Feasibility of Rainwater Catchment in the Taos Mesa Community in Northern New Mexico

Miranda Rivera

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Professional Project

Feasibility of Rainwater Catchment in the Taos Mesa Community in Northern New Mexico

Miranda Rivera

University of New Mexico

Committee Members: Professor Bill Fleming, Professor Caroline Scruggs and W.R.P Director John Fleck

May 9th, 2017

This professional project identifies a strategy to help the Taos Mesa community in Northern New Mexico gain sustainable access to clean water.
ACKNOWLEDGMENTS

I would like to personally thank all my committee members including: Professor Bill Fleming, Professor Caroline Scruggs, and Water Resource Program Director, John Fleck. I would not have been able to finish out this three-year long journey without the support and patience of my committee members. I am very grateful for all the input and wealth of knowledge you all have given me throughout my graduate career in the Water Resource Program and the Community and Regional Planning Program. I would also like to acknowledge Tony Benson and David Jacobs from the Taos Soil and Water Conservation for all the data and full on support of my project. I would also like to thank Gaël Whettnall for coming along on this journey and supporting me through stressful times. I seriously could not have done it without your delicious snacks and meals you provided while I was sifting through data and writing. I would also like to thank George Richardson who first initially provided me with contact information of community members out on the Taos Mesa. I would also like to thank all the participants of the interviews who allowed me to go to their homes and see for my self their rainwater catchment systems. I am without words of all that I have learned from you all and made me believe that rainwater can be an alternate true source of water and especially for domestic use. Also, I would like to thank my parents, Tim and Kellie Rivera who no matter what I do and dream of doing have always supported me through the very end. Lastly, I would like to thank the rain, the mountains, the river and the soil for allowing us to be apart of your intricate environmental systems.
# Feasibility of Rainwater Catchment in the Taos Mesa Community in Northern New Mexico

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INTRODUCTION
Lack of water is nothing new for New Mexico’s general population. However, its immediate negative effects are unevenly distributed throughout the state, which is increasingly evident in the context of rising temperatures and decreases in precipitation. Access to clean drinking water is significantly more pressing in rural and off-the-grid communities than in metropolitan areas of New Mexico. On the Taos Mesa in northern New Mexico, these off-the-grid communities continue hauling as the only available method for accessing water today. In these communities, water is not only a vital source of livelihood but also necessary for the continuance of cultural practices like farming and irrigation. Lack of infrastructure and monetary funds for drilling wells are primary explanations for the challenging situations these communities find themselves in today. Thus, on the dry land of the Taos Mesa, each drop of water is accounted for and budgeted accordingly.

PROBLEM STATEMENT
The objective of this project was to evaluate creative, sustainable solutions for accessing clean drinking water in the Taos Mesa communities of Taos County, New Mexico, with a focus on rainwater catchment. Eight interviews with community members on water management were conducted across five communities within the Taos Mesa area. A case study of a particular rainwater harvesting system was analyzed, and rainwater catchment calculations were conducted for one household within the Tres Orejas community. This case study evaluated whether rainwater harvesting is appropriate for all communities on the Taos Mesa as an effective approach to access water and to prepare for a changing climate.

PERSONAL STATEMENT
Water was a huge foundation for me growing up in the small community of Ranchos de Taos. I remember my father attending monthly acequia meetings to make sure we were getting our share of the water. I would often take walks with my mother after dinner to the valley below
our house to see the small farm that depended on that water. Today, that stream is dry. Driving north to look at the Rio Grande River from the Gorge Bridge has always been sublime to me, seeing the small sliver of water that cut the earth. Today, I notice that surrounding the bridge there are communities who live on the Mesa by choice and do not have the same luxury of easy access to water. After entering the Water Resources Program, I began to understand that this is a worldwide issue and became passionate about helping rural communities to access clean water. I decided to start within my own community and search for creative strategies to help rural communities with this worldwide issue of accessing clean water.

**AREA OF INTEREST**
The Taos Mesa community includes the communities of Two Peaks, Three Peaks, the Greater World Earthships, Star Earthships, and Carson, New Mexico. This is a vast area of the mesa in Taos and Rio Arriba Counties. This professional project will focus on the mesa area within Taos County west of the Rio Grande Gorge (Figure 1).

**FIGURE 1. STUDY SITE LOCATION.**
LITERATURE REVIEW

This professional project’s main component is rainwater catchment, which is one of the main solutions for accessing water for the Taos Mesa communities. This section will focus on a synthesis of published work that summarizes methodologies, policy, and techniques of rainwater harvesting. In order to understand the complexities of rainwater harvesting, it is important to review the relevant published literature.

A. RAINWATER HARVESTING

Brad Lancaster (2008, 2013) has become an expert on rainwater harvesting in the United States. His two books outline methods for rainwater harvesting specifically in dry lands. Lancaster’s methodologies were developed in the Tucson area, which has a similar climate to the Taos Mesa area. Although Rainwater Harvesting for Drylands and Beyond (2008) focuses on non-potable water, his methodologies can be applied to residents in the Taos Mesa community who would like to reuse rainwater. The books discuss landscape architecture methodologies for sustainable land and water management. Using his techniques, the Taos Mesa community could learn about rainwater harvesting and how to preserve ecological functions of the landscape.

New Mexico policy on rainwater harvesting by the Office of the State Engineer (OSE) encourages the use of rainwater catchment as long as it does not harm the natural volumes of groundwater or flows of surface water that would naturally occur in the river need (OSE,2004). This policy is especially important for communities depending on rainwater harvesting.

Kinkade-Levario (2007) discusses different techniques of rainwater harvesting, including storm water catchment and alternative methods of water reuse. He focuses on different building methods for urban environments that deal with alternative designs for water management. Even though these methods are for urban environments, they can be applied to the Taos Mesa communities.
Terry Thomas’ (1998) article focuses on domestic water supply using rainwater harvesting. The article has three different case studies in North China, East Africa, and Singapore. The case studies evaluate present practices of rainwater harvesting, design components, and water quality treatment. These case studies can be used as examples for the Taos Mesa community. The article discusses household water treatment methods and the size of water catchment areas needed to supply daily water needs. Some of these practices are being done within the Taos Mesa community.

Han and Ki’s (2010) article describes sustainable practices for water supply systems on small islands. Rooftop rainwater harvesting is one of the main avenues for collecting precipitation. The article has a case study in Guia-Do, a small island off the coast of Korea dependent on rainwater harvesting for domestic use. Even though their case study has a different climate, it is important to evaluate different rainwater harvesting techniques that can be adapted to the dry climate in New Mexico.

Laura Allen’s (2015) book *The Water-Wise Home* is a guide on how to become more conscious of water use at home. For example, this book focuses on how to conserve, capture, and reuse household and landscaping water. One chapter includes details for building a rainwater harvesting system that could be an efficient example for the Taos Mesa Community.

Pelak and Porporato’s (2016) article *Sizing a Rainwater Harvesting Cistern by Minimizing Costs* includes guidance on sizing a cistern for a rainwater harvesting system. This article provides information on how to design a cost efficient cistern. This article is especially useful for developing a rainwater harvesting system at a minimal cost for communities like the Taos Mesa, where there are few coding regulations.

The Environmental Protection Agency (2013) evaluates the costs of alternative rainwater harvesting systems, summarizing regulations for communities in the management of rainwater harvesting and water reuse.

**STUDY SITE ANALYSIS**
This section reviews groundwater availability and water use in Taos County and the Taos Mesa community, the current and past precipitation data, and the community’s social and cultural identity.

A. GROUNDWATER IN THE TAOS AREA

Benson’s (2004) report examines groundwater geology within Taos County. Because groundwater is the Mesa communities’ main source of water, understanding the fundamentals of groundwater is vital for developing future alternative practices to obtain fresh water.

Johnson and Bauer (2012) wrote a comprehensive assessment prepared for the New Mexico Bureau of Geology and Mineral Resources on the groundwater system of the northern Taos plateau. This study site is north of the study site on the Taos Mesa, but the report contains valuable information that relates to the Taos Mesa including geologic and hydrologic data that help with understanding the connection between surface and ground water.

DuMars and Minier’s (2004) article focuses on groundwater rights and management in New Mexico. The article discusses the current law on groundwater use. One of the main recommendations is to adopt groundwater laws that focus on conservation efforts. The authors advise strong links between science and the law to manage resources, including regulations that impact most of the residents in the Taos Mesa communities.

Groundwater is a major component of the hydrologic system and one source of water for the Taos Mesa community. The hydrology of groundwater in Taos County is unique to the area because the Rio Grande Rift has many geologic faults (Benson, 2004). These structures occur west of the Rio Grande where ground water flows at great depth southeasterly toward the river. On the east side of the Rio Grande river, groundwater flows west toward the river and groundwater recharge fluctuates with mountain-front streams. There are multiple fault systems that are within the Taos Valley, the first extending from the Picuris Mountains to the Rio Hondo and Rio Grande confluence. The second fault system is under the town of Taos. The fault systems divide the groundwater into sections that make locating groundwater difficult (Benson, 2004). According to Benson’s (2004) research on groundwater geology, groundwater quality is
good. However, groundwater that is closer to the faults tends to have more contamination because of mineralization.

Another component of groundwater evaluation is analyzing water levels in wells within the Taos Mesa community, which helps with understanding how groundwater levels fluctuate. The *Groundwater Geology of Taos County*, by Anthony Benson (2004), provides background on the groundwater geology within the study site area. Specifically, west of the Rio Grande Gorge, the groundwater table has a steep gradient that drops to the southeast (Benson, 2004). When examining wells in this area, which are few, depths range from 400-800 feet (Figure 3). Six wells that are important to identify from the cross section of the Western Taos County include: WG-5 “Kirby” RG-48497, WG-2 “Benson” RG-NA, WG-10 “Montoya” RG-NA, WG-09 “Benson” RG-62825, TP-22 “Diamond” RG-58558, and TP-15 “Montoso” RG-64632. These well depths illustrate the difficulty of accessing ground water within the study site location. The water level starting from TP-15 “Montoso” is approximately 800 feet and drops at TP—22 “Diamond” with the water level at 1000 feet. The groundwater level rises at WG-09 “Benson” to 600 feet. The water level at the WG-10 “Monotoya” well is also 600 feet and stays at that level for the WG-2 “Benson” well and the WG-5 “Kirby” well. Because of the hydrogeological complexity of the area, it is extremely difficult to drill successful wells (Benson, personal communication, February, 2017).

In his report, Benson (2004) mentions why it can be difficult to drill productive wells in this area. The first reason is that where the water table is deepest in the Miocene...
Ojo Caliente Formation, the aquifer is made up of fine-grained sand that is easily collapsible. The second reason is because of the slow rate of seepage in the Ojo Caliente Formation.

B. LOCAL WATER USE

The Interstate Stream Commission of the Office of the State Engineer (2016) prepared the most recent Taos County regional water plan, updated every five years. The regional water plan identifies the water supply and demand problems Taos County is facing. This document examines the current practices of the Taos Mesa community and outlines a plan for the future that could have significant impacts on the environment. The Office of the State Engineer also prepares reports on water use throughout New Mexico, updated every five years. The 2010 Water Use report was used in this study to assess how much water the Taos Mesa communities use.

For water use, data are analyzed from the Office of the State Engineer (OSE) water use report for the year 2010 (OSE, 2010). The information presented includes: commercial (self-supplied), domestic (self-supplied), industrial (self-supplied), irrigated agriculture, livestock (self-supplied), mining (self-supplied), power (self-supplied), public water supply, and reservoir evaporation. These data on water use are important for understanding how much water the Taos County uses.

**TABLE 1. WATER USE SUMMARY TAKEN FROM THE OFFICE OF THE STATE ENGINEER WATER USE 2010 REPORT.**

<table>
<thead>
<tr>
<th>CN</th>
<th>COUNTY</th>
<th>CATEGORY</th>
<th>WSW</th>
<th>WGW</th>
<th>TW</th>
</tr>
</thead>
<tbody>
<tr>
<td>55</td>
<td>Taos</td>
<td>Commercial (self-supplied)</td>
<td>14</td>
<td>12,470</td>
<td>12,614</td>
</tr>
<tr>
<td>55</td>
<td>Taos</td>
<td>Domestic (self-supplied)</td>
<td>0</td>
<td>1,143</td>
<td>1,143</td>
</tr>
<tr>
<td>55</td>
<td>Taos</td>
<td>Industrial (self-supplied)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>55</td>
<td>Taos</td>
<td>Irrigated Agriculture</td>
<td>91,065</td>
<td>1,218</td>
<td>92,283</td>
</tr>
<tr>
<td>55</td>
<td>Taos</td>
<td>Livestock (self-supplied)</td>
<td>46</td>
<td>66</td>
<td>112</td>
</tr>
<tr>
<td>55</td>
<td>Taos</td>
<td>Mining (self-supplied)</td>
<td>4,456</td>
<td>6,804</td>
<td>11,262</td>
</tr>
<tr>
<td>55</td>
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<td>Power (self-supplied)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>55</td>
<td>Taos</td>
<td>Public Water Supply</td>
<td>187</td>
<td>2,097</td>
<td>2,284</td>
</tr>
<tr>
<td>55</td>
<td>Taos</td>
<td>Reservoir Evaporation</td>
<td>686</td>
<td>0</td>
<td>686</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>County Totals</th>
<th>WSW</th>
<th>WGW</th>
<th>TW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>96,566</td>
<td>23,799</td>
<td>120,365</td>
</tr>
</tbody>
</table>

Key: CN=county number; WSW=withdrawal, surface water; WGW=withdrawal, groundwater; TW=total withdrawal
C. LOCAL RAINWATER HARVESTING

Analysis of rainwater harvesting was conducted within the Taos Mesa community. Households were surveyed in the Taos Mesa community in order to understand the personal household function of rainwater harvesting. Researching creative solutions to accessing clean water in an arid and drought stricken environment helps with the goal of providing clean water for the Taos Mesa community.

The Environmental Protection Agency (2013) also has a report on rainwater harvesting that focuses on conservation, credits, codes, and costs with a case study. There are multiple articles that were used to compare and contrast rainwater harvesting techniques. Lancaster and Marshall (2008) was a major source of information for this project. They offered specific techniques that are usable in a dry climate such as Taos. Lancaster and Marshall’s work, in conjunction with the local interviews, helped with understanding the techniques of rainwater harvesting.

D. SOCIAL AND CULTURAL IDENTITY OF THE TAOS MESA

Nichols’ (1986) autobiography describes the simple lifestyle of living on the Taos Mesa. Some of the most important aspects of living on the Mesa include the natural beauty of the landscape. Nichols beautifully narrates the importance of keeping the land free from development. This book is an essential component for understanding the lifestyle of communities on the Mesa and why they prefer to live off the grid.

The publication by Mayagoitia, Hurd, Rivera, and Guldan (2012) concentrates on how rural communities, specifically in northern New Mexico, will be prepared and adapt to changing climates and demographics. Some of the main areas of interest include acequias, which many rural communities depend on. This article helps with understanding how climate change will affect rural communities, and within the Taos County boundary of the Taos Mesa there are many communities who will face the same issues.

The documentary, Off the Grid (Juhola, Stulberg, & Stulberg, 2007) concentrates on the lifestyle of living without urban amenities. This movie is about the Taos Mesa community and why
people have decided to move there. The documentary does not focus on accessing environmental resources but does describe the lifestyle of living on the Mesa.

Nicolas’ (1986) book *On the Mesa* was used to understand why people decide to live on the mesa and what challenges they have. The film, *Off the Grid*, is a documentary that shows the culture of living on the mesa and the sacrifices the residents endure.

Interviews with multiple households in the Taos Mesa community were conducted in March of 2017 to understand the social aspect of the Taos Mesa community as well as their cultural identity. Interviewing current residents in the Taos Mesa area was obligatory in order to understand what the community needs and wants in terms of accessing clean water. Without the input of the residents it would be difficult to find sustainable solutions for the Taos Mesa community.

**METHODOLOGY**

**A. GEOGRAPHIC INFORMATION SYSTEM**

Geographic Information System (GIS) tools were used to create general maps of the study site. Template layers including states, cities, rivers, and highways were used to identify the location of the area. The base map that was used, topographic base layer, was downloaded from ArcGIS ESRI. Well GPS locations were gathered either from the Taos Soil and Water Conservation District or identified via Google Earth. All coordinates were identified in Universal Transverse Mercator (UTM) and organized and put into Excel. Once the GPS coordinates were organized, the X-Y Coordinate tool was used to put in place the well coordinates. North American Datum 1983 was projected on the template layers with the new well location points.

**B. PRECIPITATION ANALYSIS**

The Western Regional Climate Center precipitation data (Figure 4) are based on monthly averages including average maximum temperatures, average minimum temperatures, and precipitation from 1981-2010 (2017). After the year 2010, data are collected from the Southwest Climate and Environmental Information Collaborative (SCENIC) for the Taos 4.3
NNW station (2017). For the Northern Mountain Region Division, data are from the National Oceanic and Atmospheric Administration (NOAA), Climate Divisional Dataset (2017). For each climate division, such as the Northern Mountain Division in New Mexico, the values are calculated from daily observations and averaged for monthly values. These observations are weighted by area to calculate statewide values and weighted by area for regional values (NOAA, 2017). This data is relevant to the study site area because it shows the climate and precipitation trends within the study area, which is important when analyzing how much rainwater are these communities receiving.

**TAOS, NEW MEXICO**

1981 - 2010 Temperature and Precipitation

![Temperature and Precipitation Graph](image)

Data is smoothed using a 29 day running average.

**FIGURE 4. 1981-2010 TEMPERATURES AND PRECIPITATION AVERAGES TAKEN FROM THE WESTERN REGIONAL CLIMATE CENTER.**

C. INTERVIEWS

Interviews required an IRB review with the University of New Mexico before they could proceed. Participants were found in four different areas of the study location, including Carson, Two Peaks, Three Peaks, Star Earthship community, and the Greater World Earthship community (Figure 5) Eight interviews were conducted over two weekends. Seven participants were found from a contact and friend who previously did research on the Taos Mesa. The
contacts were shared and it was noted that these specific community members who live on the mesa are especially knowledgeable about water management. A majority of the ten community members contacted responded with enthusiasm to talk with me. During the first weekend, two people invited me to their houses to examine their rainwater catchment systems. The second weekend, three participants opened their homes to show me their rainwater catchment systems. A time and place for the interviews was decided by the participants. The other participant who was not previously contacted, was at the West Rim Well where the project was explained to her. All participants who were contacted agreed to participate with the interviews.

The interview questions included:

1) How often do you haul water to your house? If you do not haul water, where does your water come from?

2) How do you currently manage your water? For example, do you use the water for mostly household use, or do you have a garden/farm or animals that need a lot of water?

3) How much water do you typically use on a monthly basis?

4) How much of this use is for indoor domestic use and how much for outdoor watering?

5) Do you practice any type of water recycling? For example, gray-water systems?

6) Do you practice rainwater harvesting and/or groundwater storage?

7) With current predictions of climate change (increasing temperature during the summer, decreasing rainfall, decreasing snowfall...), are you concerned with water management in the future?

8) If water management does become more difficult in the future, what are some alternative ways of accessing clean water while living on the Taos Mesa.

9) What solutions currently do you believe would make it easier for you to access clean water? For example, having more wells in your community, having private wells, connecting to city water...

10) On a scale of 1 to 5, how active are you in your community with water management, with 1 being not active and 5 being very active? For example, active could mean: attending community meetings on water management, on the board of a water association, or water activist.
D. Rainwater Catchment Calculations

An equation to evaluate how much rainwater is being harvested comes from the University of Texas A&M Agrilife Extension (2016). The equation that was used to estimate how much rainwater was falling off the roofs was:

\[
\text{Catchment Area (ft}^2\text{)} \times \text{Rainfall Depth (in)} \times 0.623 \text{ (one inch deep in once square foot of water)} = \text{Rainwater (gal)}
\]

RESULTS

A. Geographic Information System

GIS is an important mapping tool that identifies where the study site is and where the nearest wells are located. GIS’s toolbox that was used for this project include: drawing polygons that represent the study site area, and entering data from excel to a table in GIS to identify the well coordinate system. Figure 5 shows the location of the study sites and the weather station where precipitation data were collected. Figure 6 shows the locations of some of the wells that are on the Taos Mesa.
B. Analysis of Precipitation

1. Northern Mountain Division
Precipitation data were collected for the Northern Mountain Division 2 for New Mexico via the Climate Divisional Dataset from NOAA. Data were collected for the years 2009-2016 (NOAA, 2017). According to the divisional data provided by NOAA, the Northern Mountain Division for New Mexico includes 71 different stations for the years 2009-2016. The seven-year monthly averages (Figure 7) indicate the highest amounts of precipitation in July with 74 mm and the lowest in January with 16 mm. The seven-year monthly averages show that the most rain is in the summer season and the lower amounts are in the winter and spring.

![Graph of Northern Mountain Division for New Mexico: Monthly Precipitation (mm) Averages (2009-2016)](image_url)

**FIGURE 7. NORTHERN MOUNTAIN REGION 2 FOR NEW MEXICO: MONTHLY AVERAGES PRECIPITATION DATA (2009-2016). DATA COLLECTED FROM SCENIC DATASET FEBRUARY 2017.**

2. Taos 1.6 SSE, US1NMTS0009_SATION
Daily precipitation data from the Taos 4.3 NNW Station were collected from the WRCC SCENIC dataset for the years 2009-2016 (Figure 8). The precipitation pattern shown in Figure 3 is similar to the Northern Mountain Region 2. The month of July had the highest rainfall with 2.1 mm. The lowest rainfall occurred in April with a low of .55 mm. This means that rainfall on the Taos
Mesa was highest during the summer and driest during the spring and winter (excluding snowpack). The Northern Mountain Region 2 had more rain than Taos 1.6 SSE Station. This could be because the Northern Mountain Region 2 has stations that are within some of the highest elevations in northern New Mexico, which collect some of the higher amounts of precipitation.

![Monthly Precipitation (mm) Averages from 2009-2016 Taos 1.6 SSE Station](image)

**FIGURE 8. TAOS 1.6 SSE, US1NMTS0009_STATION MONTHLY PRECIPITATION AVERAGES DATA (2009-2016). DATA COLLECTED FROM SENIC DATA SET FEBRUARY 2017.**

**C. INTERVIEWS**

The catchment systems ranged from simple to very sophisticated. These interviews provided information on how people manage their water and the feasibility of their rainwater systems. A majority of the interviewees who live in an Earthship have installed a filtering system where they can drink the rainwater they have collected. Earthships, designed by Mike Reynolds, are constructed to be self environmentally sustaining by using local materials, such as earth, recycled tires and bottles. Because Earthships originally were planned to have rainwater
catchment systems, it is likely that a majority of the Earthships that have been built have some type of rainwater catchment system (Reynolds, 2005). However, one interviewee lives in one of Reynolds’s original Earthships, and the only rainwater catchment system is collecting water on the roof and storing it in a cistern for the garden. Examining the newer Earthships, it is evident that the rainwater catchment system, which includes the filtration system, has become more developed over the years. Interview 2 and interview 6 (Appendix A) provide examples of a more sophisticated rainwater catchment and filtration system. For example, they both catch rainwater from a metal Pro-Panel roof (Figure 9) through a screen funnel filter to catch debris material. A Pro Panel roof is a simple metal roof with rib features. The water then runs by gravity to the cistern, where the water is stored. The water flows by gravity to the pump panel, where the “water organizing module” (WOM) is located (Figure 10). Both Earthships that use these techniques also have similar filtration systems for drinking water.

The Earthships have at least three different water filters. Two filters are mesh filters that catch debris like silt before it goes to the pressurized pump (Reynolds, 2004). The pressurized pump allows enough pressure to wash dishes or take showers. There is a third charcoal or a ceramic candle filter that is only used for drinking water. In one of the Earthships, interview 6, the gray-water line that is connected to the sink passes first through a grease trap and second though a gravel plastic lined open cistern that is filled with hydroponic plants that clean the water. This water is treated naturally with plants and then pumped to the toilet. The black water is pumped outside to another plant cistern where the septic tank is, and then the water is cleaned for a third time.
and used in the garden. It is important to note that this use and reuse rainwater catchment system can be adapted to all types of homes, not only for Earthships.

Some other examples of simple rainwater catchment systems can be found in interview 4 and interview 7 (Appendix A). Their type of rainwater catchment system uses less water. For example, in each of their homes, their rainwater is harvested from their Pro-Panel roof to their catchment gutters and straight into a cistern (Figure 11). Both of the participants from interviews 4 and 7 did not have a WOM. Instead, they directly used the water for washing dishes and showering. The gray water was then used in their gardens. This type of use and reuse of rainwater harvesting is meant to put less stress on our resources. Both participants also hauled water. Interviewee 7 hauled water from his family well in Carson, and the other home hauled water from town. Both participants use between 1.2 and 2 gallons a day for drinking and cooking.

The last two interviews were with residents who hauled water from wells (interviews 1 and 3 in Appendix A). One interviewee manages the West Rim well and depends solely on groundwater. He talked about the importance of the well for the community. He stated that there is a one-time membership fee of $200 to access the well and afterwards it costs $.03 per gallon. He also talked about how the well does not use its full permit of three acre-feet/year of water. Interviewee 1 indicated that she travels 34 miles round trip to access water from the West Rim well for domestic use. Both participants indicated that they do not use well water for drinking. Rather, they both get their drinking water from town. They both use the well water for domestic use such as showering, washing dishes, and gardening. When asked why they do not practice any type of rainwater catchment, interviewee 3 explained that contamination can be a problem, especially in cisterns. Interviewee 1 said for the 20 years she has been living on the mesa, she had received no information about how rainwater catchment could be applicable to
her house. She said she has been hauling water for 20 years, and she has not needed to change her routine (Interview 1, personal communication, March 4, 2017).

After having conducted seven interviews in four different communities, it is apparent that there are two ways people obtain domestic water on the Taos Mesa: they either haul their water or they have a rainwater catchment system that allows them to drink the water. Three people depend on only rainwater harvesting as their main source of water, indicating that it can be done on the Taos Mesa. However, these interviews show that these systems must be planned carefully in order to function properly. With guidance from Michael Reynolds’s Earthship rainwater harvesting system, it will be easier for more people to set up these systems in the future. A summary of all the interviews is included in the Appendix.

CASE STUDY
A rainwater catchment system was used as a case study to understand how feasible rainwater harvesting can be within the Taos Mesa community. The participant’s property resides in the Tres Orejas (Three Peaks) community (Figure 12) where there are approximately 200 inhabitants.

The participant has been living on the property for almost 20 years and raised two kids with his partner. The property is an oasis in the desert. With fruit trees and terraces of plants. The participant has educated himself on rainwater catchment systems that he believes would work best for him and his family. The participant’s rainwater catchment system is adequate for a 1500 square foot house with a family of four. The participant indicated that he relies solely on rainwater for both potable and non-potable use. His roof catchment area is 1500 square feet. His cistern is unique because it is made of cement approximately 12 feet deep, and it can hold around 5,000 gallons of rainwater (Figure 14). He placed downspouts where the water drains to the cistern. Each downspout has
a screen to catch debris so that it will not get into the cistern. He installed a WOM that allows him to use the water for domestic purposes, which includes his drinking water. Within his household he uses a low flow toilet and low flow washing machine. One of the most important aspects of his rainwater catchment system is that he reuses water at least three times (Figure 13).

FIGURE 13. GREY WATER SYSTEM TO GARDEN.
A. IMPORTANT FACTORS OF THIS RAINWATER CATCHMENT SYSTEM

Figure 14 shows the most important steps the case study participant took in order to create a sustainable rainwater catchment system.

- He put in a Pro-Panel roof to quickly catch as much rainfall as possible (A).
- He used four downspouts to capture as much rainfall as he could (B).
- He constructed an underground cistern so that it would not freeze.
- The cistern sits underneath his house with a trap door, so no contaminants can get in (C).
- A WOM was installed in order to drink the rainwater (D).
- A gray water planter was installed to clean the water for reuse (E).
- Gray water cistern installed for connection to drip system to yard.

FIGURE 14. DESIGN LAYOUT OF CASE STUDY HOUSE OF RAINWATER CATCHMENT SYSTEMS (NOT EXACT LAYOUT OF HOUSE) (DRAWN BY GAEL WHETTNALL).
B. Rainfall Calculations
The following equation was used to calculate the amount of rainfall that collects in his cistern.

\[ \text{Catchment Area (ft}^2) \times \text{Rainfall Depth (in)} \times 0.623 \text{ (one inch deep in once square foot of water)} = \text{Rainwater (gal)} \]

C. Results from Calculations
Precipitation data from 2009-2016 is from the Taos 1.6 SSE Station. In 2009 the smallest amount of rain was in March with less than an inch, resulting in the collection of 65 gallons of water (Figure 15). The case study participant’s more successful months were in July with almost two inches of rain, collecting 1832 gallons and in October with almost two inches of rain, collecting 1841 gallons. April through June were all above one inch of rain, collecting 1000 gallons.

![Harvested Rainwater per Month in 2009](image)

**FIGURE 15. HARVESTED RAINWATER (GAL) PER MONTH IN 2009 AT THE CASE STUDY HOUSE.**

In 2010, the amount of rainwater increased in March significantly to 2.49 inches, resulting in the collection of 2327 gallons (Figure 16). Rainfall decreased during the rest of the spring months to below an inch. In July there was a spike with 2.49 inches of rain, resulting in the collection of 2327 gallons. Rainfall decreased during the summer months.
In 2011, the amount of rain was lower compared to the previous two years. During the summer months, the amount of rain dropped to .01 inches in June, producing only nine gallons of rainwater for that month. In the summer, the amount of rain increased to 1.67 inches in September, producing 1561 gallons of rainwater (Figure 17). When there are dry periods, the interviewee explained, “it is important to conserve more water than usual. However, with a 5,000-gallon cistern I’ve never seen it go dry” (Case study interviewee, personal contact, March 4, 2017).
In 2012, the amount of rain decreased. In April, there was .003 inches of rainfall producing three gallons of rainwater. During the summer months, the rainfall increased slightly with a peak of 1.53 inches, producing 1430 gallons of rainwater (Figure 18). During the summer months, rainfall dropped again in October and November.

In 2013, during the spring season the amount of rainfall remained low with rainwater catchment levels below 1500 gallons (Figure 19). However, the amount of rain in the summer
increased with a peak rainfall during September of 4.47 inches, producing 4,117 gallons of rainwater. The amount of rain during September was almost enough to fill his cistern.

FIGURE 19. HARVESTED RAINWATER (GAL) PER MONTH IN 2013 AT THE CASE STUDY HOUSE.

In 2014, the rainfall followed a seasonal trend, with little rain in the first two months, and then a sustained amount of rainfall over the next three months until a drop in June. This was followed by a sustained amount of rain over the following three months until October when there was another drop in rainfall (Figure 20).

FIGURE 20. HARVESTED RAINWATER (GAL) PER MONTH IN 2014 AT THE CASE STUDY HOUSE.
In 2015, there were two months when the rainfall was more than two inches, producing over 2,000 gallons of rainwater (Figure 21). The amount of rainfall during the overall year was more than the year before, especially during the first three months where the amount of rain collected exceeded 1,000 gallons.

![Harvested Rainwater per Month in 2015](image)

**FIGURE 21. HARVESTED RAINWATER (GAL) PER MONTH IN 2015 AT THE CASE STUDY HOUSE.**

In 2016, the area remained generally wet, beginning with low amounts of rain in March and October and a peak in August (Figure 22). However, in 2016 there were lower amounts of rain than in 2015. The amount of rain per month was never above three inches, nor below 1/10 of an inch.
D. Recommendations from the Case Study

This case study is a unique example that shows the feasibility of a rainwater harvesting system in the Taos Mesa community. Using rainwater as his only source of water for domestic use and gardening, he shows that it is feasible even in drought years. His system can be used as a model for communities who face the same issues as the Taos Mesa community. Having a rainwater catchment system that uses and reuses water multiple times helps conserve depleting water resources. This model is an example of a future of water saving and not water wasting.

This case study shows that it takes special planning and forethought for a rainwater catchment system to not only work for routine domestic water use, but to also be used for drinking water. There are some basic essential steps that need to be done to have a successful catchment system. The first step is to establish water and financial budgets for a single individual or a family. During the dry season a family or an individual must discuss water use and how they will adapt to how much water they have stored. The second step is to find a roofing material that can move rainwater quickly off the roof into the gutters. The case study had 1500 square feet of Pro-Panel. The roof was pitched so that rainwater was not stagnant. The third step is to install enough downspouts to capture sufficient rainwater. With more downspouts the probability of catching most of the rainwater that falls on the roof is higher. The third step is
planning the capacity of the cistern system. There should be a cost and benefit analysis of a cistern system that fits the needs of the household. In the case study, the cistern was planned according to how deep the backhoe could dig, which was 12-feet. However, not every individual will be able to afford a 5,000-gallon cistern. Planning must consider how much an individual or family can afford and how they can adapt their water use lifestyle to the amount of rainwater they can store. The fourth step is to consider investment in a WOM. For example, in the case study the family decided to only use rainwater for domestic use. That meant that the family had to install and invest in at least three different filters and pumps to get water from the cistern to the rest of the house. The price of filters and pumps varies. The case study participant said, “It just depends if you want a Ferrari or a Honda Civic” (personal communication, March 4, 2017). The fifth step is considering a gray water system. In the case study, gray water from the kitchen sink and shower was used in the toilet. However, he indicated that he would have changed his design for the gray water from the kitchen sink to go directly into the septic tank because of grease. Once these steps are thought out and the catchment system is designed to fit the needs of a family or individual, rainwater harvesting can be done using minimal amounts of water, and puts less pressure on other resources such as groundwater.

CONCLUSION
Options for water management on the Taos Mesa include hauling water, rainwater catchment, or personal wells. Many people on the Taos Mesa haul water, whether from the community well or from the grocery store, which can be costly because of the cost of gas and vehicle maintenance. There are some people on the mesa who have been fortunate enough to have their own wells. However, from personal interviews and communication with hydrogeologists in the Taos area, obtaining water from wells is not considered to be the best management practice for the Taos Mesa community because of the costly factor of drilling. The only other option is rainwater catchment. From analyzing rainwater data in the Taos area and conducting personal interviews, rainwater catchment is appropriate and practical for the Taos Mesa community.
Results from the analysis of precipitation and from rainwater catchment calculations show that rainwater catchment can be the sole option for using rainwater for domestic use on the Taos Mesa. This study recommends water budget planning when moving to the Taos Mesa area. People who already live on the Taos Mesa can implement steps towards rainwater management. Education about rainwater management and on using rainwater for domestic use is extremely important.

A rainwater catchment system is not suggested for individuals or families that use high amounts of water throughout the entire year. It requires a water conscious person to use the right amount of rainwater during the monsoon season and to not use as much during the dry season. Most of the participants were aware of how much water they use, so the Taos Mesa communities are already ahead of most people who live in cities. It would be an easier transition to a rainwater catchment system for someone who lives in a community that is mindful of the limited resources that exist. Michael Reynolds (2005) states, “A conventional home and conventional requirements for water should no longer be the gauge for determining water use in the future” (p. 13). In an area like the Taos Mesa where drilling wells is not feasible for the community, rainwater catchment is the most practical option. Even if an individual still would like to haul water for drinking and use a rainwater catchment system for non-potable use, this would be a sustainable solution.

Rainwater catchment systems are feasible for the Taos Mesa community where water supply options are limited. The case study presented is for a family of four with a specific budget. It would be beneficial to use the case study as a model for individuals and/or families who are willing and motivated to use a rainwater catchment system in their homes and design it in a way that works for them.
REFERENCES


APPENDIX

INTERVIEW WRITE-UPS

INTERVIEW 1

The first interview took place at the West Rim Mutual Domestic well right off of Highway 64. The participant was a member of the West Rim Mutual Domestic well and hauled her water into a 150-gallon tank, which she does less then twice a month. She lives 17 miles away from the well. She indicated that she does not haul water too often. She uses approximately 600 gallons of water a week. She does not use the well water for drinking and only uses it for domestic use. She has been hauling water for almost 20 years. She currently does not have any type of rainwater catchment system. She buys one gallon of drinking water every time she goes grocery shopping twice a week and that is her only source of drinking water. She indicated that in the past, she tried drilling a well several times, however at 1,000 ft. there was still no water to be found. Throughout the interview, the participant expressed that “Water is precious!” The participant did not know what she would do if climate change were ever to change her lifestyle with managing water. (Interview 1, personal communication, March 4, 2017.)

INTERVIEW 2

The second interview was at the Earthship Visitor Center, also right off of Highway 64. The visitor center is a major asset for the community of Taos because it is an example of sustainable living in a dry climate. Michael Reynolds was the creator of the Earthships, and the visitor center portrays an example for people who are interested in sustainable living and/or would like to build a home similar to the Earthship. Michael Reynolds’s book Water from the Sky (2005) discusses the mechanisms for water harvesting. A tour through the Earthship Visitor Center includes an introduction to harvesting water, using the water, reusing the water, and then reusing the water.

FIGURE 23. GREENHOUSE IN EARTHSHIP VISITOR CENTER.
again. The rainwater harvesting techniques are models for other Earthships to be built in Taos County and throughout the world. The interview was conducted with a visitor center employee who provided insight into how Earthships function in relation to water harvesting. The participant stated that rainwater catchment is their only source of water. However, there is a backup well in the community in case of severe drought or fires. She explained that the visitor center alone has four 17,000-gallon cisterns that are constructed under the earth and insulated with tires. She also stated that the Earthship communities in the area never really have problems with running out of water. However, people have to strategically plan how they will harvest rainwater. The building materials used and simple decisions like what direction the house will face are extremely important. (Interview 2, personal communication, March 4, 2017.)

**INTERVIEW 3**
The third interview was conducted with an employee of the West Rim Mutual Domestic Water Users Association (WRMDWUA) (Figure 24). The West Rim well is a very important asset to the community on the Taos Mesa. According to the interviewee, the well has been in use for almost ten years. The well was funded by a grant from the United States Department of Agriculture (USDA). The well is permitted for 3 acre-feet of water. The interviewee indicated they are not even using that full amount. He also stated that the well is approximately 740 feet deep. The well is accessible to members of the water association, which has around 250 members, according to the interviewee. There is a one-time payment membership fee and the cost for water is three cents per gallon. He said in terms of water use, there are a variety of members, some who use little amounts, such as 50 gallons per week, and others who use larger amounts, up to 200

**FIGURE 24. WEST RIM M.D.W.U.A.**
gallons per week. So all types of water users use the well. He also indicated that some use the well for drinking water and some do not, it is really the members’ preference. One important factor that he mentioned is that a lot of members use the well as backup during droughts. Otherwise, members tend to use some kind of rainwater catchment system. (Interview 3, personal communication, March 4, 2017.)

**INTERVIEW 4**
The fourth interview took place at the participant’s home in the community of Carson. This participant just built his one-bedroom home and was working on a second addition. This participant’s house sits on his family’s property, which has a well. His well is around 600 ft. deep. He uses the well for drinking water and fills his two 6-gallon water containers every five days. The first component of his property he wanted to show was his rainwater 165-gallon cistern (Figure 25) He indicated that he just had one, but was working on getting more to catch as much rainwater as possible. His house has a metal roof, which is approximately 250 square feet. He did not have any indoor plumping. He does not use the rainwater for drinking, but he uses the water for his animals (four dogs), washing clothes, and washing dishes. He did indicate that after he uses the water for washing dishes he will use it a second time to water his plants outside. Regarding his family’s well, he stated that their family has never run out of water. He said that Carson is in a valley that has a sufficient amount of water that will last. He said, “I am lucky enough to have a family well where I haul water from, which takes five minutes.” His recommendations included rainwater catchment, dry farming, and having dry ponds, which allows water to seep back into the aquifer. (Interview 4, personal communication, March 4, 2017.)
**INTERVIEW 5**

The fifth interview was in the Star Earthship community, which is approximately 7.8 miles from the West Rim well. The participant’s home is one of the first homes that Michael Reynolds built in the 1990s. The participant has been living at this Earthship for almost seven years. The design of the Earthship is one of the original designs. Since this Earthship was built, there have been upgrades in terms of catching rainwater. For example, the participant’s roof is made out of Bria, which is an older material that Reynolds used on Earthships. The interviewee discussed that the Bria roof is breaking down and her animals frequently are on the roof so she does not use the rainwater for drinking. However, there is still a vast amount of rainwater that collects on the roof and gets collected into the open cistern in her house. The 3,000-gallon open cistern is in her bedroom, which she rarely uses for washing dishes and/or showering. She gets her drinking water from the West Rim well, which she is on the board as the Treasurer. She uses around 2.5 gallons per week. She does have a gray water system that is used for her plants. The house also came with a composting toilet and solar oven. Since she rarely uses the rainwater she goes into town to shower. Her main recommendations were to have a big enough catchment area that enables you to catch a lot of water. This interviewee is very active in her community, specifically with the West Rim Water Users Association. (Interview 5, personal communication, March 11, 2017).

**INTERVIEW 6**

The sixth interview was at the Greater World community off of Highway 64. The interview was conducted with two households of the Earthship, who explained the function of their rain catchment water system. The approximate area of catchment on the metal roof is 1,100 square feet. The water flows down into two different cisterns that holds 3,000 gallons of water. The
water from the cistern is then gravity fed to the WOM where it filters the water with a ceramic filter that has silver in it. With this filter, the participant is able to drink the water. The water that is not being used by drinking is used for plants. The gray water is connected to the kitchen sink and the bathroom. The gray water is then pumped into a 12-gallon garden cistern, where the plants clean the water. The black water is then pumped to a septic tank, which drains to a drain field. The participant felt that Earthships, in general, already use little amounts of water, so with the climate changing, the owners of Earthships already have the knowledge to use less water, which will benefit them in the future. Some suggestions the interviewee had were to have a drought tolerant garden, reuse the water as many times as possible, try not to use too many pumps, and use gravity as the main source of energy. The orientation of cisterns via the rest of the house is extremely important because gravity assist in the plumbing of the rainwater catchment system. (Interview 6, personal communication, March 11, 2017).

INTERVIEW 7
The last interview was located in the community of Two Peaks. The interviewee had been living on this property for seven years. He built his own house, which he calls a tiny home. It is approximately 250 square feet and has three different cisterns, which hold around 100 gallons of water all together. He indicated that about once a year his cisterns dry up or freeze in the winter. He does not have any type of filtration system for his rainwater, so he buys two-gallon drinking water containers in town, and he drinks about two gallons a day (Figure 27). This amounts to 14 gallons per week. He uses this water specifically for drinking and cooking. Otherwise, the rainwater he catches he uses for showers and for his

**FIGURE 27. KITCHEN WITH SINK LEADING TO GRAY-WATER SYSTEM.**
plants. The gray water that is collected from his cooking is used for his plants. His toilet is compostable and does not use any water. The interviewee indicated that he would like to make his own filtration system in the future so that he can drink his rainwater, even though he really uses minimal amounts of water. He did not have any fear about climate change and felt that he could even live without the rainwater if need be. He expressed that we are lucky to have rainwater and that it is a bonus. He also explained that within the Two Peaks community 1/10 people probably practice rainwater catchment. He said, “There are some very knowledgeable people living on the Mesa, however there is lacking follow through, so a lot of homes are half finished or become abandoned.” (Interview 7, personal communication, March 12, 2017.)