RAINWATER HARVESTING AT THE UNIVERSITY OF ARIZONA

A Cost-Benefit Analysis, Case Study and Research Paper on Two Buildings on Campus: The Environmental and Natural Resources 2 Building and the College of Architecture, Planning, and Landscape Architecture.

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INTRODUCTION

“Sustainability is based on a simple principle: everything that we need for our survival and well-being depends, either directly or indirectly, on our natural environment. To pursue sustainability is to create and maintain the conditions under which humans and nature can exist in productive harmony to support present and future generations” (United States Environmental Protection Agency, 2016). Productivity increases the overall efficiency of the planet – creating technological advances and new products that can be used towards the future of sustainability. Research done by the United States Environmental Protection Agency explains that sustainability comes in many different forms and practices, though sustainable water management is the largest and most important issue needing to be addressed as water availability is decreasing rapidly across the globe.

Water has always been the most important natural resource on Earth. It is essential for health, productivity, and growth as life cannot be sustained without it. Climate change has become a major issue on the planet and of all the harmful effects that come with climate change, drought and water scarcity is one of the most worrisome. In 2012, 81 percent of the United States was living in extremely or abnormally dry conditions (Center for Climate and Energy Solutions, 2017). An article from the United Nations also states several facts and figures that are astonishing:

- 2.6 billion people have gained access to improved drinking water sources since 1990, but 663 million people are still without proper drinking water.
- At least 1.8 billion people globally use a source of drinking water that is fecally contaminated.
- 2.4 billion people lack access to basic sanitation services, such as latrines and toilets.
- Each day, nearly 1,000 children die due to preventable water and sanitation-related diarrheal diseases.
- Approximately 70 percent of all water abstracted from rivers, lake and aquifers is used for irrigation.
- Water scarcity affects more than 40 percent of the global population and is projected to rise to over 783 million people who will not have access to clean water. Over 1.7 billion people are currently living in river basins where water use exceeds recharge.
As many as 1.8 billion people lack the access to fresh water for drinking (United Nations, 2017). This has become a major problem among third world countries that do not have access to expensive, technologically advanced water treatment and filtration systems. Water is not only essential for humans and other life forms to stay alive, it is also crucial for social and economic development, agriculture, industry, and other types of food production. However, only 0.5 percent of the world’s water resources are available for nutritional needs for the world’s population and ecosystems. It has become necessary to explore viable options that can help solve access to water. Rainwater harvesting may be one such option.

For years, drought has been a frequent, long time issue in the arid southwest. This is mainly due to changes in land use and the impacts that have resulted and affected the ecology and hydrology of the landscape. An article entitled “Rethinking Water in The Arid Southwest: The Need for A New Framework for Managing Water in Arizona”, by Anderson et al. (2007), states that drought can be linked to two criteria and “the changing landscape of the American Southwest, however, is a direct result of both human activity and climate”. Groundwater has played an important role in the arid southwest - contributing to human development and helping to maintain natural ecosystems within this community, as well as maintaining the natural flows of both streams and rivers. It has also provided humans with drinking water and has helped to support agriculture within communities. However, “population expansion has not been without consequences. It has led to increasing groundwater withdrawals that are outpacing the rate at which the vital resource is naturally replenished. As a result, the region’s groundwater resources are among the most overused in the United States” (Guido, 2008). As the growth of these areas and water demand are only increasing, the water supply is going to drastically decrease, and this will, in turn, effect water consumption in a major way.

Before exploring widespread use, however, a case study could be a useful way to explore rainwater harvesting on a large scale. If we can analyze the efficiency and cost effectiveness of systems already installed, we can begin making an argument for further use. For example, installing rainwater harvesting systems on several buildings at
the University of Arizona could benefit the campus as well as save large amounts of water within the desert city of Tucson, Arizona. The University of Arizona’s College of Architecture, Planning, and Landscape Architecture (CAPLA), has installed a rainwater collection system on the 36,000 square-foot building – collecting about 269,000 gallons of rainwater per year for use within the building (irrigation, water fountains, etc.). The Underwood Family Sonoran Landscape Laboratory (SLL), which is located within CAPLA, won several “Crescordia” awards at the 2017 Environmental Excellence Award Gala. The awards were given by a consortium of large and small business, government jurisdictions, and education/non-profit communities called Arizona Forward. The “Crescordia” awards given were the highest honors given out by Arizona Forward which promotes the improvement of the environment and quality of life in the region (Valdez, 2017). They encourage the balance between economic development and environmental quality as well. Arizona Forward recognizes the SLL’s rainwater harvesting system that was installed on CAPLA. “The SLL harvests water to create and sustain five biomes. Water is harvested from roof runoff, heating and air-conditioning condensate and drinking fountains into an 11,600-gallon cistern, and then used to irrigate native low-water-use plants and source a pond. The A/C condensate alone contributes 95,000 gallons of water annually with 85,000 gallons coming from rainwater, saving 230,000 gallons per year in potable water” (Valdez, 2017).

By installing rainwater collection systems on the University of Arizona campus, a large amount of money, as well as water, will be saved by the University, creating a more sustainable environment. Because water is becoming less available and because we live in a desert landscape where water is already scarce, these systems – if installed all around Tucson – could greatly improve the landscape. Various businesses and residents around town could use this knowledge for their personal gain, and the City of Tucson could use this knowledge to create incentives and programs for those who might be on the fence about installing the systems. As Han (2017) states, “the potential for rainwater harvesting and management (RWHM) to reduce water consumption, alleviate storm water runoff and provide drinking water, has largely been neglected in the modern era. In part, this is due to local context, such as seasonal variability in rainfall, costs of storage, treatment and retrofitting water systems, as well as policy and
institutional barriers. Add to this short-sighted water management policies that rely on the overexploitation of river water or groundwater."

While there are some other water conservation techniques and practices out there, rainwater harvesting is the most beneficial practice of them all. With 50 percent to 70 percent of all water usage being used for household or irrigation purposes, that leaves a small percentage for the essential functions of drinking water and food production. It is a low cost and high value solution that can create a greener community and environment for us all.

This study focuses on answering whether these systems reap more benefits than the costs associated: What is the cost-benefit analysis of installing rainwater harvesting systems on the University of Arizona campus and how can we expand this practice? How can certain buildings on campus become less of a scarce water burden? What will the long-term impact be? These questions will be answered through a case study of the College of Architecture, Planning, and Landscape Architecture, along with another building on campus such as the Environmental and Natural Resources 2 building, using qualitative data in a mixed-use research paper. Within this case study, there will be a cost-benefit analysis on the two buildings showing costs, volume of water harvested, and other benefits associated to the collection systems.

**LITERARY REVIEW**

Sustainability can be defined as meeting the needs of the present without compromising the ability of future generations to meet their needs (Brundtland Commission, 2016). Within sustainability, there are three pillars: the economic pillar, the environmental pillar, and the social equity pillar. These pillars can also be named profits, planet, and people. These three pillars of sustainability were first introduced after much public concern about long term damage created by short term products, profits, and practices. "Sustainability encourages business to frame decisions in terms of years and decades rather than on the next quarter’s earnings report, and to consider more factors than simply the profit or loss involved" (Brundtland Commission, 2016).
Rainwater Harvesting Defined

The natural resource of water falls within all three pillars of sustainability. Rainwater harvesting is one method of extending this limited resource. Rainwater harvesting is the collection of water from surfaces on which rain falls and then storing the collected rainwater for later use. It is used for many things including drinking and irrigation purposes. Thus, it has become a wonderful solution to the decreasing water situation. “Rainwater systems counteract storm water runoff and thereby reduce flooding, erosion, and groundwater contamination. Taking water out of our lakes, reservoirs, and rivers also affects ground water. On the other hand, irrigating with rainwater helps replenish groundwater supplies” (Eco Vie Water Management Systems, 2017).

History of Rainwater Harvesting

With the world population growing at a rapid pace, water resources are becoming less available and even scarce in some countries. Different types of water management tools have been designed and used; however, water harvesting has proven to be a successful solution in the battle against water availability. “The capturing and storing of rainwater goes back thousands of years to when we first started to farm the land and needed to find new ways of irrigating crops. In hotter climes, catching that intermittent rainfall often meant the difference between life and death for communities. Whilst the need to conserve water fell away with great urbanization in the last thousand years, we are once again returning to this ancient and vital part of greener living” (History of Rainwater Harvesting, 2016). Because this practice extends back thousands of years, it is not a new technology. As we have seen in previous civilizations, small dams as well as runoff control have been introduced for agricultural purposes. In ancient times, civilizations located in the Indus Valley were among the first to create versions of rainwater harvesting systems. Huge vats cut into cliff faces in order to collect water runoff from rainfall have been found in the ancient cities that are still standing today. Used to maintain the vegetation and population of these ancient cities, these vats were filled by “numerous stone gullies that weaved their way through the city” (History of Rainwater Harvesting, 2016).
The United States of America Renewable Energy Hub explains that the history of rainwater harvesting can also be traced back hundreds of years to civilizations in India. The rainwater harvesting systems found in these civilizations have spread to countries like Brazil and China and involve installing the systems on top of the houses in order for rainwater to directly collect in the vat.

India's civilizations were not the only people who were advanced in these ancient times. The Romans saw rainwater harvesting and collection as an art form and scientific practice. “During the time of the Roman empire, many new cities incorporated state of the art technology for the time” (History of Rainwater Harvesting, 2016). It was found that in Istanbul, there is a rainwater harvesting system that is so large, sailing is the only way to get around it.
Rainwater and Quality

The journey into the rainwater harvesting system is not the cleanest. Water quality refers to the chemical, physical, biological, and radiological characteristics of water. It measures the condition of water relative to the requirements of one or more biotic species and or to any human need or purpose (United States Environmental Protection Agency, 2016). The rain hits the roofs and collects organic material that has been lying on the roof for days. There are several methods to make rainwater suitable for drinking, such as naturally filtered through solar distillation. This short-term fix is best used for emergency water situations and the long-term rainwater filtration method is best used for any other type of need.

Another short-term rainwater filtration fix is a forward-osmosis technology that, “is designed to convert dirty water into a liquid that is safe to drink using a semi-permeable membrane and a concentrated sugar solution” (NASA, 2017). Although this fix is a perfect tool in an emergency situation, it does have its limitations, thus, not making it suitable for household water options. The long-term fix is a larger-scale filtration system involving processes like reverse osmosis. Reverse osmosis “is a pressure-driven
membrane separation process. Water is forced through a membrane with small pores by pressures ranging from 100 to 150 psi (pounds per square inch). Any molecules larger than the pore openings are excluded from the product stream along with a significant portion of the water. Treated water is collected on the other side” (United States Environmental Protection Agency, 2015). These systems cost more but are worth the cost. These systems will allow for water that is suitable for drinking.

**Rainwater Harvesting Examples**

In modern times, rainwater harvesting has come in many different forms and found in many different locations. For example, the United States National Volcano Park in Hawaii has installed rainwater harvesting systems that are made to supply 1,000 employees of the park, as well as up to 10,000 visitors of the park each day. “The Park’s rainwater utilization system includes the rooftop of a building with an area of 0.4 hectares, a ground catchment area of more than two hectares, storage tanks with two reinforced concrete water tanks with 3,800 m3 capacity each, and 18 redwood water tanks with 95 m3 capacity each” (United Nations Environment Programme, 2016). Additionally, the Park installed several other collection systems on smaller buildings, as well as the installment of a water treatment and pumping plant to ensure safe drinking water for employees, residents, and visitors.

Other examples of rainwater harvesting systems outside of the United States are located in Singapore and Thailand. Singapore, being the small island nation that it is, has issues with water demand and limited land resources. Because of this, the country has been searching for different ways and practices of harvesting water for its residents. In order to do so, light roofing is placed on top of residential high-rise buildings in order
to act as catchment for rainwater. The water that is collected is then kept in cisterns on top of the roofs for non-potable use. At the Changi airport in Singapore, a larger rainwater harvesting system is present. The rainfall from the runways of the airport, as well as the forest and green areas surrounding the airport, is diverted into two different reservoirs located close to the property. “One of the reservoirs is designed to balance the flows during the coincident high runoffs and incoming tides, and the other reservoir is used to collect the runoff. The water is used primarily for non-potable functions such as firefighting drills and toilet flushing. Such collected and treated water accounts for 28 – 33 percent of the total water used” (United Nations Environment Programme, 2016). In Thailand, rainwater from rooftops is stored in jars called run-off jars. The jars come in many different sizes and are considered the most appropriate and inexpensive ways to store safe drinking water for residents in the country. Because of the success of these jars, the government within Thailand has decided to design and implement rainwater harvesting programs for the nation.

Legal Issues Surrounding Rainwater Harvesting

There are numerous interesting examples in Colorado, Oregon and others where it is highly regulated how much water you can capture, or, if you can capture any at all. In some places, you cannot capture any amount of water because it is deemed the property of those downstream in the watershed.

In Colorado, “the collection of rainwater for beneficial use has been recognized as a potential injury to senior water rights in the past, and, therefore, was historically prohibited in Colorado” (Meehan, 2017). A study was conducted in 2007 by the Colorado Water Conservation Board, as well as nearby districts, and Douglas County to figure out how much rain truly reached the ground in their area. The study determined that as little as 3 percent of rainfall actually reached the ground. In an article written in the Los Angeles Times, by Nicholas Riccardi, it explained that in the state of Colorado, “the rain that falls is not yours to keep. It should be allowed to fall to the ground and flow unimpeded into surrounding creeks and streams, the law states, to become the property of farmers, ranchers, developers and water agencies that have bought the rights to those waterways” (Riccardi, 2009). The laws in the state of Colorado regarding water harvesting are tricky and complicated, however, organic farmers and “urban dreamers”
are pushing to pass a law that will legalize the harvesting of rainwater for use among their businesses or residences.

In the state of Oregon, it is not illegal to collect rain water. This is true only if you have a water rights permit to use public water. However, some exceptions can be made for the general public to capture rainwater in a barrel, bucket, tub or rain gauge. In an article by an Oregon newspaper called the "Mail Tribune", in 2012, a resident of Oregon by the name of Mr. Harrington was sentenced to 1 month in jail for “unauthorized use of water”. Mr. Harrington apparently built dams across channels of public water that was running across his property and collected over 40-acre feet of water for reuse. This amount of water is unfathomable – “enough to fill 20 Olympic size swimming pools” (Gonzalez, 2015). With these 40-acre feet of water, he stocked his brand-new reservoirs with ducks, boats, and fish for recreational fishing. Laws in different states have been put in place in order to prevent instances like these from happening – to create fairness among residents throughout different states. However, so long as the capture volume does not exceed reasonable use, there are few issues in most states.

**METHODOLOGY**

This capstone will focus on rainwater harvesting and how to expand it on campus at the University of Arizona. In order to conduct the research for this capstone, a mixed methods approach will be utilized. On the qualitative side, I will be conducting observations, using photographs, documents, and informal interviews. Collecting the qualitative data will provide me with insight on the costs associated in the building of the rainwater harvesting systems, what benefits will be shown in either the long term or short term, what the advantages and disadvantages are regarding costs, and what the building materials needed will be.

A case study approach will be utilized and is a “process or record of research in which detailed consideration is given to the development of a particular person, group, or situation over a period of time” (UNSW, 2017). A case study including a cost benefit analysis would be beneficial in the following ways:

- It can simplify the complex concept of rainwater harvesting and low-water usage.
● Exposes the campus to real-life rainwater harvesting that is already on campus.
● It will add value to everyone’s opinions.
● The solutions that can come out of the case study will majorly benefit the U of A – financially and environmentally.
● It will improve analytical thinking, communication, and help to develop tolerance for different views on this subject.

The capstone will focus on the College of Architecture, Planning and Landscape Architecture (CAPLA) and the Environmental and Natural Resources, Phase 2, (ENR2) buildings. The aim is to collect different types of data such as costs and volume of water that can and is harvested. From those two comparisons, we will identify several different buildings on campus that would greatly benefit from having a rainwater harvesting system installed on them. Finally, a cost benefit analysis will be utilized on these selected buildings to provide more proof that rainwater harvesting is extremely beneficial and will save money as well as benefit the University of Arizona campus and our environment.

DATA, DISCUSSION, AND RESULTS

Case Study One: ENR 2
The University of Arizona has recently completed the construction of a new building on campus for environmental and natural resources studies that has a major contribution to the decrease of water use on campus. The initiative for the building was
to go “beyond LEED” certifications and explore new solutions to different types of architecture in the desert environment. While there are both passive and active water harvesting systems involved in the building, it also has many different sustainable components incorporated within its walls – it majorly minimizes energy and water use in its design. “The environmental mission of the facility compels a fundamental response to our region, context environment, sense of place and the special qualities of the Southwest and the Sonoran Desert. The project borrows from the iconic imagery of our region: striking landforms of canyon and mesa, the dramatic play of light, shade and shadow, the painted sky of sunsets, desert monsoons, highly adapted plants and animals” (Sustainability, 2018). Completed in June 2015, the building is categorized as a LEED Platinum building and leads the way for many other buildings on campus.

After much research and interest in this building, I was able to meet with Mark Novak, the Landscape Architect for the University of Arizona, to have him answer some questions that I had about the building in question. Mr. Novak explained to me that the inspiration for the extensive rainwater harvesting system that was installed in the ENR2 building was really thought through. The aspect they were trying to get across was the integration of landscapes and to create a landscaped interior.

Included in the building are southwest courtyards for students, faculty, and visitors to gather in – enclosed spaces where the landscapes focus on the interior of the buildings, while the walkways are on the exterior of the building. More money was spent on the different landscape terraces, which are located on each level of the building and have tables and chairs so that the students can enjoy the environment that was created. Also, the landscape that is on each level of the building contributes to the cooling of the
building, while the large roof courtyard and active rainwater harvesting system helps with the watering and irrigation of the plants throughout the building.

After contacting the Facilities Project Manager for the University of Arizona, Chris Wilt, he explained to me that “the slot canyon inspired building design begged to celebrate rainfall – because the need to limit storm water runoff from the project, a rainwater/detention-collection system was required for those purposes – the water reuse system required a slightly larger tank and the added pumps, filters and controls to connect the tank to the irrigation system” (Wilt, 2018). This particular active rainwater harvesting system contributes to the sustainability of the building and creates not only a kind of environment that is comforting to the users but controls the temperature and lighting naturally. This building “is a part of the University of Arizona’ ongoing and concerted effort to promote interdisciplinary research that focuses on Earth Science and Environmental Programs. A key goal of this facility is to establish an atmosphere for collaboration of scientific and interdisciplinary research which creates opportunities for graduate students across multiple disciplines. Capitalizing on existing core disciplinary strengths will further establish the University of Arizona as a preeminent institution in basic earth sciences and environmental programs research. The location of the large high-tech auditorium in this project will produced undergraduate students the opportunity to experience a sustainability multi-discipline learning and research environment and participate in the outreach efforts developed by the occupants” (Sustainability, 2018).

How exactly does the rainwater harvesting system on the ENR2 building work? Mr. Novak explained that the water is captured on the roof and it then falls into the courtyard and drains into a 52,000-gallon underground storage tank that is located on the south side of the building. It is then filtered, pressurized, and pumped for the irrigation needs. In this particular building design, there is no wasted water in any of these processes and in case of a drought, if the tank is fully used up, it is then replenished with reclaimed water in order to keep providing water for the plants. Maggie Heard, the Administrative Associate and Building Manager for the Environmental and Natural Resources 2 building, added that “HVAC condensate and rainwater are collected into the tank and utilized for irrigating the landscaping throughout the building”.

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The maintenance on the building was an intriguing topic for me, as I was curious whether it was worth maintaining and if so, how often the building and system needed to be cleaned and maintained. Novak stated, "there is a little bit of a higher maintenance on this system because of the filtration and pumping equipment. However, it does not need to be maintained frequently – only when sediment needs to be cleaned (about every 5-7 years)". On top of this, there is a minimal amount of surface cleaning involved with this system – you basically just scoop out debris that is on the top of the tank in order to clean it. Because the building incorporates a standard irrigation system, there is not much maintenance within the building.

Finally, the entire pump and filtration systems are all managed by a centralized computer system so that it can all be monitored for leaks and problems. The system can detect a leak if there is one and shut down the entire system for fixing. Wilt also added that the systems pumps, and filters do require monitoring and maintenance – “the pumps require annual inspection and the filters are cartridge type and pressure drops are monitored quarterly as a minimum".
Another question that interested me was whether cost was a factor in this building or was sustainability the main purpose of the project. “It was recently a major factor because of the LEED requirements by the state. The buildings are to be Silver LEED certified. The costs depend on the programming, location, size, occupancy, and value to the occupants, and the interest with performance” (Novak, 2018). They would like to create more sustainable buildings throughout the campus but must also factor in costs to predict whether it is truly worth the money for a particular building. The buildings are not only there to function, but they are also there to create inspiration among people.

The occupants enjoy the space and make wonderful use of the space – the shape of the building contributes to the comfort of the occupants as well, and also contributes to the cooling of the building. Heard believes that the installation of the system was beneficial for the building and its size because during the first year of occupancy (summer 2015 to summer 2016), “almost 50 percent of the water used to irrigate the ENR2 landscaping came from the harvested water. There are obviously some give and take with that – ordinarily, buildings do not have landscaped areas above the ground floor (and therefore would not need that irrigation), but the landscaping here serves to keep the courtyard cool(er) even in the middle of the summer, and also creates a beautiful canyon aesthetic”.

Both Novak and Wilt agree with Heard’s statement adding that the system was worth it because the occupants enjoy the space and make good use of it. The shape of the building contributes to both the comfort of the occupants and well as the cooling of
the building (Novak, 2018). Since March 2016, 35 percent of the total water use with the system has been used to irrigate the building. Overall, payback is definitely a consideration in installing any of these systems – especially this extensive system. The investment of AC/heat and cost/returns is what has to be looked at and the challenges of these rainwater harvesting systems is that often times, their costs can exceed the particular consideration.

Figure 8. The following a cost-benefit analysis table showing what the payback period for the rainwater harvesting system on the ENR2 building is:

<table>
<thead>
<tr>
<th>Cost of System</th>
<th>Gallons Collected Per Year</th>
<th>Tucson Water Price</th>
<th>System Collection</th>
<th>Payback Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENR2</td>
<td>$69,000</td>
<td>196,940 gallons</td>
<td>$3.66/ 748 gallons = $.005/gal</td>
<td>$69,000/$984.70 = ~70 years</td>
</tr>
</tbody>
</table>

Case Study Two: College of Architecture, Planning, and Landscape Architecture

The first building on campus to include a water harvesting system in its construction was the east wing addition of the College of Architecture, Planning, and Landscape Architecture (CAPLA). The addition boasts approximately 35,000 square-feet and contains four stories. Three of the four stories include 11,500 square-feet each, with a fourth story meeting room. The “rooftop meeting room” occupies 15 percent of the roof. Two full floors on the new addition, as well as the fourth-floor meeting room, are both heated and cooled through refrigerated air conditioning. Only the ground floor of the building is cooled using evaporative cooling. Incorporating sustainability, along with architectural themes throughout – exposed building systems, mechanical, structural and architectural systems, the use of glass, steel, and concrete, exposed utility systems, and natural low VOC emitting materials – the building reflects the curriculum of the students that occupy the space (Sustainability, 2018).
However, what the building is most known for is what is on the south side of the building. "Occupied by a water conservation demonstration garden showcasing five different Arizona ecosystems, where students and the public can learn about water efficient irrigation and native plants" (Sustainability, 2018). In short, the building has included an outdoor classroom that is truly beautiful, as well as sustainable. In charge of the CAPLA garden and rainwater harvesting system installation, Ron Stoltz explains that “the landscape is a representation of five natural communities (loosely referred to as biomes) of the Sonoran Desert. 1) Desert Wetland in the center, 2) Desert Riparian along the south border, 3) Mesquite Bosque also along the south, 4) Desert Canyon to the west between the buildings, and 5) Upper Sonoran on the east border".

Figure 9. The Underwood Family Sonoran Landscape Laboratory located at CAPLA (Bill Timmerman, 2013)

Figure 10. The Water Feature in the Underwood Family Sonoran Landscape Laboratory (Bill Timmerman, 2013)
The inspiration for this building was simple according to Mark Novak. CAPLA's extensive garden was designed with five specific guiding principles related to sustainable practices kept in mind:

- Water sustainability – keeping focus on the harvesting and processing of collected water, and the majority use of low-water-use plants.
- Reduction of the Urban Heat Island Effect
- Reduction of Urban Flooding
- Reconnection with Nature – the demonstration of different microclimates and effect man-made habitats for urban wildlife.
- The creation of an urban oasis that demonstrates not only ecological, social, and engineering examples, but educational and horticultural examples as well.

(Stoltz, 2010).

The department was gaining a new building while adding onto an existing building and the designers wanted to demonstrate the academics of the occupants which was an important part of the planning. Connected to the University of Arizona's central plant system, the building can efficiently generate all of the energy to serve the building's heating, cooling, and electrical demands. “High performance HVAC and lighting systems integrated with the state of the art digital controls work in unison with the building's architectural elements to ensure maximum efficiency, flexibility, and environmental comfort. HVAC system performance is further enhanced by continuously monitoring and dynamically utilizing seasonally available outdoor air heating and cooling energy” (Sustainability, 2018). On the University of Arizona's CAPLA website, some of the major benefits of the newly constructed landscape performance are highlighted:

- The reclamation of 1.2 acres of former university parking lots into a viable Sonoran Desert Landscape.
- Demonstrates four guiding principles: water conservation, reduction of urban flooding, reduction of urban heat island effect, and a public university interpretative oasis.
- Total integration with the building mechanical systems including harvesting of roof runoff, HVAC condensate, and drinking fountain graywater into the 12,000-gallon tank.
• 83 percent reduction in potable water use for irrigation during desert establishment period (first seven years) and annual potable water use reduction to about 230,000 gallons.
• An expected 100 percent reduction in non-harvested water after the established period.
• Irrigation is 100 percent ET controlled by the University of Arizona.
• Demonstration of 5 biomes of the Sonoran Desert.
• Establishment of an 18,000-gallon desert wetland.
• The utilization of 300-gallons-per-day of university well water that was previously sent for sewage treatment.
• The introduction of three threatened and endangered fish and two reptile species as part of a reclamation program.
• Reduction in storm water runoff in 5 different micro-basins and 10,500-gallon retention capacity in the lower patio, the runoff is released over a 14-18-hour period.
• It serves as a model for regional government’s water harvesting/conservation legislation.
• Creates significant terrestrial/aquatic habitat with significant opportunistic repopulation with active predation activities.

(Underwood Family Sonoran Landscape Laboratory, 2017).
The rainwater harvesting system is one of the most important and well-known aspects of the building – being named the Underwood Family Sonoran Landscape Laboratory. First, both rainwater, condensate from the air-conditioning systems, and drain water from the drinking fountains is all collected into the cistern. The cistern is located within the building lab just north of the addition. It is an 11,600-gallon fiber-glass lined and coated steel cistern – measuring approximately 7 feet in diameter and 38 feet in height. It all drains into the large pond and is then recirculated through the waterfall feature. If, and when, the amount of water exceeds the pond, it drains its way through the landscape and the through the main building to the quad area – where it irrigates all of the plants. The drinking water blow off is filtered through a small cistern located at the southwest corner of the garden. The water in this location drains through an underground pipe – directly into the pond. “It is somewhat of a mini-wash feature”, Novak explains. The overflow area in this building is called the “well blow-down” and it is a part of the many university wells. The “well blow-down” is pumped into the pond every day (Stoltz, 2010). The release from the well-water back-wash goes through a very large sand filter that filters approximately 300 gallons each day. The holding tank on the building can hold up to 12,000 gallons – which results in an impressive 87 percent reduction in the use of potable water for the garden.

Novak explained to me that no major maintenance on the system is needed, however, the filtration and pumping systems are what will need maintenance throughout the years. Margaret Livingston, a professor at the University of Arizona (CAPLA), states that “the biggest maintenance on the system is the pump system that controls flow through the irrigation system. We are currently changing the pump on this system.” Just like the Environmental and Natural Resources 2 building, all of the pumps and filters are managed by a centralized computer system so that they can check for leaks or any malfunctions. “Passive systems you may let be, while active systems need to filter smaller particles out, then treat it for whatever use it is intended for” (Novak, 2018). Public health is a major consideration in this, because, then arises the issue of greywater reuse within the system. Stoltz explains that there are three related items that must be cleaned periodically on the system: “two small filters associated with the cistern/potable water (clean every month when actively collecting). Make sure to release
the pressure. Rinse the areas between the rings. The large “first flush” pipe should be cleaned after a large rainfall. It is an electric valve about 10-12 feet above the floor”.

Livingston believes that installing the rainwater harvesting system on the College of Architecture, Planning, and Landscape Architecture was definitely beneficial for the building and its size, however realizes that it does have some drawbacks. “I think it is beneficial, but maintenance of the pumping system can be time-consuming. These pumps need to be able to handle fairly dirty water, and that can be the biggest problem, dealing with clogged systems. Passive harvesting systems, which are drive by gravity flows, are much easier to deal with”.

Figure 12. The above is a cost-benefit analysis table showing what the payback period for the rainwater harvesting system on the ENR2 and CAPLA buildings are:

<table>
<thead>
<tr>
<th></th>
<th>Cost of System</th>
<th>Gallons Collected Per Year</th>
<th>Tucson Water Price</th>
<th>System Collection</th>
<th>Payback Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPLA</td>
<td>$40,000</td>
<td>230,000 gallons</td>
<td>$3.66/748 gallons = $.005/gal</td>
<td>230,000 gallons x $.005 = $1,150/yr</td>
<td>$40,000/$1,150 = ~35 years</td>
</tr>
<tr>
<td>ENR2</td>
<td>$69,000</td>
<td>196,940 gallons</td>
<td>$.005/gal</td>
<td>$984.7/yr</td>
<td>~70 years</td>
</tr>
</tbody>
</table>

The rainwater harvesting system on the ENR2 building cost approximately $69,000 (a little less than $30,000 more than the system on CAPLA) including all pumps, filters, and tanks. The average collection of water for the previous years totaled out to about 196,940 gallons. As the City of Tucson Water Company is pricing water at $3.66 per 748 gallons of water, this equals out to $0.005 per gallon of water. With this number, we can multiply it by the amount of water collected (196,940 gallons) and reach a dollar amount saved for the year. This dollar amount for the ENR2 building is $984.70 saved in water per year. Taking the amount that the system cost in total and dividing that by the money that is saved on water per year, because of the system, we can see that the payback period for the rainwater harvesting tank on the ENR2 building is approximately 70 years.

However, the CAPLA rainwater harvesting system cost approximately $40,000 for all pumps, tanks, and materials. It collects about 230,000 gallons of rainwater runoff, A/C condensate, greywater from the drinking fountains, and back-wash from a
neighboring U of A drinking water well per annum. With the cost of each gallon, for the city of Tucson, still sitting at $0.005, and the rainwater harvesting system on CAPLA collects the 230,000 gallons of water for the year, based on the above numbers, that saves $1,150 in water costs per annum. The payback period for the system on this building is about 35 years – calculating the $40,000 it cost to build and dividing that by the amount of money saved per year ($1,150).

While these might seem like long payback periods, it is important to note that these water harvesting systems are doing more than just saving the university money - these systems help the buildings sustain their landscapes and other features while making more water available to residents and other consumers. This cost benefit calculation did not include tax credits, which would not be available to the university, but are to residents and commercial properties. Often these credits can pay for up to 25 percent of a system's cost, which helps dramatically reduce the payback period.

**CONCLUSION**

The issue of water conservation has long been a crucial part of life, however, recently it has become an even larger issue across the globe. Sustainable water management is the largest and most important issue that is currently needing to be addressed as water availability is decreasing at a highly rapid pace. Fixing this issue is crucial because water is the most important natural resource on Earth because it is essential for the health, productivity, and growth of all living things. Because climate change is increasing, both drought and water scarcity are a major situation that is coming forward. The Center for Climate and Energy Solutions stated in 2017 that “in 2012, 81 percent of the United States was living in extremely or abnormally dry conditions”. The numbers are astonishing and largely worrying. As stated previously, an article from the United Nations website stated several different facts and figures pertaining to water supply and conservation:

- 2.6 billion people have gained access to improved drinking water sources since 1990, but 663 million people are still without proper drinking water.
- At least 1.8 billion people globally use a source of drinking water that is fecally contaminated.
2.4 billion people lack access to basic sanitation services, such as latrines and toilets. Each day, nearly 1,000 children die due to preventable water and sanitation-related diarrheal diseases. Approximately 70 percent of all water abstracted from rivers, lake and aquifers is used for irrigation. Water scarcity affects more than 40 percent of the global population and is projected to rise to over 783 million people who will not have access to clean water. Over 1.7 billion people are currently living in river basins where water use exceeds recharge. (United Nations, 2017).

Again, here in the arid southwest, groundwater has played an important role in contributing to human development and helping to maintain natural ecosystems, as well as maintaining the natural flows of both streams and rivers. However, our rapid population growth has overtaxed the natural system and has led to decreasing groundwater levels and an increasing reliance on water pumped in via the Central Arizona Project (CAP) (Guido, 2008). Based on the information I was able to collect during my interviews and from the research, I conducted, the installed rainwater harvesting systems on the University of Arizona campus are beneficial to, not only conservation of water on the University of Arizona campus, but also the conservation of water in the state of Arizona, and in a larger scale, the world. Installing other rainwater harvesting systems on different buildings of the University of Arizona, buildings in which would truly benefit, could save large amounts of money and water for the University – creating a more sustainable environment for the users. Although the payback periods for both systems range between 35 and 70 years, which might seem long, the amount of water that is saved each year by these two buildings combined is over 425,000-gallons. Using this knowledge, various businesses and residents around the city can use this information for their personal gain and the City of Tucson can use this knowledge to adapt more desirable incentives and programs for those who might be on the fence about installing the systems.

As stated previously in this paper, while there are some other water conservation techniques and practices out there, rainwater harvesting is the most beneficial practice of them all. With 50 percent to 70 percent of all water usage being used for household
or irrigation purposes, that leaves a small percentage for the essential functions of drinking water and food production. It is a low cost and high value solution that can create a greener community and environment for us all.

**LIMITATIONS**

The first major limitation that was encountered during this research was not being able to collect the data needed to create an extensive table. The construction company and builders for the ENR2 building’s rainwater catchment system did not keep a record of major data and numbers that could have been a crucial part of my data collection. I continued to try to find the information elsewhere, through several different people, but no one seemed to have access to this kind of information. However, I was able to get a lot of questions answered that I had, which was beneficial in helping me to provide a detailed analysis of the building.

The second major limitation that was encountered during my research was that I was not able to get my hands on a detailed breakdown of what exactly the CAPLA rainwater harvesting system cost. This was because a lot of the materials were donated to the University of Arizona by various vendors, so no one kept track of exactly what these materials and labor cost. However, I was able to get my hands on a pamphlet that was left for CAPLA that described in detail many different aspects of the system and how it works.

On the other hand, there are many other opportunities for further research to expand on this study about rainwater harvesting at the University of Arizona. Case studies from other Universities across the nation would be a helpful tool in helping to understand more about the systems. Another potential research avenue would be looking at the cost and efficiency of designing water harvesting systems into a building prior to construction versus adding a system on to a building after it is completed. Additionally, suitability and benefit figures that are more complex and advanced would improve the quality of the data greatly and would overall improve the usefulness of the research.
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