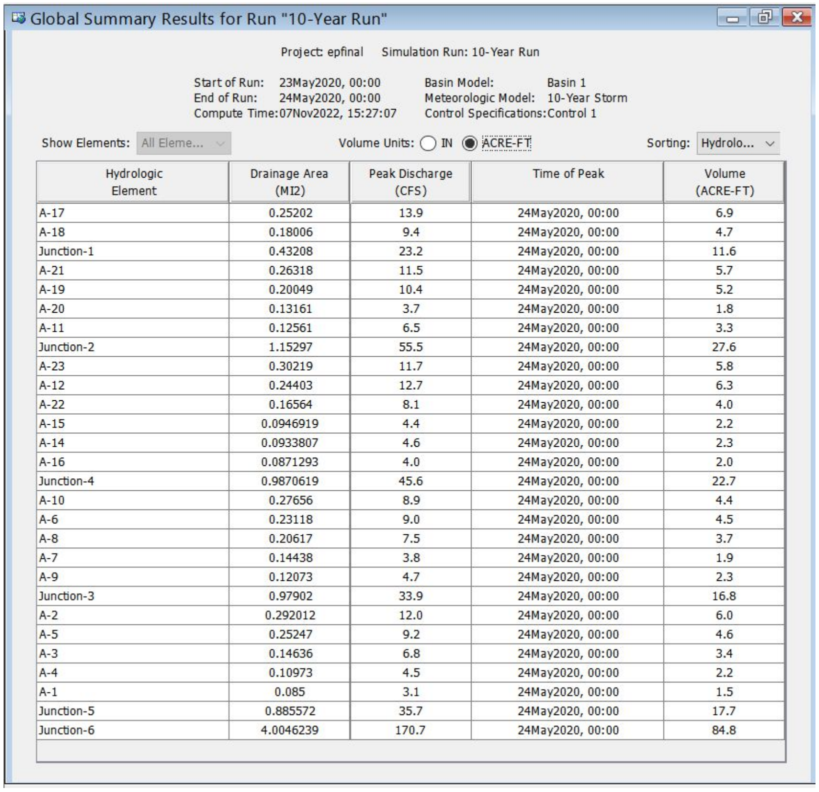
Project: epfinal Simulation Run: 1-Year Run

Start of Run: 23May2020, 00:00
End of Run: 24May2020, 00:00
Compute Time: 07Nov2022, 15:25:30

Basin Model: Basin 1
Meteorologic Model: 1-Year Storm
Control Specifications: Control 1

Show Elements: All Eleme... Volume Units: ○ IN ● ACRE-FT Sorting: Hydrolo...

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (ACRE-FT)
A-17	0.25202	2.6	24May2020, 00:00	1.3
A-18	0.18006	1.6	24May2020, 00:00	0.8
Junction-1	0.43208	4.3	24May2020, 00:00	2.1
A-21	0.26318	1.5	24May2020, 00:00	0.8
A-19	0.20049	1.8	24May2020, 00:00	0.9
A-20	0.13161	0.2	24May2020, 00:00	0.1
A-11	0.12561	1.1	24May2020, 00:00	0.6
Junction-2	1.15297	9.0	24May2020, 00:00	4.5
A-23	0.30219	1.3	24May2020, 00:00	0.6
A-12	0.24403	2.2	24May2020, 00:00	1.1
A-22	0.16564	1.3	24May2020, 00:00	0.6
A-15	0.0946919	0.6	24May2020, 00:00	0.3
A-14	0.0933807	0.7	24May2020, 00:00	0.4
A-16	0.0871293	0.6	24May2020, 00:00	0.3
Junction-4	0.9870619	6.8	24May2020, 00:00	3.4
A-10	0.27656	0.7	24May2020, 00:00	0.3
A-6	0.23118	1.0	24May2020, 00:00	0.5
A-8	0.20617	0.7	24May2020, 00:00	0.4
A-7	0.14438	0.2	24May2020, 00:00	0.1
A-9	0.12073	0.5	24May2020, 00:00	0.3
Junction-3	0.97902	3.1	24May2020, 00:00	1.5
A-2	0.292012	1.5	24May2020, 00:00	0.7
A-5	0.25247	0.9	24May2020, 00:00	0.5
A-3	0.14636	1.0	24May2020, 00:00	0.5
A-4	0.10973	0.6	24May2020, 00:00	0.3
A-1	0.085	0.3	24May2020, 00:00	0.2
Junction-5	0.885572	4.2	24May2020, 00:00	2.1
Junction-6	4.0046239	23.2	24May2020, 00:00	11.5



Global Summary Results for Run "10-Year Run"

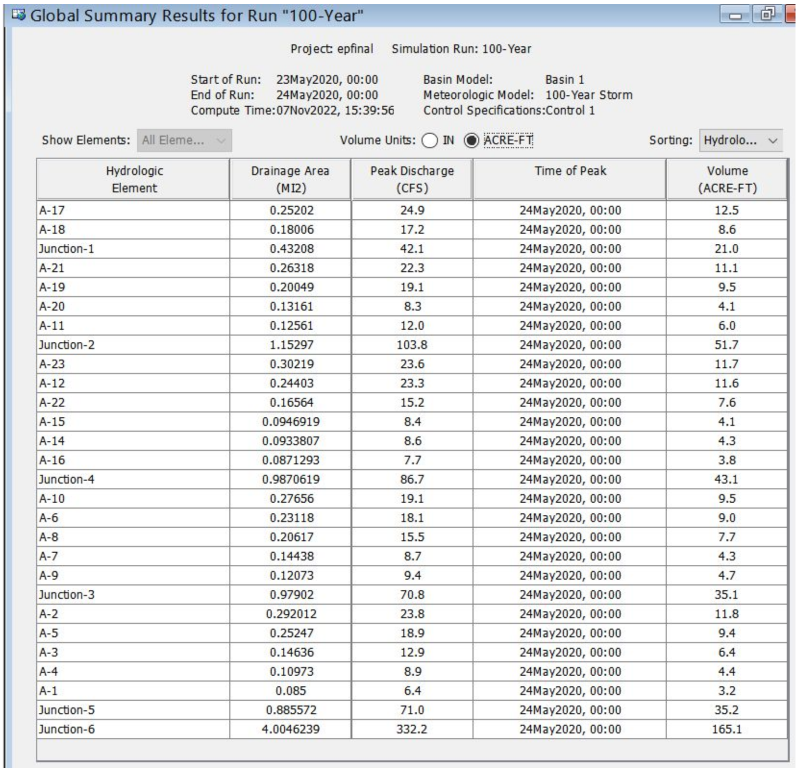
Project: epfinal Simulation Run: 10-Year Run

Start of Run: 23May2020, 00:00
End of Run: 24May2020, 00:00
Compute Time: 07Nov2022, 15:27:07

Basin Model: Basin 1
Meteorologic Model: 10-Year Storm
Control Specifications: Control 1

Show Elements: All Eleme... Volume Units: ○ IN ● ACRE-FT Sorting: Hydrolo...

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (ACRE-FT)
A-17	0.25202	13.9	24May2020, 00:00	6.9
A-18	0.18006	9.4	24May2020, 00:00	4.7
Junction-1	0.43208	23.2	24May2020, 00:00	11.6
A-21	0.26318	11.5	24May2020, 00:00	5.7
A-19	0.20049	10.4	24May2020, 00:00	5.2
A-20	0.13161	3.7	24May2020, 00:00	1.8
A-11	0.12561	6.5	24May2020, 00:00	3.3
Junction-2	1.15297	55.5	24May2020, 00:00	27.6
A-23	0.30219	11.7	24May2020, 00:00	5.8
A-12	0.24403	12.7	24May2020, 00:00	6.3
A-22	0.16564	8.1	24May2020, 00:00	4.0
A-15	0.0946919	4.4	24May2020, 00:00	2.2
A-14	0.0933807	4.6	24May2020, 00:00	2.3
A-16	0.0871293	4.0	24May2020, 00:00	2.0
Junction-4	0.9870619	45.6	24May2020, 00:00	22.7
A-10	0.27656	8.9	24May2020, 00:00	4.4
A-6	0.23118	9.0	24May2020, 00:00	4.5
A-8	0.20617	7.5	24May2020, 00:00	3.7
A-7	0.14438	3.8	24May2020, 00:00	1.9
A-9	0.12073	4.7	24May2020, 00:00	2.3
Junction-3	0.97902	33.9	24May2020, 00:00	16.8
A-2	0.292012	12.0	24May2020, 00:00	6.0
A-5	0.25247	9.2	24May2020, 00:00	4.6
A-3	0.14636	6.8	24May2020, 00:00	3.4
A-4	0.10973	4.5	24May2020, 00:00	2.2
A-1	0.085	3.1	24May2020, 00:00	1.5
Junction-5	0.885572	35.7	24May2020, 00:00	17.7
Junction-6	4.0046239	170.7	24May2020, 00:00	84.8



Global Summary Results for Run "100-Year"

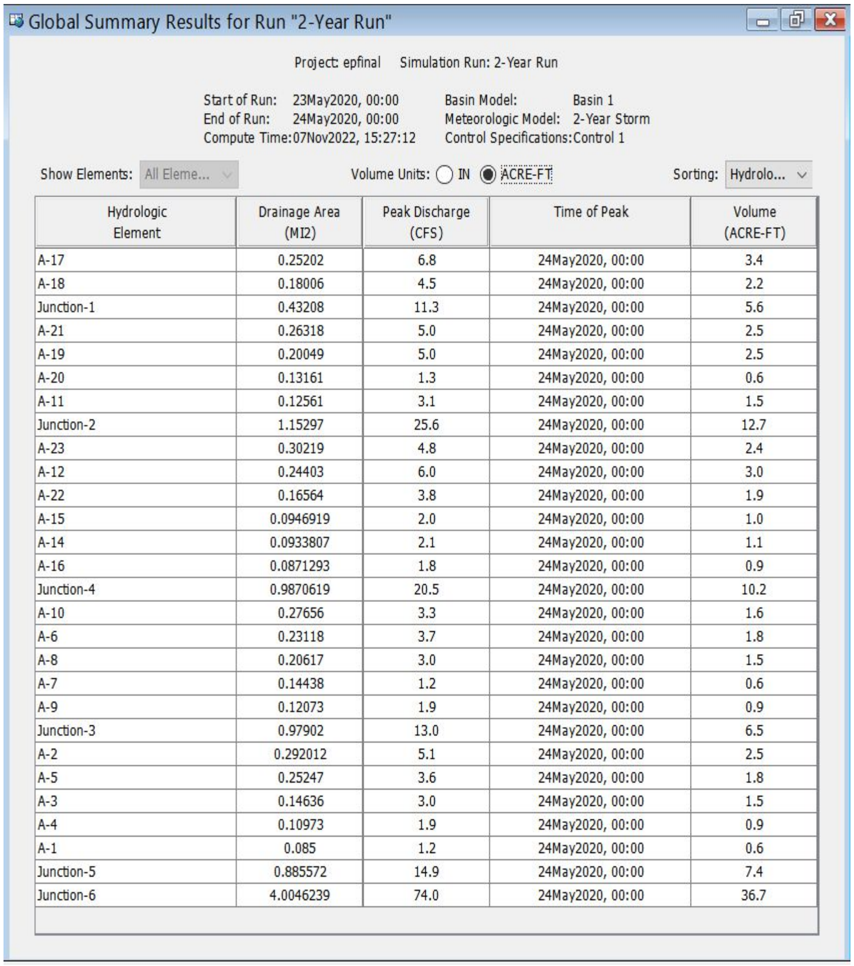
Project: epfinal Simulation Run: 100-Year

Start of Run: 23May2020, 00:00
End of Run: 24May2020, 00:00
Compute Time:07Nov2022, 15:39:56

Basin Model: Basin 1
Meteorologic Model: 100-Year Storm
Control Specifications:Control 1

Show Elements: All Eleme... Volume Units: ○ IN ● ACRE-FT Sorting: Hydrolo...

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (ACRE-FT)
A-17	0.25202	24.9	24May2020, 00:00	12.5
A-18	0.18006	17.2	24May2020, 00:00	8.6
Junction-1	0.43208	42.1	24May2020, 00:00	21.0
A-21	0.26318	22.3	24May2020, 00:00	11.1
A-19	0.20049	19.1	24May2020, 00:00	9.5
A-20	0.13161	8.3	24May2020, 00:00	4.1
A-11	0.12561	12.0	24May2020, 00:00	6.0
Junction-2	1.15297	103.8	24May2020, 00:00	51.7
A-23	0.30219	23.6	24May2020, 00:00	11.7
A-12	0.24403	23.3	24May2020, 00:00	11.6
A-22	0.16564	15.2	24May2020, 00:00	7.6
A-15	0.0946919	8.4	24May2020, 00:00	4.1
A-14	0.0933807	8.6	24May2020, 00:00	4.3
A-16	0.0871293	7.7	24May2020, 00:00	3.8
Junction-4	0.9870619	86.7	24May2020, 00:00	43.1
A-10	0.27656	19.1	24May2020, 00:00	9.5
A-6	0.23118	18.1	24May2020, 00:00	9.0
A-8	0.20617	15.5	24May2020, 00:00	7.7
A-7	0.14438	8.7	24May2020, 00:00	4.3
A-9	0.12073	9.4	24May2020, 00:00	4.7
Junction-3	0.97902	70.8	24May2020, 00:00	35.1
A-2	0.292012	23.8	24May2020, 00:00	11.8
A-5	0.25247	18.9	24May2020, 00:00	9.4
A-3	0.14636	12.9	24May2020, 00:00	6.4
A-4	0.10973	8.9	24May2020, 00:00	4.4
A-1	0.085	6.4	24May2020, 00:00	3.2
Junction-5	0.885572	71.0	24May2020, 00:00	35.2
Junction-6	4.0046239	332.2	24May2020, 00:00	165.1



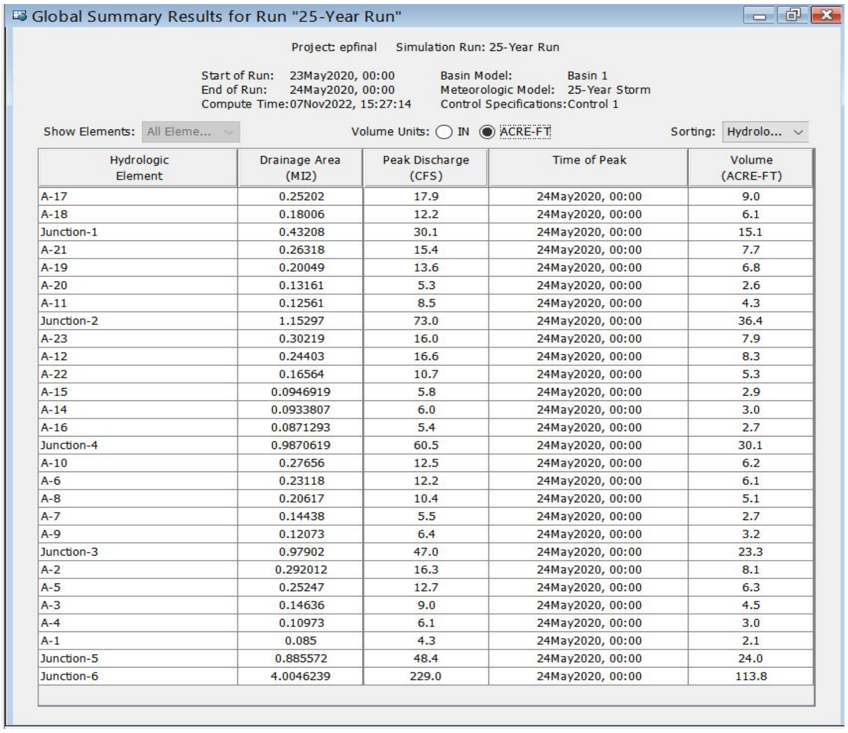
Global Summary Results for Run "2-Year Run"

Project: epfinal   Simulation Run: 2-Year Run

Start of Run: 23May2020, 00:00   Basin Model: Basin 1
End of Run: 24May2020, 00:00   Meteorologic Model: 2-Year Storm
Compute Time: 07Nov2022, 15:27:12   Control Specifications: Control 1

Show Elements: All Eleme...   Volume Units: ○ IN ● ACRE-FT   Sorting: Hydrolo...

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (ACRE-FT)
A-17	0.25202	6.8	24May2020, 00:00	3.4
A-18	0.18006	4.5	24May2020, 00:00	2.2
Junction-1	0.43208	11.3	24May2020, 00:00	5.6
A-21	0.26318	5.0	24May2020, 00:00	2.5
A-19	0.20049	5.0	24May2020, 00:00	2.5
A-20	0.13161	1.3	24May2020, 00:00	0.6
A-11	0.12561	3.1	24May2020, 00:00	1.5
Junction-2	1.15297	25.6	24May2020, 00:00	12.7
A-23	0.30219	4.8	24May2020, 00:00	2.4
A-12	0.24403	6.0	24May2020, 00:00	3.0
A-22	0.16564	3.8	24May2020, 00:00	1.9
A-15	0.0946919	2.0	24May2020, 00:00	1.0
A-14	0.0933807	2.1	24May2020, 00:00	1.1
A-16	0.0871293	1.8	24May2020, 00:00	0.9
Junction-4	0.9870619	20.5	24May2020, 00:00	10.2
A-10	0.27656	3.3	24May2020, 00:00	1.6
A-6	0.23118	3.7	24May2020, 00:00	1.8
A-8	0.20617	3.0	24May2020, 00:00	1.5
A-7	0.14438	1.2	24May2020, 00:00	0.6
A-9	0.12073	1.9	24May2020, 00:00	0.9
Junction-3	0.97902	13.0	24May2020, 00:00	6.5
A-2	0.292012	5.1	24May2020, 00:00	2.5
A-5	0.25247	3.6	24May2020, 00:00	1.8
A-3	0.14636	3.0	24May2020, 00:00	1.5
A-4	0.10973	1.9	24May2020, 00:00	0.9
A-1	0.085	1.2	24May2020, 00:00	0.6
Junction-5	0.885572	14.9	24May2020, 00:00	7.4
Junction-6	4.0046239	74.0	24May2020, 00:00	36.7



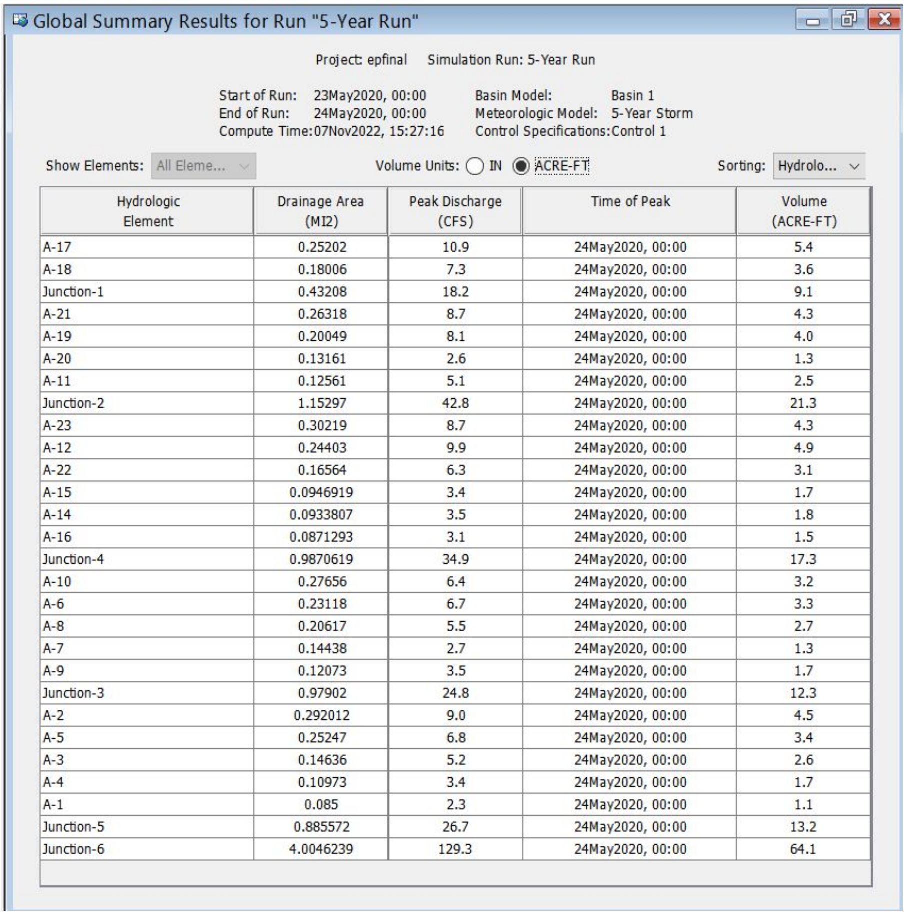
Global Summary Results for Run "25-Year Run"

Project: epfinal   Simulation Run: 25-Year Run

Start of Run: 23May2020, 00:00   Basin Model: Basin 1
End of Run: 24May2020, 00:00   Meteorologic Model: 25-Year Storm
Compute Time: 07Nov2022, 15:27:14   Control Specifications: Control 1

Show Elements: All Eleme...   Volume Units: ○ IN ● ACRE-FT   Sorting: Hydrolo...

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (ACRE-FT)
A-17	0.25202	17.9	24May2020, 00:00	9.0
A-18	0.18006	12.2	24May2020, 00:00	6.1
Junction-1	0.43208	30.1	24May2020, 00:00	15.1
A-21	0.26318	15.4	24May2020, 00:00	7.7
A-19	0.20049	13.6	24May2020, 00:00	6.8
A-20	0.13161	5.3	24May2020, 00:00	2.6
A-11	0.12561	8.5	24May2020, 00:00	4.3
Junction-2	1.15297	73.0	24May2020, 00:00	36.4
A-23	0.30219	16.0	24May2020, 00:00	7.9
A-12	0.24403	16.6	24May2020, 00:00	8.3
A-22	0.16564	10.7	24May2020, 00:00	5.3
A-15	0.0946919	5.8	24May2020, 00:00	2.9
A-14	0.0933807	6.0	24May2020, 00:00	3.0
A-16	0.0871293	5.4	24May2020, 00:00	2.7
Junction-4	0.9870619	60.5	24May2020, 00:00	30.1
A-10	0.27656	12.5	24May2020, 00:00	6.2
A-6	0.23118	12.2	24May2020, 00:00	6.1
A-8	0.20617	10.4	24May2020, 00:00	5.1
A-7	0.14438	5.5	24May2020, 00:00	2.7
A-9	0.12073	6.4	24May2020, 00:00	3.2
Junction-3	0.97902	47.0	24May2020, 00:00	23.3
A-2	0.292012	16.3	24May2020, 00:00	8.1
A-5	0.25247	12.7	24May2020, 00:00	6.3
A-3	0.14636	9.0	24May2020, 00:00	4.5
A-4	0.10973	6.1	24May2020, 00:00	3.0
A-1	0.085	4.3	24May2020, 00:00	2.1
Junction-5	0.885572	48.4	24May2020, 00:00	24.0
Junction-6	4.0046239	229.0	24May2020, 00:00	113.8

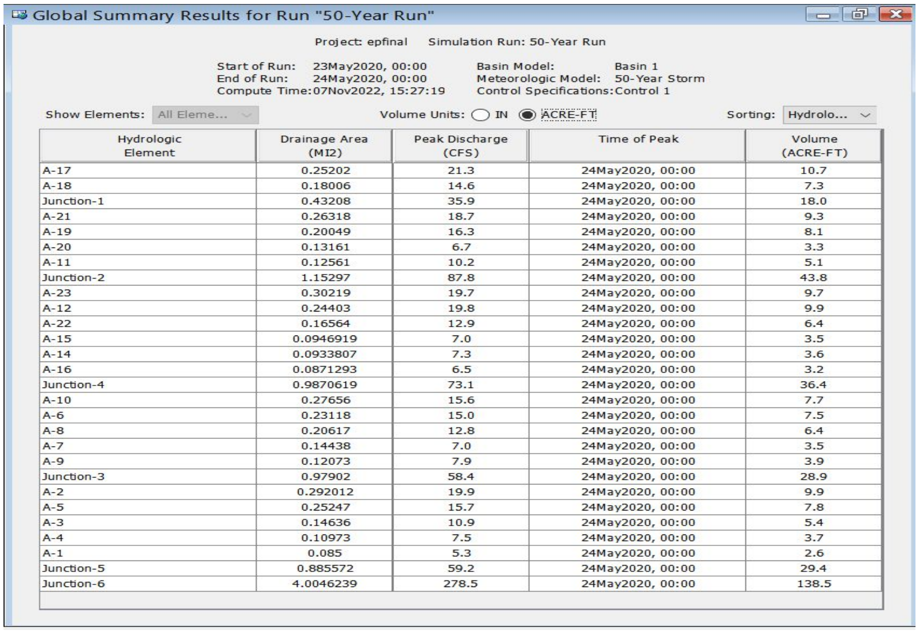


Project: epfinal   Simulation Run: 5-Year Run

Start of Run: 23May2020, 00:00   Basin Model: Basin 1
End of Run: 24May2020, 00:00   Meteorologic Model: 5-Year Storm
Compute Time: 07Nov2022, 15:27:16   Control Specifications: Control 1

Show Elements: All Eleme...   Volume Units: ○ IN ● ACRE-FT   Sorting: Hydrolo...

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (ACRE-FT)
A-17	0.25202	10.9	24May2020, 00:00	5.4
A-18	0.18006	7.3	24May2020, 00:00	3.6
Junction-1	0.43208	18.2	24May2020, 00:00	9.1
A-21	0.26318	8.7	24May2020, 00:00	4.3
A-19	0.20049	8.1	24May2020, 00:00	4.0
A-20	0.13161	2.6	24May2020, 00:00	1.3
A-11	0.12561	5.1	24May2020, 00:00	2.5
Junction-2	1.15297	42.8	24May2020, 00:00	21.3
A-23	0.30219	8.7	24May2020, 00:00	4.3
A-12	0.24403	9.9	24May2020, 00:00	4.9
A-22	0.16564	6.3	24May2020, 00:00	3.1
A-15	0.0946919	3.4	24May2020, 00:00	1.7
A-14	0.0933807	3.5	24May2020, 00:00	1.8
A-16	0.0871293	3.1	24May2020, 00:00	1.5
Junction-4	0.9870619	34.9	24May2020, 00:00	17.3
A-10	0.27656	6.4	24May2020, 00:00	3.2
A-6	0.23118	6.7	24May2020, 00:00	3.3
A-8	0.20617	5.5	24May2020, 00:00	2.7
A-7	0.14438	2.7	24May2020, 00:00	1.3
A-9	0.12073	3.5	24May2020, 00:00	1.7
Junction-3	0.97902	24.8	24May2020, 00:00	12.3
A-2	0.292012	9.0	24May2020, 00:00	4.5
A-5	0.25247	6.8	24May2020, 00:00	3.4
A-3	0.14636	5.2	24May2020, 00:00	2.6
A-4	0.10973	3.4	24May2020, 00:00	1.7
A-1	0.085	2.3	24May2020, 00:00	1.1
Junction-5	0.885572	26.7	24May2020, 00:00	13.2
Junction-6	4.0046239	129.3	24May2020, 00:00	64.1

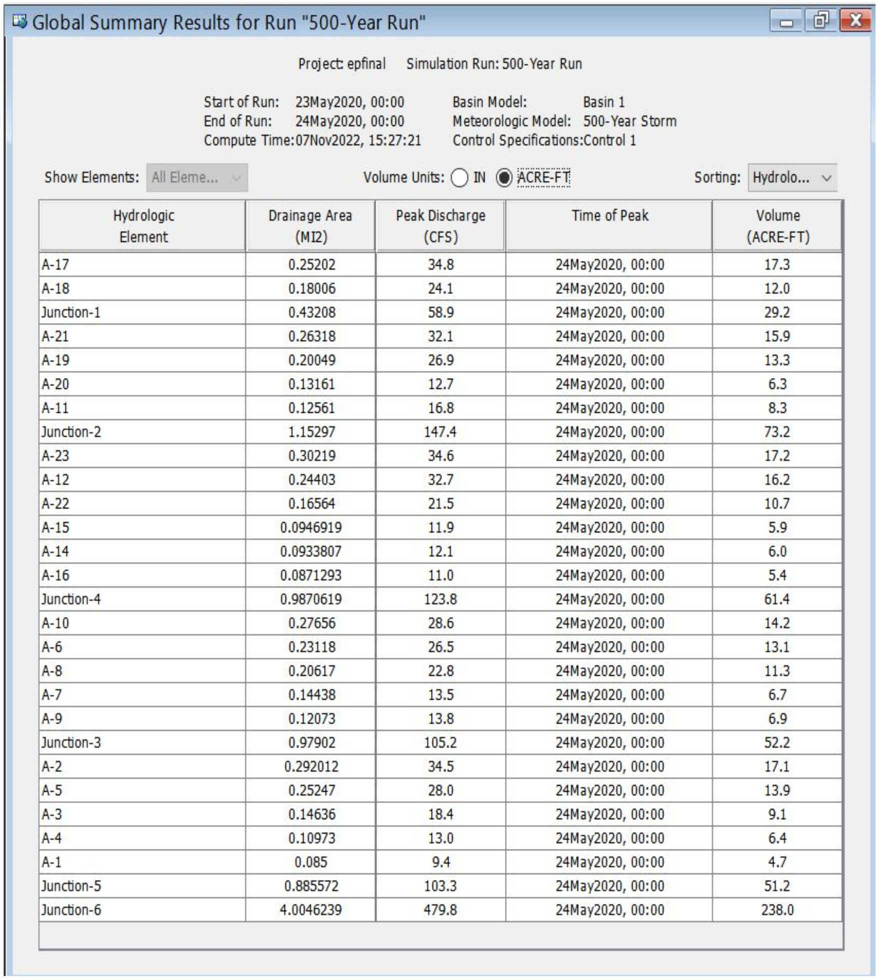


Project: epfinal   Simulation Run: 50-Year Run

Start of Run: 23May2020, 00:00   Basin Model: Basin 1
End of Run: 24May2020, 00:00   Meteorologic Model: 50-Year Storm
Compute Time: 07Nov2022, 15:27:19   Control Specifications: Control 1

Show Elements: All Eleme...   Volume Units: ○ IN ● ACRE-FT   Sorting: Hydrolo...

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (ACRE-FT)
A-17	0.25202	21.3	24May2020, 00:00	10.7
A-18	0.18006	14.6	24May2020, 00:00	7.3
Junction-1	0.43208	35.9	24May2020, 00:00	18.0
A-21	0.26318	18.7	24May2020, 00:00	9.3
A-19	0.20049	16.3	24May2020, 00:00	8.1
A-20	0.13161	6.7	24May2020, 00:00	3.3
A-11	0.12561	10.2	24May2020, 00:00	5.1
Junction-2	1.15297	87.8	24May2020, 00:00	43.8
A-23	0.30219	19.7	24May2020, 00:00	9.7
A-12	0.24403	19.8	24May2020, 00:00	9.9
A-22	0.16564	12.9	24May2020, 00:00	6.4
A-15	0.0946919	7.0	24May2020, 00:00	3.5
A-14	0.0933807	7.3	24May2020, 00:00	3.6
A-16	0.0871293	6.5	24May2020, 00:00	3.2
Junction-4	0.9870619	73.1	24May2020, 00:00	36.4
A-10	0.27656	15.6	24May2020, 00:00	7.7
A-6	0.23118	15.0	24May2020, 00:00	7.5
A-8	0.20617	12.8	24May2020, 00:00	6.4
A-7	0.14438	7.0	24May2020, 00:00	3.5
A-9	0.12073	7.9	24May2020, 00:00	3.9
Junction-3	0.97902	58.4	24May2020, 00:00	28.9
A-2	0.292012	19.9	24May2020, 00:00	9.9
A-5	0.25247	15.7	24May2020, 00:00	7.8
A-3	0.14636	10.9	24May2020, 00:00	5.4
A-4	0.10973	7.5	24May2020, 00:00	3.7
A-1	0.085	5.3	24May2020, 00:00	2.6
Junction-5	0.885572	59.2	24May2020, 00:00	29.4
Junction-6	4.0046239	278.5	24May2020, 00:00	138.5



Global Summary Results for Run "500-Year Run"

Project: epfinal   Simulation Run: 500-Year Run

Start of Run: 23May2020, 00:00   Basin Model: Basin 1
End of Run: 24May2020, 00:00   Meteorologic Model: 500-Year Storm
Compute Time: 07Nov2022, 15:27:21   Control Specifications: Control 1

Show Elements: All Eleme...   Volume Units: ○ IN ● ACRE-FT   Sorting: Hydrolo...

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (ACRE-FT)
A-17	0.25202	34.8	24May2020, 00:00	17.3
A-18	0.18006	24.1	24May2020, 00:00	12.0
Junction-1	0.43208	58.9	24May2020, 00:00	29.2
A-21	0.26318	32.1	24May2020, 00:00	15.9
A-19	0.20049	26.9	24May2020, 00:00	13.3
A-20	0.13161	12.7	24May2020, 00:00	6.3
A-11	0.12561	16.8	24May2020, 00:00	8.3
Junction-2	1.15297	147.4	24May2020, 00:00	73.2
A-23	0.30219	34.6	24May2020, 00:00	17.2
A-12	0.24403	32.7	24May2020, 00:00	16.2
A-22	0.16564	21.5	24May2020, 00:00	10.7
A-15	0.0946919	11.9	24May2020, 00:00	5.9
A-14	0.0933807	12.1	24May2020, 00:00	6.0
A-16	0.0871293	11.0	24May2020, 00:00	5.4
Junction-4	0.9870619	123.8	24May2020, 00:00	61.4
A-10	0.27656	28.6	24May2020, 00:00	14.2
A-6	0.23118	26.5	24May2020, 00:00	13.1
A-8	0.20617	22.8	24May2020, 00:00	11.3
A-7	0.14438	13.5	24May2020, 00:00	6.7
A-9	0.12073	13.8	24May2020, 00:00	6.9
Junction-3	0.97902	105.2	24May2020, 00:00	52.2
A-2	0.292012	34.5	24May2020, 00:00	17.1
A-5	0.25247	28.0	24May2020, 00:00	13.9
A-3	0.14636	18.4	24May2020, 00:00	9.1
A-4	0.10973	13.0	24May2020, 00:00	6.4
A-1	0.085	9.4	24May2020, 00:00	4.7
Junction-5	0.885572	103.3	24May2020, 00:00	51.2
Junction-6	4.0046239	479.8	24May2020, 00:00	238.0

Vita

Isabel Lopez obtained her undergraduate degree in Civil Engineering from the University of Texas at El Paso in 2020. In January 2021, she began to pursue her Master of Environmental Engineering. She completes training and research development in environmental science, remote sensing technology and electric vehicle adoption. Isabel Lopez has been a Graduate Research Assistant at the University of Texas at El Paso for two years pursuing a master's degree in environmental engineering. As graduate research assistant she has also participated in projects investigating the access of electric vehicle chargers and investigated social and economic disparities in their distribution and location. Currently her research focuses on exploring alternatives to reduce sunny-day flooding through use of active rainwater harvesting using a Land Use Land Cover (LULC) classification method in GIS. Additionally, her focus is to obtain communities perceptions, opinions and knowledge through mixed-methods survey and correlate that to the solutions presented. From the socio-economic part of her research, she has a publication "How Active Rainwater Harvesting May Help Reduce Nuisance Flooding: Flood Analysis and Social Barriers to Adoption" in the American Society of Engineering Education (ASEE) where it was awarded "Best Diversity Paper".