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Greywater IQP Report

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A Greywater Recycling System to Support a Fog Harvesting Initiative in Aït Baâmrane, Morocco

An Interactive Qualifying Project Report submitted to the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science.

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Abstract

The goal of this project was to help advance Dar Si Hmad's fog water harvesting project in the Aït Baâmran region of Morocco by designing a greywater recycling system to capture and re-use water at the household level. Accounting for cultural and environmental factors that could hinder the adoption of water recycling, our group developed a guide outlining three potential greywater recycling techniques and proposing a greywater recycling system for the Dar Si Hmad test house.

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Miriam, thank you for being a warm, friendly face in the Rabat medina

Executive Summary

1. Background

Throughout the rural areas of Morocco there is a lack of clean water. Amazigh villages surrounding the Anti-Atlas Mountains, a few kilometers from Sidi Ifni, are located at the base of these mountains. The demand for water puts strain on not only the people, but the land around them.

After a decade of research our sponsor, Association Dar Si Hmad for Development, Education and Culture, constructed and implemented fog harvesting nets at the summit of Mt. Boutmezguida, located in the Anti-Atlas Mountains. In May 2014, the Fog Water Collection System began supporting villages by providing them with potable water piped directly into their homes. Dar Si Hmad is considering the best option to take advantage of this surplus of water, thus not wasting a valuable resource that has been recently provided.

Greywater, which domestic household water produced from personal hygiene, laundry, washing and cooking, can potentially be recycled and reused, closing this water loop (Paris & Schlapp, 2010). Recycled greywater does not pose an immediate health risk once recycled if used for non-consumption household activities. Greywater recycling removes contaminants from water, improving the safety of the greywater, and expanding the potential applications of the water. There are three main components of a greywater recycling system: capture methods, a filtration system, and an end application. Different forms of filtration have a range of effectiveness from removing the solid materials to almost making the water potable again.

We explore three promising types of filtration: Sand filtration, reed bed filtration, and solar distillation.

2. Goals, Objectives, and Methods

Our project goal is to help advance Association Dar Si Hmad's Fog Net initiative and support their efforts by introducing greywater management practices that close the water use loop, allowing for the capture and re-use of fog water at the household level. Accounting for cultural and environmental factors that could hinder the adoption of water recycling, our group will implement a guide specifically outlining the situational appropriateness of three key greywater systems, which will include recommendations for implementation of a system at the Dar Si Hmad test house, in the countryside.

To accomplish our mission we developed several key objectives that were completed in Rabat and Sidi Ifni, Morocco.

1. Inspect and understand the operation of the fog net harvesting system
2. Understand the water management practices of the countryside and livelihood of the Amazigh villages
3. Understand our stakeholder's perceptions and interests regarding greywater use
4. Develop a recommendation guideline for the appropriate use of each greywater system and what would be the most culturally acceptable to use in specific application.
5. Recommend a specific system for the household space Dar Si Hmad owns in Aït Baâmrane

Our work was conducted over an eight week period, consisting of three phases: (1) an initial visit to Sidi Ifni hosted by Association Dar Si Hmad with five days of intensive field work, (2) an analysis and design phase in Rabat, and (3) a second field visit to Sidi Ifni to present and seek feedback from our stakeholders.

During our first project phase we visited the countryside where Dar Si Hmad took us on a tour to representative sites around the countryside including the fog water collection system, the mixing station, a cistern, the piping of the fog water delivery system, and the Dar Si Hmad house in the countryside. For our second objective we held in-depth discussions with our stakeholders: Dr. Jamila Bargach, the Director of Dar Si Hmad; Mounir Abbar, the Fog Net Project Lead; Houssin Soussan, the Water Technician; and Najib Kebir, an interpreter for Dar Si Hmad. The first meeting was held in Dar Si Hmad's library in Sidi Ifni as an open discussion with everyone previously mentioned in attendance. Our third objective was wrapped up with a conversation with Mr. Soussan at his home, covering topics regarding water management practices and livelihoods in the countryside as we had tea and traditional foods in his living room.

The second phase of this project took place in Rabat where we developed a recommendation for Dar Si Hmad that comprises all of the data from our findings and notes to complete objectives four and five. Through this information we put together a guide that addressed each system, detailing where they would be appropriate at the Dar Si Hmad house as well as suggesting ideal locations within the countryside. We individually analyzed key system components such as descriptions, materials, placement options, strengths, weaknesses, maintenance, and required input of water.

Lastly, we returned to Sidi Ifni to further discuss with Dr. Bargach and Dr. Leslie Dodson, an executive director of Dar Si Hmad, presenting our recommendations regarding the implementation of a system at the Dar Si Hmad test house in the countryside.

3. Findings

The following contains findings from our early research before the initial field visit to Sidi Ifni and the information we gained from that visit. These findings address our first three project objectives.

Operation of the Fog Net System

We were informed that the average production amount was 10.5 liters per square meter of netting per day. With 600 m^2 of nets total, on an average during the foggy season the system produces 3,150 liters of water a day. The reservoir at the top of the mountain can hold 50 tonnes of water. The mixing station is where they add in groundwater to mineralize the fog water to satisfy the Moroccan state standards of potable water.

To evaluate the water management in homes the cistern at Mr. Soussan's house was a big stone pit with a channel leading rain into the stone tank. The last part in the delivery system was an in home faucet. Dar Si Hmad uses water meters to charge the villagers and these prices have been altered to be a more suitable scale for the impoverished villagers.

Water Management and Livelihood Practices

Some villages were located close to wells and others access to wells consists of half an hour to over an hour's journey to the closest well on foot or fewer with a donkey. A few residents have a garden because the climate makes the soil difficult to grow anything and not having enough water to properly maintain the garden. With Dar Si Hmad's years of hard work they managed to overcome challenges that came with laying down pipes to villages. In implementing greywater recycling systems would bring up the similar problems in finding optimal locations for the systems and the greywater piping to each filtration unit.

The primary uses for water are consumption, bathrooms and toilets, laundry, cleaning and dishes, livestock, and gardens. Many residents do not like the taste of tea made with the piped fog water, so they prefer to use their cisterns water for drinking tea. Greywater is generated from laundry, kitchen, cleaning, and the bathroom. Greywater generated in households contains many different chemicals that can be damaging to greywater recycling systems. Many houses have separate drains for blackwater and greywater, which means that the greywater drain can be used as an introductory piece in adding a greywater recycling system to the end of the drain.

Stakeholder perceptions regarding greywater

Once greywater and blackwater definitions were made clear in the discussion at the water manager's home it revealed that recycled greywater would be acceptable to use as long as it was safe and effective. The residents also mentioned that households may not produce enough greywater to be recycled and think that they conserve well enough. A new water concern that residents have is that one day the fog will disappear and water will no longer be available to their homes.

Figure 1: Dar Si Hmad test house in the bled.

4. Proposed Greywater System

With the information presented a sand filtration unit is recommended to be implemented at the Dar Si Hmad house as shown in Figure 1. Greywater collection would be a basin on a wall in the inside of the courtyard. From that basin the water would be pumped outside towards the left side of the house where the sand filtration unit will be sitting on the side of the house, filter the water and pump water back into the house. As the water re-enters the house it will travel to the garden in the center of the courtyard. Another option to use the recycled greywater would be to flush the toilet.

5. Conclusion and Broader Implications

Introducing a greywater recycling system into the countryside enables every resident to preserve and extend use out of fog water. Any implementation of a greywater recycling system will come with expected maintenance each household will need to perform. Solar distillation, sand, and reed bed filtration all have their strengths and weaknesses but doing case studies of each recycling system in households who are open to introducing a new concept to their lives will assist in the long run to determine which system works best in the countryside.

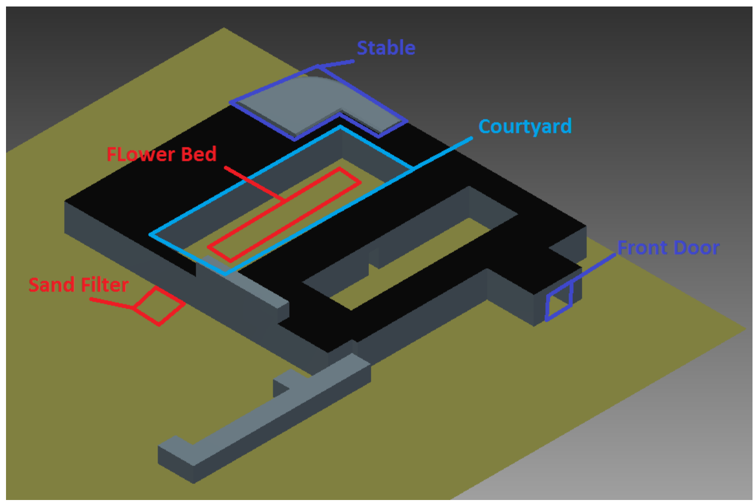

Figure 2: Computer Aided Design of Dar Si Hmad House

The design is suitable to the site location and considers the current context of the building being unoccupied as shown in Figure 2. Three greywater recycling systems were all considered for the Dar Si Hmad test house, and a supplemental document for Dar Si Hmad is located in Appendix A details all three greywater recycling systems and their future implications. Our proposed design utilizes a sand filtration system. Other important aspects of the design include greywater capture within the house, and suggestions for the end use application. This recommendation leads into new opportunities for Dar Si Hmad to receive further input from the Aït Baâmrane people in what they would like to get out of a greywater recycling system. Informing the community that there are other means in maximizing their greywater is a step towards accepting recycling systems in their villages.

Authorship

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Water Management and the Agricultural Sector	Carolina Ramos	Edited by All
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System to be Implemented at the Dar Si Hmad House in the Bled	Nathaniel Jefferson	Edited by All
Considerations for Implementing Greywater Recycling More Widely in the Bled	Carolina Ramos	Edited by All
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Nomenclature

°C – Degrees Celsius
°F – Degrees Fahrenheit
Bled – Arabic word for country or countryside
CAD – Computer Aided Design
In. - Inch
IQP – Interactive Qualifying Project
L – Liter
m – Meter
m^2 – Squared Meters (Surface Area)
m^3 – Cubic Meters (Volume)
MENA – Middle East and North America
NGO – Non-Government Organization
POSS- PEMA – POSS-polymethacrylate
UNICEF – The United Nations Children's Fund

1. Introduction

Throughout the rural areas of Morocco, there is a widespread lack of available clean water sources. The Amazigh villages surrounding the Anti-Atlas Mountains have a steadily declining water supply and poor access to the few sources that exist. Standing just a few kilometers outside of the city of Sidi Ifni are seven villages like the one in Figure 3, that are located at the base of these mountains. The demand for water is putting strain on not only the people, but the land around them. This region, located in close proximity to the Sahara Desert, shares many characteristics with the desert including an arid climate and a lack of bountiful water cycles. Per capita available water resources in all of Morocco are an estimated 700 m^3 per year for a population of 32.5 million. Annual per capita water availability is expected to drop to less than 400 m^3 by the year 2020 (The World Bank, 2009).

Figure 3: Village near Sidi Ifni in the Countryside

Allocation of water in Morocco is heavily geared towards agricultural applications. Current irrigation practices are inefficient, which has led various water sources to be heavily strained. Agricultural irrigation is allocated 83% of withdrawn water leaving the rest for municipal, tourism, and industrial uses (The World Bank, 2009). Even with so much of Morocco’s water consumption used by agricultural irrigation practices, only 15% of the total agricultural land is irrigated. This leaves a majority of agricultural lands to have a heavy dependence on rainfall (USAID). This lack of efficient crop irrigation in Morocco leads to mass quantities of water being wasted; evaporation from the top soil causes the farmers to use a significant amount of extra water to produce prosperous cash crops. Efficient irrigation processes have poor adoption rates, causing a large portion of water used in agricultural irrigation to be lost due to evaporation. Additional water is needed to properly grow crops in these regions, leading to dwindling water supplies in rivers and groundwater sources. Residents of rural Morocco depend on agricultural practices for their livelihoods and survival. With the already harsh environment becoming increasingly challenging to live in, many residents of rural villages decided to move away from the rural villages in an effort to obtain basic needs for survival.

In May 2015, Association Dar Si Hmad launched a solution to the problem of drought in Southwestern Morocco. After a decade of research our sponsor, Association Dar Si Hmad for Development, Education and Culture constructed and implemented an array of fog harvesting nets at the summit of Mt. Boutmezguida, which is located in the Anti-Atlas Mountains. The Fog Water Initiative supported those living in the location of the bordering Sidi Ifni by providing them with potable water piped directly into their homes. This non-governmental organization has installed fog nets that span 600 m^2 and 8 kilometers of pipelines (Dodson, 2014). The expected increase in water use resulting from the addition of the fog net supply leaves room for a more relaxed water management practices as well as increased amounts waste water. With the implementation of fog nets that support and sustain the villages, Dar Si Hmad is looking for the best way to stretch the use of this water supply that is readily accessible, thus not wasting the valuable resource that has been recently provided.

The water that is being used in the village on a daily basis has a one-time use lifespan, meaning that water is being discarded rapidly, when it could be reused for other purposes. Nearly

3% of total water usage are treated and reused; this water recycling is in cities that have the facilities to treat the wastewater. Reuse of water in rural areas is important because there is no sewage system for the water to funnel down and be introduced to a water treatment facility to handle it; once the water is thrown out it becomes useless to the environment that desperately needs it.

While fog water has become readily available in the homes, there are some issues that still need to be addressed. These homes are built in a location that very rarely sees much water so most are created from adobe, which in constant water flow will erode quickly (Khattabi, Faouzi, & Matah, 2013). If a leak springs, it could lead to devastation for a home. In turn the vast amount of water needs to be handled properly so as not to allow system overflow and unnecessary waste. Also since the septic tanks that were introduced decades ago are not apt to manage excess water, there is a need to incorporate a system that allows for the surplus of water to remain effective to ensure that the scarce commodity can be most effectively distributed and used. With this increased influx of water to the homes it also raises the question of how is the excess water being disposed of after it is used. Social and cultural issues may arise with the introduction of new household level resource management due to unrelated men and women are prohibited to speak to one another. With these communication barriers, the woman whose ancestral job was to fetch water for their households now had problems in communicating to the male water manager. This project will discover the specific needs and uses that would be culturally, socially, and environmentally acceptable to repurpose this water for and design a system that will attempt to achieve this.

2. Background

Currently water is in high demand in North Africa due to the droughts the region experiences. Key areas to be understood about Morocco are the climate, water availability, the water conservation, and water management. This information about Morocco and the addition of water recycling to a fog water collection system showcases the importance of water conservation to the southwestern region in Morocco.

2.1 Water Scarcity Concerns in Morocco

Water has become an increasingly scarce commodity around the world during the 21st century. Demand for freshwater has increased while availability has diminished. Morocco faces problems with droughts as aquifers dry up and rainfall decreases. Sustainable water management is needed as water access to rural communities' increases and agricultural production expands. The Atlas Mountains' streams are a major source of water after the snow melts making water to be used for irrigation or daily needs. Drought has an overarching effect on daily activities in many communities, including food scarcity. A few areas in Northern Morocco that receive enough rainfall to allow agriculture to flourish, but drought is causing major socioeconomic concern due Morocco being heavily dependent on farming. Crops in which Moroccan farmers specialize are wheat, barley, maize, oats, and rye.

> "During a typical drought year, food prices rise, food shortages develop, herds perish for lack of forage, malnutrition becomes more extensive, refugees from the countryside arrive in cities, soil erosion and desertification become more pervasive, the economy

contracts, and foreign debt increases to pay for cereal imports (Swearingen, 1992)."

Climate change will lead to extended periods of drought, which will exacerbate water scarcity problems that the Moroccan state will have to handle (Swearingen, 1992). Summer months bring little to no rainfall in Morocco, while the winter months between October and April bring the most. Average annual rainfall trends have been decreasing in Morocco, from 356 mm between 1961-1990 down to 330 mm between 1990 and 2005. Precipitation amounts are greatest at the northeast of Morocco, decreasing towards the southwest of the country (Tekken, Costa, & Kropp, 2013).

2.1.1 Urban vs. Rural Access to Water

Access to improved water sources has improved dramatically in Morocco over the past few decades. Despite this, Morocco still lags behind many of its neighboring nations when it comes to improved water access in its rural communities. In 2014, 98% of the urban population had access to improved water sources, while only 64% of the rural population had similar access. In perspective, of the 13 countries in the World Bank's Middle East and Northern Africa group (MENA), 95% of the urban population has access to improved water along with 83% of the rural population (The World Bank, 2014).

Morocco's rural population has a much greater need of improved water sources compared to that of other countries of similar financial standing. From 2000 to 2014, access to improved water sources in rural communities has only increased by 7% (The World Bank, 2014). As of 2013, the water availability in Morocco is 867 m^3 per capita per year (The World Bank, 2014). The United Nations defines a region to be in water stress at 1,700 m^3 per capita per year. At

1,000 m^3 per capita per year a region is considered to be in water scarcity (United Nations, 2014). When a region experiences water scarcity, not all of the demands for water can be satisfied fully, including demands from industry, agriculture, domestic use, and the environment.

There is often a disconnect between the urban and rural areas of Morocco, with those who live in more remote spatial locations experiencing more hardship accessing clean drinking water, as expressed by Moroccan water quality standards (The World Bank, 2014). In 2014, only 56% of rural Morocco has access to improved water sources. These improved water sources consist of a cleared set of specifications that are directly outlined by the World Health organization and the UNICEF Joint Monitoring Program.

Due to the lack of clean and safe drinking water in these rural villages of Morocco, there is a necessity to travel lengthy distances to arrive at a source of clean water. This responsibility falls under the responsibility of the women in this culture and these women normally spend upwards of three hours daily transporting water, which inhibits their daily life (Diao, Dinar, Roe, & Tsur, 2008).

2.1.2 Water Management and the Agricultural Sector

Agricultural irrigation uses up to 95% of total groundwater used in parts of the southwest region of Morocco. Groundwater table levels have a deficit year after year, steadily decreasing groundwater reserves (The World Bank, 2014). In order to maintain sustainable water supplies, groundwater tables have to be tracked and regulated in order to ensure regeneration in the aquifers as well as to avoid contamination.

As a whole, agricultural use of Moroccan water supplies in 2013 was 87%. On the other hand, only 10% was for domestic use, along with 3% industry use. Even though water supply cannot meet demand, water pricing in Morocco is quite low, with flat rate prices being less than \$0.10 per m^3 of water (Allan, Keulertz, Sojamo, & Warner, 2013). This leads to irrigation techniques used in agriculture to be less efficient than they could be, as a bigger strain on water costs would drive individuals and businesses to reduce water loss.

2.2 Fog Net Water Harvesting System

A fog water harvesting system operates to pull water from a heavily water saturated foggy atmosphere. Through this operation the fog collection can provide increased water availability to semi-arid regions. Fog harvesting was first proposed by Chilean researchers to the government of Canada in the 1980s (Frazen, 2001). As of 2013, 17 countries across the world use "airborne potable water" systems, also known as fog technology (Chandler, 2013). One example of the numerous fog collecting systems around the world is the "El Movimiento Perunos Sin Agua" or "Peruvians Without Water." The founder of this project, Abel Cruz, says that during winter months there are nearly no water costs for the towns connected to the fog net system (Collyns, 2012).

Figure 4: Fog Nets upon the Top of the Mountain

A fog nets in Figure 4 collect water by condensing fog as it passes through the mesh. As fog blows through the netting, small water droplets collect on the surface of the net. Over time, as more fog and mist pass through the netting more and more moisture condenses until the water drips down the net into collection gutters. Several factors influence the effectiveness of water collection of the fog nets, such as the mesh's material and placement of the net. Constructed with nylon mesh or polypropylene netting, the nets used in fog nets use very fine fibers to increase heat transfer of the net and allow for increased water condensation. In order to maintain optimal conditions for fog and mist condensation, the nets must not become too hot or the passing fog will not condense on the net effectively. Black ultraviolet-stabilized netting is a necessary feature in order to ensure long term durability and sustainability of the system due to high exposure to the sun. Previous fog net systems in place use a Raschel knit for the netting, being easily available as well as cheap (Boulware, 2013).

Furthermore, in order to arrange for good-quality consumable water, understanding the water intake and water usage practices in rural homes would change with the distribution of clean water to the rural villages in the Anti-Atlas Mountains. Depending on whether the villages use water more frequently for agricultural use or individual household use the circumstance of using communal water taps or family water taps depends on the research gathered.

2.2.1 The Fog Net Initiative in Sidi Ifni, Morocco

Since 2006 Association Dar Si Hmad for Development, Education and Culture, a Non-Governmental Organization facilitated the water development of Sidi Ifni as well as educating the youth in good water use practices. This association promotes programs that encourage the sustainability and profit of the Southwestern Moroccan region. Through multiple initiatives Dar Si Hmad has drawn more Amazigh individuals that left the region years ago to come back and resettle upon the land. Dar Si Hmad is currently taking on the mission to investigate septic systems that are in place inside of the Amazigh villages at the bottom of Mt. Boutmezguida located on the map in Figure 5, with a student intern from University of Bolder Colorado. After nearly a decade, Dar Si Hmad inaugurated a fog water harvesting project that captured fog from the top of the Anti-Atlas Mountains and converted it to pure drinking water for the villages located at its base.

Figure 5: Map Indicating location of Sidi Ifni and surrounding villages (Dodson, 2014)

The Association Dar Si Hmad has adopted its most recently inaugurated initiative, which included supplying over 500 people clean drinking water. This project uses large nets stretched out at the top of the Anti-Atlas Mountains where fog condenses when it passes through the nets and creates a clean source of drinking water. With a capacity of 600 m² of nets, each net being 40 m², Dar Si Hmad's fog net initiative in Sidi Ifni is one of the largest in the world. These nets consist of a giant mesh surface pulled between a rectangle of pipe, the bottom one of which collects the water that slowly accumulates and drips down the net. Through advances in the fog net technology in the last decade, the systems that Dar Si Hmad was able to put in place yield a large quantity of water.

A recent study released by researchers at Massachusetts Institute of Technology targeted the efficiency of fog harvesting nets deployed around the world. Using data taken from Chilean fog harvesting systems as well as meshes used at the site, the team sought out any recommendations in improving the current design. Measuring various aspects of the netting, the researchers discovered much more optimal mesh patterns, sizes and materials that significantly improve water collection per unit area. Through changing the knit pattern used for the mesh from a Raschel knit to a cross knit (similar to what is seen on window screens), and by altering the spacing in the mesh, the researchers were able to reduce the effect of water clogging in the mesh. When water clogs the mesh, it reduces the ability for the fog to pass through the net, decreasing the efficiency of the system. Reducing the frequency and quantity of clogging in the net helps maintain the systems effectiveness in peak operating conditions (Park, Chhatre, Srinivasan, Cohen, & McKinley, 2013). In addition to improving patterns in the netting, the researchers also focused on materials used for the netting. Using a sample of netting identical to the ones used in Chile as a basis, researchers discovered there were more efficient material solutions for the mesh than those most commonly used at existing fog collection sites. Research pointed towards the use of a POSS-PEMA coated metal mesh, which has a more porous structure allowing easier fog condensation and water flow down the net (Park, Chhatre, Srinivasan, Cohen, & McKinley, 2013).

Storage of the water collected from fog nets needs to meet certain requirements in order to maintain the safety of the water and ensure the long term effectiveness of the entire system. Due to the high temperatures and sunny climate, evaporation is a threat to any exposed water that is not stored properly. The most effective means of reducing evaporation during storage is through the use of a cistern.

A cistern is a large waterproofed container, typically used to store rainwater. Common materials used for cisterns include concrete or plastic. The effects of sunlight must also be considered, as algae could grow on the surface of the water in the container with enough sunlight. Thus, the cistern must be designed to be opaque to prevent any algae from contaminating the water that may be wanted to be put in safekeeping for months especially during the dry season where the fog nets may not harvest as much fog (Boulware, 2013). Another aspect about storing the collected water would be the size of the cistern. While dependent on several factors the total capacity of the tanks should be at least double the peak production of water by the fog nets in any one day.

2.2.2 Complexities in Fog Water Harvesting

A number of issues and difficulties can arise depending on where the fog nets are located ecologically, economically, and culturally. Fog harvesting nets are implemented to help poor areas and thus the cost of implementing the technology can be a drawback (Klemm, et al., 2012). In areas that have high topographical relief the cost of the pipeline required to bring the water to its area of consumption could be too costly to be effective (Organization of American States, 1998). Other issues include the technology needing specific climate conditions, the quality of fog water not meeting standards, and the impact fog nets and systems may have on the environment (Organization of American States, 1998).

Another important complexity arises from the resource management practices and communication norms of Sidi Ifni. Moroccan women in Amazigh villages are the primary water collectors, however, unrelated men and women are not allowed to have contact with one another due to the cultural norms of the area (Dodson, 2014). If men and woman cannot have contact it imposes a logistical problem when distributing the water collected by fog harvesting. This poses a problem for women coming forward to a male water manager with any concerns to the system; vice versa is true for a male interacting with a female water manager.

2.3 Greywater Management in Arid Communities

Part of domestic household water is called greywater, water that is produced from "personal hygiene, laundry, washing and cooking (Paris & Schlapp, 2010)." Recycled greywater does not pose an immediate health risk if used for non-consumption household activities. In contrast to greywater is blackwater, which refers to the water associated with human waste that can pose health risks even if used for non-consumption purposes. Greywater recycling has become increasingly common in many parts of the world such as the United States, Vietnam, and Australia to name a few. There are some places where greywater recycling has been adopted that there are not any governmental regulations over the treatment or use of greywater. There are three main components of a greywater recycling system; these involve a capture method, a filtration system, and an end use.

2.3.1 Methods of Greywater Capture

Greywater capture is an important process of recycling and having greywater separate from blackwater is important because the appropriate water is being lead to the greywater recycling system. With water loss to evaporation already being high combined with the limited water supplied to the villages, reducing further water loss during collecting greywater and transferring it to the recycling systems is a concern. Throughout the recycling system greywater must be properly handled so it does not come into contact with humans or animals, and greywater cannot be stored because it is deemed blackwater after 24 hours. For this reason the collection system needs to completely drain and not have places where small amounts of water can be trapped and contaminate the next batch of greywater to flow through the system. All horizontal pipes in the system must have a ¼" drop per foot (2 degree pitch) so that all the water will adequately drain from the system and not stagnate (Ludwig, 2015). The goal of this greywater capture system is to allow for the easy collection of a realistically sized volume of water, without letting any of the water to be stored before filtration or end use.

The main solution that is used in greywater systems is using a small basin located on the inside or outside of the building with a sloped base towards the drain. Usually this drain leads directly to the filtration system or a garden patch. In these systems the plumbing is usually connected to a septic or sewage system using a valve. This allows for the greywater to be routed to a waste area while the system is having maintenance preformed or is backed up. Many of the guidelines for greywater systems in the southwestern United States of America have specifications to make the management of greywater safe and effective.

2.3.2 Greywater Filtration

The filtration component of greywater recycling systems' purpose is to remove contaminants from the water, improving the safety of the greywater and expanding the potential applications of the water. Several of the main focus points to the filtration stage include removing hazardous pollutants, bacteria or viruses within the water, as well as decreasing turbidity of the water. Forms of filtration have a range from removing the solid materials to almost making the water potable again. We explore three promising types of filtration: sand filtration, reed bed filtration, and solar distillation.

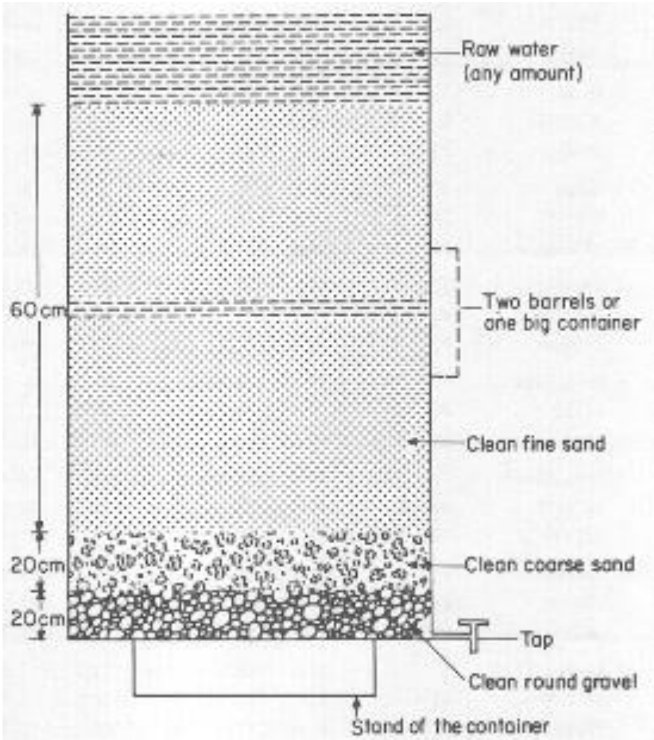

Figure 6: Diagram of a sand filtration system. (Dodson, 2014)

Sand Filtration

One method of filtering greywater is through the use of a sand filtration system. Utilizing various properties of sand, a sand filtration method allows water to pass through the system while preventing course of various contaminants and particles found in the greywater. Designs of greywater sand filtration systems can vary depending on the quality of raw greywater as well as desired quality of the effluent stream.

With raw greywater added to the system from the top, there are three layers of sand used to filter out several contaminants in the water. The sand layers in greywater sand filtration systems are layered with a large layer of fine sand on top, with a smaller layer of coarse sand and then a layer of gravel on the bottom, as seen in Figure 6. The top layer of fine sand is the primary filtering layer, removing most of the contaminants in the greywater as it passes through. The purpose of the bottom two layers is to keep the layer above it together so it does not separate and fall to the bottom as well as regulate the flow rate through the system. Using clean sand and gravel in sand filter systems is critical, as dirty and contaminated sand could negate any possible benefits of a properly assembled sand filtration system. Typical containers used are made out of a water tight concrete structure or plastic barrel, with size depending on application and volume of raw greywater being treated.

Concrete cisterns have the benefit of being flexible and adaptive, being able to be made in varying size depending on application. Typical concrete cisterns are buried halfway down the height of the structure.

Plastic cisterns consist of a modified barrel for sand filter use. These barrels are cheap, reasonably sized for most sand filter applications, low weight, and easily relocated. Installation of plastic barrel sand filtration systems requires little preparation of the surrounding land, making it a good choice for pilot systems or systems restricted on space.

Most greywater sand filtration systems include a siphoning component, raising the effluent flow of the system to the same height as the top layer of sand. This prevents the layers of sand from drying out, enabling the top layer of sand to develop a bio-filter like property. Microorganisms survive in the moist environment, feeding on and killing bacteria and viruses that are contained in the greywater. The siphoning system also prevents any of the gravel or sand from traveling out the effluent flow, a desirable property preventing possible clogging in other components of a greywater recycling system. Other benefits of using a siphoning system include no power requirements and long term reliability without need for regular maintenance (Clarence Valley Council, 2013).

More advanced greywater sand filtration systems include additional filtering elements. One such component is a bag filter, used to remove larger debris and particles in the raw greywater. Filters can be added to the effluent valve as well, further decreasing the amount of oils and particles in the effluent flow. Other filters can be installed to target other contaminants that may in the water, such as biological matter. Bio-filters can be used to significantly reduce the amount of pathogens that make it through the system, increasing the safety of the effluent water. For systems subject to periodic large surges in raw greywater, diffusion plates can be used to restrict water flow from being forced through the system too quickly, reducing the possibility of water not being filtered effectively (Friedler, Kovalio, & Galil, 2005).

Reed Bed Filtration

Reed bed filtration systems use a bed of reeds to remove contaminants from greywater. Construction of reed bed systems consists of a watertight bed of reeds with a layer of gravel on top to prevent exposure of the water to humans and potentially offensive odors. Water feeds are below the gravel layer, which travels laterally through the system until it reaches the effluent flow. This process lasts five to seven days before reaching the output flow at the other end of the bed.

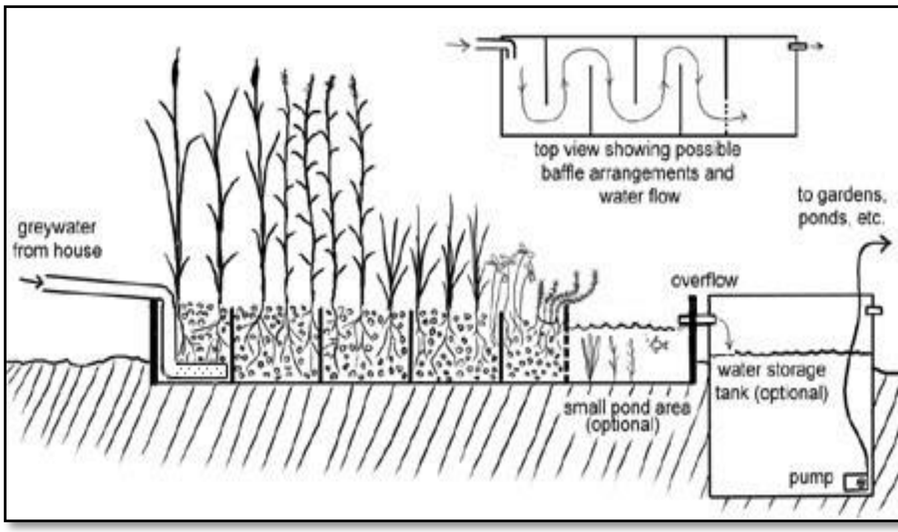

Figure 7: Reed Bed Filtration System (Bradley, 2012)

The primary method of filtration of pathogens in reed bed systems is from microorganisms growing on the roots of the reeds, acting similarly to the reed bed system by breaking down organic components and making conditions difficult for bacteria and viruses to survive. Excess nutrients within the greywater are removed by the roots of the reeds, such as nitrogen which commonly pollutes greywater (Clarence Valley Council, 2013). Figure 7 shows a diagram of a reed bed filtration system that can be adopted in households.

Sizing of reed beds can vary depending on the volume of greywater needing to be processed. Basic designs suggest systems having a depth of 0.5 m (26 in.), with 0.1 m (4 in.) of rocks where the input and output flows are. In addition to this, it is suggested to have a length of width ratio between four-to-one and one-to-one in order to have a sufficient size to ensure the water is filtered enough as it passes through. Further considerations include designing the system around a sloped terrain as to use gravity to promote the flow of water through the system. Terraced sections of reed beds can also be used to achieve this design.

Reed beds require many small design elements to function as efficiently as possible (Kabeel, Hamed, & El-Agouz, 2010). Systems that require several beds to filter water are most effective when constructed in series rather than in parallel, due to increase times flowing through the system and thus higher removal rates of contaminants and excess nutrients. For input and output flows, adding a component to spread the flow of water through the width of the structure improves the ability of the system to filter as well as increased flow rates (Kabeel, Hamed, & El-Agouz, 2010).

Solar Distillation

Solar distillation is a form of water purification utilizing the suns energy to separate water from impurities within it. The premise of a solar distiller is to heat up contaminated water, causing the water evaporate and leave the undesired contaminants behind. After the water evaporates, it condenses and is then collected for reuse.

Since water requires less energy to evaporate than many contaminants found in greywater, it will more readily evaporate and separate from these contaminants. But, if too much energy is applied to a solar distillation system, certain chemicals can evaporate as well, negating the effectiveness of the system.

Typical solar distillation systems as seen in Figure 8 are a box or tray with a sloped piece of glass on top. The tray is colored black to absorb the most heat from the suns radiation. The water is pumped into the tray where it will sit and heat up as the sun's energy bypasses the clear glass and heats the tray. The water then evaporates and the resulting water vapor collects on the glass above it. After the water has condensed on the glass it beads up and rolls down the slope, where it drips into a small semi-circular tube, which is referred to as the "gutter." The gutter is slightly sloped as to allow the water to escape out of a tube at the end of the tray and be collected. This system also needs to be as close to air tight as possible, other than the exit and entry points of the water. This seal minimizes loss of vapor to the atmosphere thus increasing water to be recycled.

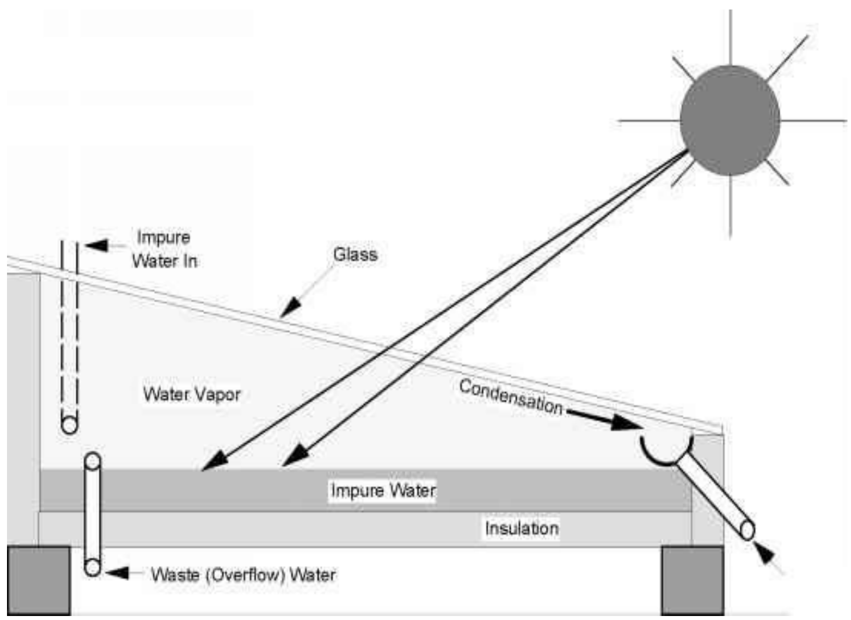

Figure 8: Solar distillation Diagram (McCracken, 2015)

Solar distillation systems work most effectively at removing chemical pollutants and salts from greywater. Typically unable to process at as high volumes as other filtering methods, solar distillations are more commonly used in applications treating brackish water (Kabeel, Hamed, & El-Agouz, 2010).

Table 1: Filtration comparisons between the three greywater recycling methods

Design Type	Strengths	Weaknesses
Sand Filter	• Low cost to build • Minimal regular maintenance • Versatile placement options	• Large task to clean sand • Strong chemicals destroys the system
Reed Bed	• Minimal to no maintenance required • Can be used to remove harmful contaminants that would otherwise require special filters • Reeds can rejuvenate	• Water loss to evaporation • Must have a constant supply of water • Must tend to plants • Industrial chemicals would kill the reeds
Solar Distillation	• Produces potable water • Simple to maintenance • Works effectively in sunny environments	• Produces a chemical brine • Needs to be monitored during operation • Slow processing time • Requires large surface area

2.3.3 End Use of Recycled Greywater

Upon being filtered, greywater would be ready for its application process. With access to additional water previously unavailable or unused in the villages, the greywater can then be primarily used for various applications to fill the role clean tap water in specific situations. Due to restraints on greywater filtering processes, the best applications of greywater are those that require minimal to no human or animal interaction with the water. This removes the use of any form of consumption of the water, as it still could pose a health risk if contaminants make it through the process.

Applications of filtered greywater will vary depending on the condition of the water upon leaving the filtering stage of the system, but many uses for the water still exist. Most commonly this greywater will go to watering plants and irrigating crops, as it poses the least risk to humans and animals while still being greatly beneficial. Other uses include various cleaning applications, flushing toilets, and irrigation for crafting plants.

Up to 50% of potable water could be reduced through the practice of recycling greywater daily for landscape irrigation. There are some components in greywater that may modify the topsoil's properties, damage plants, and contaminate groundwater (Gross, Shmueli, Ronen, & Raveh, 2007). By treating small amounts of greywater to reduce or eliminate nitrogen, oils, salts, and other minerals found, the water can be reused for permaculture, a common end use for recycled greywater along with landscape irrigation.

Permaculture

Permaculture a landscape design approach in which the ecosystem created focuses on the needs of people and livestock. Permaculture would assist the people living in limited spaces for farming or gardening to live in self-sustaining environments for households. "It is possible to condition tracts of soil to make them more suited to farming, even in the hard climates of Death Valley and the Mojave Desert (Regenerative Leadership Institute, 2014)."

Permaculture is viewed as using the proper techniques to synergize resource use in a small scale environment. Permaculture is used to simulate a small scale habitat based off natural ecosystems. There are many guidelines set out by the local governments in New Mexico and Arizona, which are of similar climate to Sidi Ifni. These guidelines include ways to implement many different resources into recycling practices in daily life, but for most of the topics in permaculture reach outside of the scope of the resource availability in Sidi Ifni. But greywater system designs from larger permaculture systems can be useful to develop a set of construction plans and end uses.

Gardens

Another use for the water that would not require potable water or extremely thorough filtering would be to use the recycled greywater for irrigation purposes, such as for small gardens. Greywater systems are often linked to gardens because it is a simple solution that allows the water to be used in a way where it can provide both an ascetically pleasing outcome and potential food. Planning for a garden requires many steps before implementing the idea in a region, determining the most effective plants to be used in the venture will also be a concern. Analyzing what crops the villagers may already grow as well as possibly introducing new crops as well. Considering the function of the plants will also be a concern, which includes plants purposed for consumption, aesthetic appeal, or other uses. Assessing the long term sustainability of the plants will also be essential as well.

Drip irrigation is also an option for recycled greywater because using irrigation systems would help small gardens in vegetation grow. Water and fertilizer distributed to crops would slowly reduce the water use by 50% (Palada, et al., 2011). This would prove useful in cash crops that farmers would normally spend hours in allocating water for their crops. Treated recycled greywater could provide as a water source to families so that they could make the most out of their gardens.

Other Uses

Due to the possibility of contaminants found in filtered greywater, further uses of greywater have to be considered carefully to not pose a health risk to the villagers. Any potential uses will need to focus on tasks that will have minimal contact with the villagers and any possible wildlife or cattle in the area. Depending on the way the water is used the first time can affect other end uses such as water that has been used only for cleaning laundry, could be filtered and reused to wash the laundry again.

2.3.4 Complexities of Introducing Greywater Management in Morocco

On 8 April 2015, Jamila Bargach, Director of Dar Si Hmad for Development, Education and Culture (NGO), and Leslie Dodson, Executive Director of Tifawin Institute, visited Worcester Polytechnic Institute and gave a presentation about their organization's efforts in harvesting water from fog and delivering the water directly to Amazigh communities. In their presentation they mentioned the Amazigh people were at first skeptical in using water harvested from fog because they considered the water as "dead water" such as water that has not touched the earth. Moroccans had been dismissive of the fog as well as considering it as a nuisance. We learned that water harvested from fog is so pure that water has to be mineralized by being mixed with ground well water from in order to meet Morocco's standards in mineralized water consumption.

Dar Si Hmad organized a water school for the youth in the villages to teach them about using the fog as a resource. The children were used as ambassadors to their mothers and fathers, which created a social engagement in the community in accepting the fog nets and using the harvested water. Communities that were at first hesitant about using fog water, a resource so pure, may create discussions in educating people in accepting recycled greywater to grow their crops, gardens, or for land irrigation.

3. Methodology

Our project goal is to help advance Association Dar Si Hmad's Fog Net initiative, a cutting edge water access project that greatly increases its availability in the dry region of Aït Baâmrane in southwest Morocco. We will support their efforts by introducing greywater management practices that close the water use loop, allowing for the capture and re-use of water at the household level. Accounting for cultural and environmental factors that could hinder the adoption of water reuse behaviors, our group will design a guide specifically outlining the situational appropriateness of three key greywater systems, which will include recommendations for implementation of a system at the Dar Si Hmad test house, in the countryside.

The primary study areas where this project will take place is at the WPI Project Center in Rabat located in the Medina, or old city; the second headquarters of Dar Si Hmad at Sidi Ifni; and the bled, which means country in Arabic, which is about a 30 minute drive west of Sidi Ifni where villages of Amazigh people reside. Located along the Atlantic Ocean, Sidi Ifni is a popular vacationing spot among Moroccans and known for Legzira Beach's arches. The people of Aït Baâmrane live in rock and adobe households that may be up to a hundred years old or more. They have their own independent, efficient way of living in these lands but in recent years have been open to new methods of improving their daily lives that Dar Si Hmad has introduced.

To accomplish our mission we developed several key objectives to be completed in Rabat and Sidi Ifni, Morocco.

1. Inspect and understand the operation of the fog net harvesting system
2. Understand the water management practices of the countryside and livelihood of the Amazigh villages

3. Understand our stakeholder’s perceptions and interests regarding greywater use
4. Develop a recommendation guideline for the appropriate use of each greywater system and what would be the most culturally acceptable to use in specific application.
5. Recommend a specific system for the household space Dar Si Hmad owns in Aït Baâmrane

In order to meet our objectives there are three major phases we went through: (1) an initial visit to Sidi Ifni hosted by Association Dar Si Hmad with five days of intensive field work, (2) an analysis and design phase in Rabat, and (3) a second field visit to Sidi Ifni to present and seek feedback from our stakeholders. In preparation for our initial visit to Sidi Ifni, we received a water and sanitation report created by a Master’s student from the University of Colorado-Boulder and Dar Si Hmad that contain information pertinent to the water sanitation situation in the countryside.

3.1 Inspect and Understand the Operation of the Fog Net Harvesting System

Understanding the fog net system was a critical part of understanding the roots and background of this project and what Dar Si Hmad has already invested in this project. The fog net system provides the water that eventually becomes greywater. Knowing how the water is handled and delivered has a large place in determining how to best handle the water after it has been used. These were the research questions that we asked to understand the operation of the fog net system.

- How much water is produced and can be maintained by the system?

- What process does the fog pass through to become the end product being piped into homes?
- How far must the water be pumped to reach the villages?
- What filtration systems are used on the fog water after it has condensed?
- How is the water transformed into a socially and politically acceptable source for drinking?
- Where the taps are located in the homes, and are they easily accessible?
- What are the future goals and changes that Dar Si Hmad want to see for the fog net system?

Our first order of business when arriving to Sidi Ifni was taking an expedition to the fog net system Dar Si Hmad constructed to familiarize ourselves with it and inspect the fog nets with the water manager. During the site survey we ventured to the top of Mt. Boutmezguida, where the nets are installed, to see the facilities that Dar Si Hmad maintains. The terrain up to the top of the mountain required the use of a four wheel drive off-road vehicle. After reaching the top of the mountain we inspected the mesh on the fog nets to have a first-hand observation of how the fog condenses on the nets, which allows the fog to be captured.

We held in-depth discussions with the members who lead the fog net project such as Dr. Jamila Bargach the Director of Dar Si Hmad, Mounir Abbar the Fog Net Project Lead, Houssin Soussan the Water Technician and Najib Kebir an interpreter Dar Si Hmad hired to communicate with the locals on the overall functionality of the fog net system. Seen in Figure 9 is Mounir describing us statistics about the fog nets. Specifically noting where the fog nets are located,

Figure 9: Visiting the fog net site

their orientation and the materials they are made from and the overall design helped our team understand the needs and challenges related to inspecting and maintaining the system.

In addition, we learned how much water could be stored before the water meter stops the fog nets from collecting more water to prevent the cistern from overflowing. Having the data from the water intake helped our team understand the total amount of water collected and readily available to households. Learning the amount of water each household consumed on a monthly basis showed us how much water was being used and then thrown out as greywater or blackwater.

We then received a guided tour down the side of the mountain stopping at each critical component in the water system that Dar Si Hmad installed. The first stop was the mixing station to understand how they accommodated the government regulation and local cultural belief by mineralizing the water. We then travelled to the cistern which holds all of the water that has been collected from the fog net system and underground well. The last location we traveled on our tour was to the empty home that Dar Si Hmad owns in the bled. We were led through a brief tour and inspected the condition of the property. The last location relevant to understanding the infrastructure was a visit to the water manager, Mr. Soussan’s home, where we planned an interview to understand the thoughts of the local residents and inspected where the taps would normally be installed in a house. Knowing the primary locations would help us keep in mind the distance from each tap location to a drain, the washing room, and the kitchen: locations where water would heavily be used.

3.2 Understand the Water Management Practices and Livelihood of the Bled

A critical part in designing a greywater recycling system for effective use in the area depended on obtaining a strong grasp of the region. To achieve this, we needed to learn about life in the bled, including water practices within households. We aimed to understand their livelihood practices, the relations and governance between villages, and the condition of the landscape. Unfortunately we were unable to interview any Amazigh households due to most families being out of town to collect argan nuts. Also since the implementation of the fog nets there have been many pre and post project interviews to which Dr. Bargach stated, the villagers might be getting stressed by so much attention and interviews.

3.2.1 Visit to the Water Manager's House

The open-ended interview at the water manager's home was conducted over lunch and tea with Mr. Soussan, several relatives of his, our chauffeur, our interpreter, and the head of the fog project. This interview included a demonstration of in home water use, using both fog water and water from the family's cistern. We used this time to inspect Mr. Soussan's cistern and discussed how the cisterns function to collect rain water. We asked many questions pertaining to the livelihood and water practices from his family's daily lives, a complete list of these questions can be found in Appendix D.

During our discussion Mr. Soussan, we also took the opportunity to inquire further into his family's personal habits regarding their water use. The purpose of this was to determine how their water consumption was affected by the introduction of the piped water delivered to their home.

3.2.2 Notable Visits in the Bled

We also traveled to Dar Si Hmad's vacant house in the bled for further understanding of what typical households are like in the area. Inspecting the house, seen in Figure 10, we paid attention to the location of the home and how its construction was affected by the local environment.

In addition to the visits to the countryside we conducted, we also visited several other households and notable areas in the bled. Locations we visited include a beekeeper's house, the property of a farmer, along with several state-owned schools. Our primary focus was to further delve into life in the bled, exploring such

Figure 10: Dar Si Hmad house in the bled

topics as what residents do for their livelihoods as well as common water practices used in the area. We visited gardens in the area shown in Figure 11, observing the types of plants and the conditions each was grown under. This included investigating the methods of irrigation used for these gardens.

Figure 11: Visit to a garden

3.3 Understand our Stakeholder's Perceptions and Interests Regarding Greywater Use

A crucial aspect in interviewing the water manager and Dar Si Hmad was to determine whether or not they would use greywater for further end-use applications since this approval would allow our project to move forward in designing and prototyping a greywater recycling system.

Learning about any previous work or attempts at capturing and reusing greywater helped our group understand the reasons behind why the project was accepted or denied into the villages. Also, when speaking to the villages we needed to have a clear understanding of what greywater and blackwater is. We informed the water manager and the residents of the bled of our project's main focus of greywater recycling and have them understand the difference between greywater and blackwater. Greywater can be used once more by different recycling methods mentioned above however; informing them that water cannot be consumed yet used for growing fruits or vegetables will give us some insight to their perceptions of water that previously had a purpose. Determining whether the Amazigh people would be content with reusing greywater from bathing themselves and washing clothes is vital, due to the water captured from these two areas would primarily be recycled through the system.

3.4 Supplemental Document for Dar Si Hmad

To provide a recommendation for Dar Si Hmad we gathered all of the data from our findings and notes to put together a deliverable document. Through synthesizing this information we put together a guide that addressed each system and where they would be appropriate at the Dar Si Hmad house and ideal locations within the bled. We individually analyzed key system components such as descriptions, materials, placement options, strengths, weaknesses, maintenance, and required input of water. We then used this information to arrive at the recommended system to be implemented in the Dar Si Hmad test house so the area can be used as a case study for greywater management practices that close the water use loop, allowing for the capture and re-use of fog water at the household level. In addition, through the use of

Computer Aided Design (CAD) we recreated the house using our sketched schematics we created on our field visit to the house, and labeled the best locations to place each of the systems.

4. Findings and Results

The following contains findings from our early research before the initial field visit to Sidi Ifni and the information we gained from that visit. These findings address our first three project objectives. We include in these findings key insights from the water and sanitation report that we received from University of Boulder-Colorado Master's student, Nick Valcourt, and Dar Si Hmad. Included with the sanitation system report were results from a household level Water and Sanitation Survey. We then provide detail on which greywater recycling system could be feasibly implemented at the household level.

4.1 Water and Sanitation Report of the Aït Baâmrane Region

The data used in the report were collected between June-July 2015, shortly after the fog water delivery program launched. This report outlines common water management practices in the villages of the Aït Baâmrane. Detailed observations about greywater and blackwater practices were included within the survey. Since a short period of time had passed people were likely still adapting to the available water in their homes. Having had access to the report before our visit to the bled, we gained a thorough background on the effects of the water delivery on the village's livelihoods.

4.1.1 Effect of Improved Water Access on Standards of Living

Throughout the report it clearly states how much of an impact that improved water access has had on the residents' way of life. No longer burdened by the constant troubles associated with collecting water from wells such as containers breaking, their donkeys being too weak, no water being available in the wells, amongst other headaches, the Amazigh have experienced immediate benefits to their standard of living. The fog water project has promisingly improved living in the area given the early results. Expanded water management and greywater recycling is the next step in satisfying the region's water needs. It is still a daily and difficult task for many other villages to collect the water they need, and directly piping water to households can lead to excessive use and could amplify any water waste. Closing the loop on water use by recycling it will allow for a better upscaling of a waste water system and the overall use of less water as it is still a scares resource.

4.1.2 Water Loss and Greywater Management

The water and sanitation survey gave comprehensive information about the water management practices and facilities for many houses in the bled. Many houses have separate drainage pipes for greywater and blackwater. Blackwater drained to man-made pits which varied in age, while greywater drained separately to the land outside the home (62%) or was manually dumped outside (29%) (Valcourt & Association Dar Si Hmad, 2015). Residents increasing their daily water intake will increase the amount of greywater runoff. Approximately 91% of greywater "is absorbed by the soil or is evaporated (Valcourt & Association Dar Si Hmad, 2015)." Since the majority of households already have drains for water in place it makes it easier to capture greywater for recycling purposes.

The water and sanitation report described that there was already a system in place of separating greywater from blackwater as well as reusing somewhat clear greywater for their blackwater pits if they would like to. The method for disposing of used water is important because it determines how much water can be recovered from a greywater system. The report describes two means by which houses in the bled dispose of water: drainage to the land outside their homes or greywater is carried outside their household to a specific location where it will be absorbed in the soil or evaporated in the daylight; data taken from Figure 12 (Valcourt & Association Dar Si Hmad, 2015).

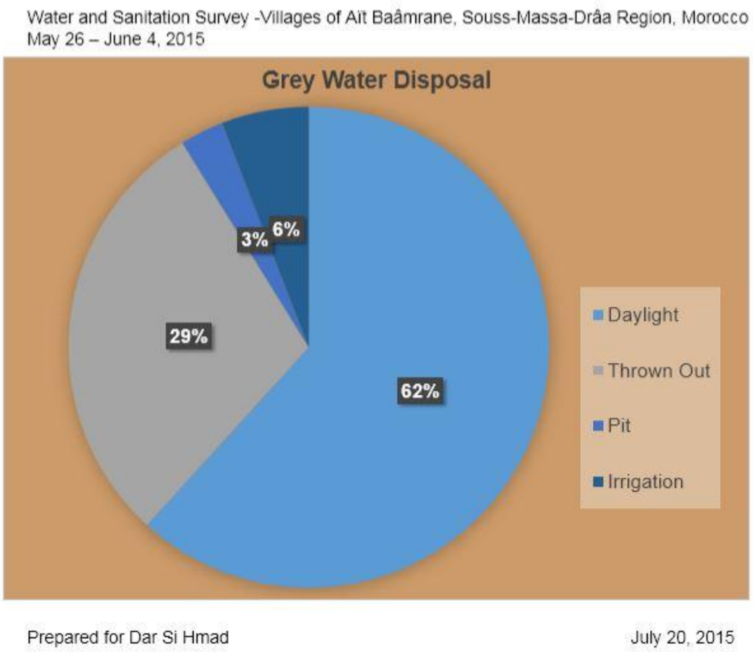

Figure 12: Greywater disposal in villages (Valcourt & Association Dar Si Hmad, Morocco, 2015)

4.1.3 Greywater Origins and Greywater Conditions after Use

In the households greywater originates from washing clothes and dishes, and cleaning the bathrooms. This outlines the origins of greywater that the

Figure 13: Hand washing basin at the beekeeper's home

homes in the bled currently practice. Showing how the water is used in the kitchen, bathroom, and washing clothes before it needs to be recycled. Also the use of chemicals has an impact on greywater recycling system, and the later use of the greywater.

Kitchen

The greywater that could be reused from the kitchen would come from a bin of water where they soak their drinking cups so they can be used again at a later time in the day. Water used to clean plants, fruits, and vegetables can also be recycled because they have not been exposed to grease, bacteria, and chemicals. We were invited into a beekeeper's home for breakfast where we washed our hands using a portable handwashing station pictured in Figure 13. Water from that handwashing station is already captured and can be easily poured into a recycling system.

Bathroom

Bathing produces an abundant amount of greywater. The villagers have adopted strict water management practices from the previous scarcity of water; they are accustomed to bathing every two to three days.

Laundry

The water that is being disposed of outside is from hand washing clothes in a basin and from washing dishes then disposing greywater to the outdoors, and a family mentioned of using well water to rinse their clothes. There are some families that avoid using a washing machine because the process to soak, wash, and rinse clothes consumes too much water. A few households avoid using greywater to flush toilets because they fear their blackwater pit will fill up though others may use some of the greywater to flush down waste (Valcourt & Association Dar Si Hmad, 2015).

Chemicals

In addition to describing the various processes in which greywater is generated in the villages' households, the report listed the various chemicals found in each of the households. These are chemicals that can be expected to be found in the greywater generated through washing and cleaning. Notable chemicals include Oni, a dish detergent, Tide laundry detergent, as well as bleaches. The presence of these chemicals complicates potential filtering and reapplications of the greywater (Valcourt & Association Dar Si Hmad, 2015). These specific chemicals such as bleach can destroy recycling systems, and less harsh chemicals can be left, resulting in a waste that will have to be cleaned and disposed of later.

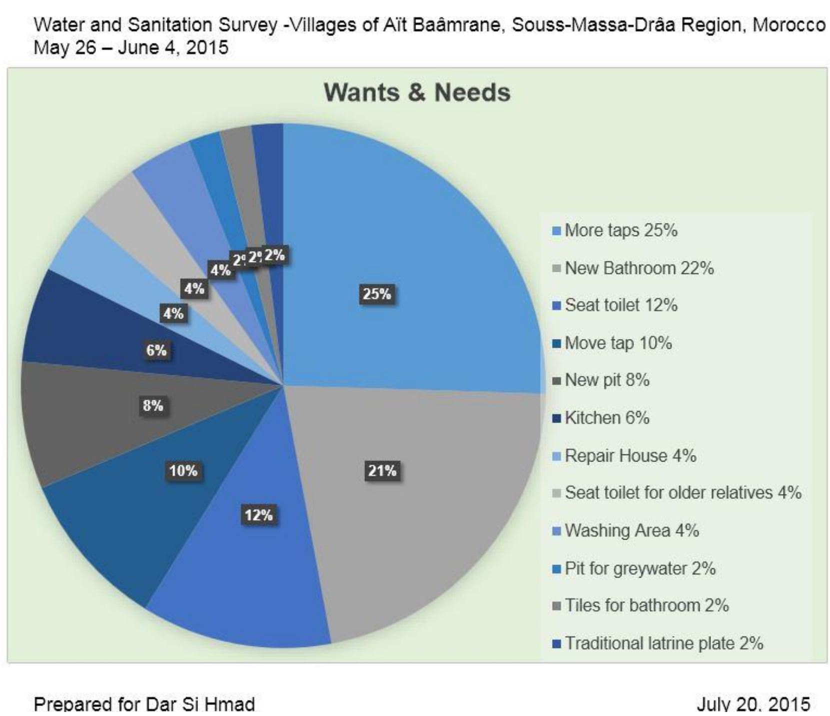

Figure 14: A graph representing the wants & needs of the communities (Valcourt & Association Dar Si Hmad, Morocco, 2015)

4.1.4 Potential Applications of Greywater

After having fog water resource readily available in homes it has given people time to think of more home improvements they would like to make, due to the fact that they no longer have to travel for hours to gather water. There were some homes that did not have a toilet and primarily use the livestock area. Households reported wanting small advances to their households, such as 25% wanted more taps in their house and 22% wanted a new bathroom to give it a more modern look as seen in Figure 14.

4.2 Fog Water Collection System

We inspected the nets to observe how the design of the mesh was able to effectively condense the fog and funnel the water down into pipes below the net. Some nets were equipped with a displacement style meter in which a small cup would fill to a predetermined amount before teetering and dumping the water, hitting a switch in the process. We were informed that the average production amount was 10.5 liters per square meter (20.7 gallons per square foot) of netting per day. With 600 m^2 of nets total, on an average during the foggy season the system produces 3,150 liters (832.14 gal) of water a day, which translates into a little over 3.15 metric tons (1 metric ton = 1000 liters = 264 gallons) a day. The reservoir at the top of the mountain that the water collects in to be filtered can hold 50 tonnes of water. We discovered a few fog nets where the nets were detached from their frames, pictured in Figure 15, which meant that the current nets they have experience problems in withstanding high winds.

Figure 15: Detached fog nets from frames due to high winds

Even though the nets were damaged Dr. Bargach informed us that they do harvest fog yet not to their full potential. The water manager goes up the mountain and checks the fog nets two times a week and performs maintenance on the fog nets.

There were six unique nets that stood out from the rest of the fog nets at the top of the mountain. These six different meshes turned out to be a test run for a German fog net systems. This was a standalone net system that had multiple pieces of advanced metering on it as well as a different construction style. Dr. Bargach said that these nets were nearing the end of a two year trial run and were providing promising results. These prototype fog nets resulted in producing 50 liters per square meter of net, and had never torn from the wind because of their design. The instruments on these specific fog nets were recording weather data and updating it in real-time to a German NGO Water Foundation (Wasserstifung) and the Technical University of Munich's database.

After we inspected the fog nets we went to the small house next to the fog nets where they filter the water before it travels down the mountain. The current process that is in use to filter the water is ultraviolet filtration followed by sand filtration to neutralize any bacteria that was present on the fog net since they are exposed to the environment. We traveled farther down the mountain where we were shown the mixing station, which is where they add in groundwater to mineralize the fog water to satisfy the Moroccan state standards of potable water. This station was a small protected room in the valley of a dried river. The small building, as seen in Figure 16 has solar panels on the roof, powering a pump inside with multiple gauges giving pressure readouts. The ratio of fog water to groundwater was described as varying based on how much fog water was collected and the amount of fog water that Dar Si Hmad has stored in their reservoir. During peak fog collection the water being sent to the villages was almost purely fog water, only introducing enough groundwater necessary for mineralization. Afterwards we visited Dar Si Hmad's cistern which is a tank where they housed all of the water that is supplied to villages. The tank was underground with an access room and a gate above it.

To evaluate the water management in homes we saw that the cistern was similar to the cistern at Mr. Soussan's house, which was a big stone pit with a channel leading into a covered stone tank. He explained that this was a cistern and how it operated. The cisterns pit would fill when it rained and then the surface water would channel into the stone tank. This process let all the sediment fall to the bottom of the pit. The last part in the system was an in home faucet, protruding from the wall near his front door with a tile backsplash and two buckets underneath.

Figure 16: Pumping Station

During the meeting with Dr. Bargach we discussed how Dar Si Hmad is delivering their water to the homes. Dar Si Hmad uses water meters to charge the villagers for the water using the ONEP pricing model. These prices have been altered to be a more suitable scale for the impoverished villagers and exact pricing can be found in Appendix E. During our meeting with the Mr. Abbar, we were given access to the water pricing information as well as the usage statistics of each individual meter, giving us accurate data of the water usage from the past five months.

The fog net system is proving a water resource in the seven villages surrounding Mt. Boutmezguida where the Amazigh have fog water piped to their homes and pay a small fee that goes towards the maintenance of the fog nets. With water consumption increasing daily it creates more greywater that is carelessly being disposed of, and calls for greywater management methods to prevent an opening in the water cycle of fog water, groundwater, and greywater water use.

4.3 Water Management Practices and Livelihood of the Amazigh Villages

In developing an effective greywater management strategy, understanding water use practices and livelihood conditions are essential in fitting the needs of the villagers.

Condition of Landscape

The soil in the bled is dry and unable to hold moisture, severely limiting the varieties of plants able to grow in the area. Apart from scattered bushes, the only plants to grow in the wild around the area are cacti and argan trees. Our first visit up Mt. Boutmezguida, Dr. Bargach stressed that the road up the mountain was much more rough and treacherous when the fog nets were being constructed. Only through multiple journeys up the mountain and clearing the road from large rocks is the road

Figure 17: View of the bled from the top of Mt. Boutmezguida

passable with regular automobiles. From the top of Mt. Boutmezguida, seen in Figure 17, is an overall view of the area.

Villages in the area were spread out, consisting of a few houses each. Some villages were located close to wells and others access to wells consists of half an hour to over an hour's journey to the closest well on foot or fewer with a donkey. The rainfall in this area is "132 mm (5.2 inches) yearly with a limited number of precipitation days" with the yearly average temperature is 19.4℃ (66.9°F) (Association Dar Si Hmad, 2015).

Figure 18: Water tap in one of the households

Households within the bled are single story buildings constructed of cinderblocks, adobe, and large rocks, with roofs consisting of logs, bamboo and a mud layer on top. Windows on the houses have no glass, and rooms often have no doors. Floors were unevenly packed dirt surfaces. Of the installed taps within the houses, most were installed in either the bathroom or kitchen area, and a small number could be found outside the house. Of the households visited, bathrooms consisted of a squat plate with a tap or bucket to wash. Seen in Figure 18 is one of the taps installed as part of the fog water project.

Livelihoods within the Bled

Within the bled, the area looks to be almost abandoned occasionally seeing a few residents as they travelled along the road either on foot, on their donkey, or working around their houses. The villages and households are few and far between in the bled. Dr. Bargach informed us that most of the men within the villages may leave the countryside to work in the cities for long times during the year. Left in the villages is predominantly the women, elderly, and children.

Figure 19: Cactus Farm

Women within the villages have several responsibilities. First, they take care of the homes by cooking, cleaning, and raising the children. For additional income many women work on the mountainsides gathering argan nuts and cactus fruits. The lands containing these argan trees and cacti are collectively owned and only used by members of the villages during the harvest season. Villages are often associated and organized through cooperatives, which provide jobs and more reliable incomes for families. The villages are abandoned during the daytime, which could pose a problem to keeping an influx of greywater into the systems that require it such as reed beds.

Other than having argan trees and some shrubs on their lands cacti can be easily grown and some villages have large cactus farms that can later be harvested for their cactus fruits, or prickly pears, pictured in Figure 19. We were told that few residents have a garden because the climate makes the soil difficult to grow anything and not having enough water to properly maintain the garden, however with enough resources it is still possible to support a lush and exotic garden as pictured in Figure 20. We came across a village in which a household was able to grow a garden on their land because they have two wells and they use goat droppings as a fertilizer. They check the water levels in each well before getting water from the well that has more water and fill up a large barrel/container. From there they are able to pump the water into a hose and effectively water their garden.

Figure 20: Garden in the bled

The following Table 2 includes a list of fruits, vegetables, herbs, and plants that we personally encountered grown in the bled or mentioned to us by our interpreter.

Table 2: List of flora overserved or previously grown in the bled

Fruit	Vegetable	Herb	Plant
Date	Carrot	Basil	Argan
Eggplant	Turnip	Parsley	Bamboo
Fig		Rosemary	Cactus
Lemon			Henna
Olive			
Orange			
Plum			
Pomegranate			
Tomato			
Watermelon			
Pumpkin			

Water Usage

Primary uses for water:

- Consumption (tea, cooking, drinking)
- Bathrooms/toilets
- Laundry
- Cleaning/Dishes
- Livestock
- Gardens

Many houses have a cistern in addition to the piped fog water to their homes. These cisterns are refilled by rain channeled down the mountains. As well as a rain fed cistern, some houses may also have a cistern they filled through gathering from nearby wells. We learned from residents that these cisterns used to be where they drew all their water from, but after the installation of taps into their households, they have had much less use.

Figure 21: Old Cistern

Attention to maintenance of cisterns, as shown in Figure 21, has decreased as the villages have gained improved access to water. Along with this, residents have found little use of the water in the cisterns, apart from a few selective uses. Many residents do not like the taste of tea made with the piped fog water, so they prefer to use their cisterns water for drinking tea. We also discovered that the villagers do not drink water to hydrate themselves; Dr. Bargach informed us that the villagers almost exclusively drink tea, with every meal and when they are thirsty.

4.4 Stakeholder Perceptions and Interests Regarding Greywater

Understanding our stakeholder's perspective on greywater recycling was important because if there was a consensus that greywater would not be used in any manner other than disposing of it in toilets or sunlight then this project would have been halted. We needed to understand that not only would it be acceptable to reuse greywater, but to confirm what purposes that the Amazigh people would be comfortable using greywater for.

The discussions at the beekeeper's and water manager's homes confirmed that recycling greywater in the bled is acceptable. After going over the topics and the multiple uses that greywater can have, after it has been treated, we reached several conclusions. Through the tour of the bled and from the water and sanitation report it was evident that some people were using greywater to flush their toilets.

We explained at the water manager's home that we would recycle greywater that comes from washing clothes, showering, and some water from the kitchen and that greywater recycling does not include human waste. Our interpreter and water manager gave clear statements that recycling blackwater would harshly be frowned upon to grow food, but they would potentially use recycled blackwater to grow henna or bamboo (crafting plants). Once greywater and blackwater definitions were made clear, the tone of the conversation changed to reveal that recycled greywater would be acceptable to use as long as it was safe and effective. The residents also mentioned that households may not produce enough greywater to be recycled and think that they conserve well enough. Water usage will increase over time and the Dar Si Hmad directors want to apply greywater recycling systems in the bled before the excess water becomes too much to handle in households. The cultural acceptance of reusing clean waste water is very high whereas the reuse of water that has become blackwater is unaccepted.

5. Proposed Greywater Recycling System

This section presents our proposed design for a greywater management system at the Dar Si Hmad house in the bled. The design is suitable to the site location and considers the current context of the building being unoccupied. Three greywater recycling systems were all considered for the Dar Si Hmad test house, and a supplemental document for Dar Si Hmad is located in Appendix A details all three greywater recycling systems and their future implications. Our proposed design utilizes a sand filtration system. Other important aspects of the design include greywater capture within the house, and suggestions for the end use application. We also present ideas for wider use of greywater recycling more widely in the bled.

5.1 Potential Filtration Designs for the Greywater Recycling System

The purpose of the filtration component of a greywater recycling system is to remove contaminants from the water, improving the safety of the greywater and expanding the potential applications of the water. Several of the critical processes that occur at the filtration stage include removing hazardous pollutants, removing bacteria or viruses within the water, and decreasing the turbidity of the water. The document in Appendix A includes the introduction of this report, details outlining sand filtration, reed bed filtration, and solar distillation units. Each system includes a section on materials, strength and weaknesses chart, ideal placement options, maintenance, optimal condition (environment and climate), benefits of system, and additional resources. Additional resources will allow Dar Si Hmad to review online guides and frequently asked questions in factors to consider when building any type of greywater recycling system.

Reed Filtration

Of the three systems analyzed the first reviewed is reed bed filtration. This system handles large quantities of greywater. This system uses indigenous reeds to filter out most of the chemicals and harmful pathogens slowly making the water very pure and can be attached to existing drainage pipes that may already be implemented in households in the bled. The drawbacks of this system are that it requires high maintenance. The reeds need to be tended to constantly to make sure there is sufficient water in the system and there needs to be a constant supply of water to achieve any output so that the reeds don't absorb all the available water in the system.

Sand Filtration

The second system we analyzed was the sand filtration system. This option is low cost and not maintenance intensive. This system can be easily adapted to be located anywhere inside or outside of a house. The issues with this system are that it takes a large effort to clean every couple of years depending on the scale filtration unit and replace the sand. Another issue would be any bleach would destroy the system.

Solar Distillation

The last system we covered was the solar distillation system. This system has the big benefit of producing potable water, and requires more frequent maintenance. The drawbacks are that this system needs to be monitored; it produces a small amount of water that contains lighter chemicals before it produces water that is actually clean. This method can only handle a specific amount of water at a time and needs to have a brine byproduct removed between each use. If this system is left unattended in the sun the harmful chemicals can evaporate and contaminate the water supply with the chemicals that it worked to remove.

5.2. System to be Implemented at the Dar Si Hmad House in the Bled

Three greywater recycling options have been detailed and considered as a case study to be applied at the Dar Si Hmad house. With the information presented a sand filtration unit is recommended to be implemented at the Dar Si Hmad house.

Filtration System

The reason we make this recommendation is that this system will be the easiest to maintain during the intermittent time when no one occupies the house. Sand filtration does not require the constant influx of water that the reed beds require and in the future when the test house is inhabited, the greywater recycling unit will be able to handle the increased flow of water to be processed, unlike solar distillation. The industrial cleaning products used in the house can be monitored in avoiding bleach which will keep the bio-layer of the sand system safe. This is also a low cost option with the most accessible materials, which leads it to being the optimal test system to be observed and later used for a wide scale resource in the bled.

Water Capture Design

The option for collecting the greywater for this system would be a sink basin mounted on the wall in the courtyard that, for easier accessibility, would pipe the greywater drain water directly to the sand filter.

End Use Application

The end use is a garden in the middle of the courtyard because this helps with the ascetic of the house as well as impeding growth of the bushes that are growing there currently. When no one inhabits this building there can be shrubs or other indigenous plants, in place of decorative plants, that can survive without the system constantly running. Figure 22 is a general design of where the sand filtration should be placed in the Dar Si Hmad house. Then when the building is being prepared for full-time occupants, switching to any other plant can be sustained in the climate with proper water management. This would help the system be used intermittently because if there are no plants to soak up the greywater in the system the water will be left to stagnate in the planter.

The sand filtration system best encompasses all the factors that pertain to maintenance, ease of implementation, cost, and the specific situation in the house. This conclusion was taken from the information presented in this document and the initial site visit of the house. This should be a guideline in making a decision to demonstrate the optimal system for the Aït Baâmrane region.

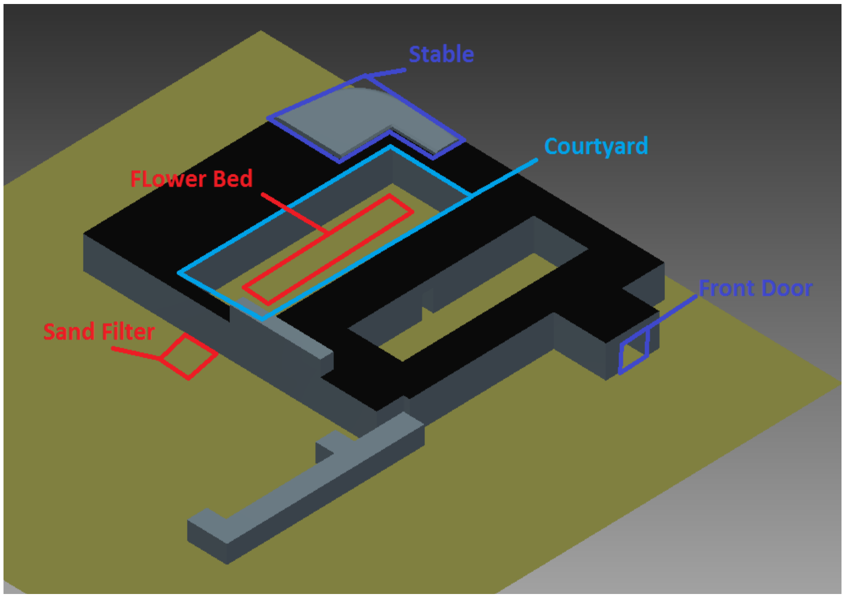

Figure 22: Computer Aided Design of Dar Si Hmad House

5.3. Considerations for Implementing Greywater Recycling More Widely in the Bled

Introducing a greywater recycling system into the bled enables every resident to preserve and extend use their newly supplied resources. Any implementation of a greywater recycling system will come with expected maintenance each household will need to perform. Solar distillation, sand, and reed bed filtration all have their strengths and weaknesses but doing case studies of each recycling system in households who are open to introducing a new concept to their lives will assist in the long run to determine which system works best in the bled.

The end-use applications for greywater can brighten their lives by having a garden for aesthetic appeal and the residents have the benefit of choosing to grow an edible, crafting, or decorative garden. Challenges in adding greywater recycling systems would be the locations of where each system will be placed. If there is not enough room on one family's property to implement the system appropriate for them then the groundwork in placing a system within a village brings the same problems faced in the fog water project. These issues are finding a property that the owners would accept placing necessary components for a community wide greywater recycling system on their land.

Recycling greywater requires the community to be mindful of the chemicals that they have been introducing into the environment through their daily living. Educating the residents that greywater does not have to be discarded and can be filtered, treated, and used for more applications, as well as in the long run saving some households money. Introducing greywater recycling to households will help close the water loop by maximizing the use of the excess water which is increasing daily.

6. Recommendations

This project developed a greywater recycling system that was suitable to the context of the bled. We utilized social science research to understand important aspects about the environment and the needs of the stakeholders. By conducting analysis we determined optimal greywater systems for the region and its communities.

The proposed design is at an early stage of development and has not yet been implemented. There are a number of recommendations we make to further development of the greywater management system at the Dar Si Hmad house as well as make greywater management viable throughout the communities served by the fog water capturing system.

Chemicals

Future research to be conducted is to test greywater produced at each household for the concentration of chemicals they contain. A thorough investigation of how the chemicals affect these three particular recycling systems would be required. Finding bio-friendly cleaning products available in southwestern Morocco and educating people to use them in substitution of major cleaning products found in this region would be a helpful endeavor.

Community Wide Approaches

Determining the feasibility of community greywater recycling systems incorporating entire villages could provide new opportunities for larger, more impactful community projects. Larger scale greywater recycling implementations would increase opportunities for end use applications of the recycled water, providing greater benefits for entire villages. Assessing community support for shared lands housing greywater recycling systems will be needed. Along with this, accounting for implementation costs as well as the value of the benefits the system provides will help determine the viability of the project.

Improved Irrigation Practices

To further increase water conservation in the communities, education about irrigation practices will complement the addition of greywater recycling systems around the bled. Efficient watering practices such as drip irrigation and watering gardens during cooler times of the day when the sun is low will help further reduce water usage.

7. Conclusion

The designs and recommendations presented here will hopefully catalyze further interest in the project and lead to further opportunities for Dar Si Hmad to advance the project. Informing the community that there are other means in maximizing their greywater is a step towards accepting recycling systems in their villages. It is inspiring to realize that the people of this region are open to new methods of improving their daily lives, and continual collaboration from the community will lead to an accelerated acceptance of greywater recycling.

During our time working with Dar Si Hmad on this project, we heard of a quote that struck us. We found this quote to express the significance of water in the communities of Aït Baâmrane. One woman, when asked about the fog water projects impact on her life responded: “Water knows no time.” Morning, afternoon, middle of the night, she had to collect water when it was needed. Sick, old, or tired, the need to collect water never stops.

While the fog net initiative has had a profound impact on these communities, implementing greywater recycling expands the potential for even greater impacts on these communities by closing the water loop and maximizing use of the valuable resource.

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Appendix A: Deliverable for Dar Si Hmad

Greywater Recycling Systems for Southwest Morocco

An Interactive Qualifying Project Supplementary report submitted to Association Dar Si Hmad for Development, Education and Culture, and Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science.

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Introduction

This document presents our findings and analysis of three greywater recycling systems and their implementation in the Aït Baâmrane region of southwest Morocco. Supporting this, we provide a recommendation on the optimal recycling system we found based on technical, regional, and cultural considerations. Drawing on our research and findings, we raise further areas of investigation for Dar Si Hmad in employing greywater recycling initiatives.

The Context and Need for Greywater Management

Throughout the rural areas of Morocco, there is a widespread lack of available clean water sources. The Amazigh villages surrounding the Anti-Atlas Mountains have a steadily declining water supply and poor access to the few sources that exist. Standing just a few kilometers outside of the city of Sidi Ifni are seven villages that are located at the base of these mountains. The demand for water is putting strain on not only the people, but the land around them. This region, located in close proximity to the Sahara Desert, shares many characteristics with the desert including an arid climate and a lack of bountiful water cycles. Per capita available water resources in all of Morocco are an estimated 700 m^3 per year for a population of 32.5 million. Annual per capita water availability is expected to drop to less than 400 m^3 by the year 2020 (The World Bank, 2009).

Allocation of water in Morocco is heavily geared towards agricultural applications. Current irrigation practices are inefficient, which has led various water sources to be heavily strained. Agricultural irrigation is allocated 83% of withdrawn water, leaving the rest for municipal, tourism, and industrial uses (The World Bank, 2009). Even with so much of Morocco's water consumption used by agricultural irrigation practices, only 15% of the total agricultural land is irrigated. This leaves a majority of agricultural lands to have a heavy dependence on rainfall (USAID). This lack of efficient crop irrigation in Morocco leads to mass quantities of water being wasted; evaporation from the top soil causes the farmers to use a significant amount of extra water to produce prosperous cash crops. Efficient irrigation processes have poor adoption rates, causing a large portion of water used in agricultural irrigation to be lost due to evaporation. Additional water is needed to properly grow crops in these regions, leading to dwindling water supplies in rivers and groundwater sources. Residents of rural Morocco depend on agricultural practices for their livelihoods and survival. With the already harsh environment becoming increasingly challenging to live in, many residents of rural villages decided to move away from the rural villages in an effort to obtain basic needs for survival.

In May 2015, Association Dar Si Hmad for Development, Education and Culture, launched a solution to the problem of drought in southwestern Morocco. After a decade of research Association Dar Si Hmad constructed and implemented an array of fog harvesting nets at the summit of Mt. Boutmezguida, which is located in the Anti-Atlas Mountains. The Fog Water Collection System supported those living in the Aït Baâmran region by providing them with potable water piped directly into their homes. This non-governmental organization has installed fog nets that span 600 square meters and 8 kilometers of pipelines (Dodson, 2014). The expected increase in water use resulting from the addition of the fog net supply leaves room for a more relaxed water management practices, and waste water. With the implementation of fog nets that support and sustain the villages, the Association Dar Si Hmad aims to not only increase water availability, but to utilize this newly available water without waste. They aim to close the water loop.

The water that is being used in the village on a daily basis has a one-time use lifespan, meaning that water is being discarded rapidly, when it could be reused for other purposes. Nearly 3% of total water usage in Morocco is treated and reused; this water recycling is in cities that have the facilities to treat the wastewater. Reuse of water in rural areas is important because there is no sewage system for the water to funnel down and be introduced to a water treatment facility to handle it; once the water is thrown out it becomes useless to the environment that desperately needs it.

Greywater Management Techniques

Reed Bed Filtration

Reed bed filtration use an arrangement of reeds with dividers inside the bed to section off water flow, making the greywater weave back and forth across the planted reeds that remove contaminants from the greywater. A mulch pre-filter to remove all the solid matter before it reaches the system to make the cleaning easier. The primary method of filtration in reed bed systems are from microorganisms developing on the roots of reeds, breaking down organic components and making conditions difficult for bacteria and viruses to survive. Excess nutrients within the greywater such as nitrogen are removed by the roots of the reeds.

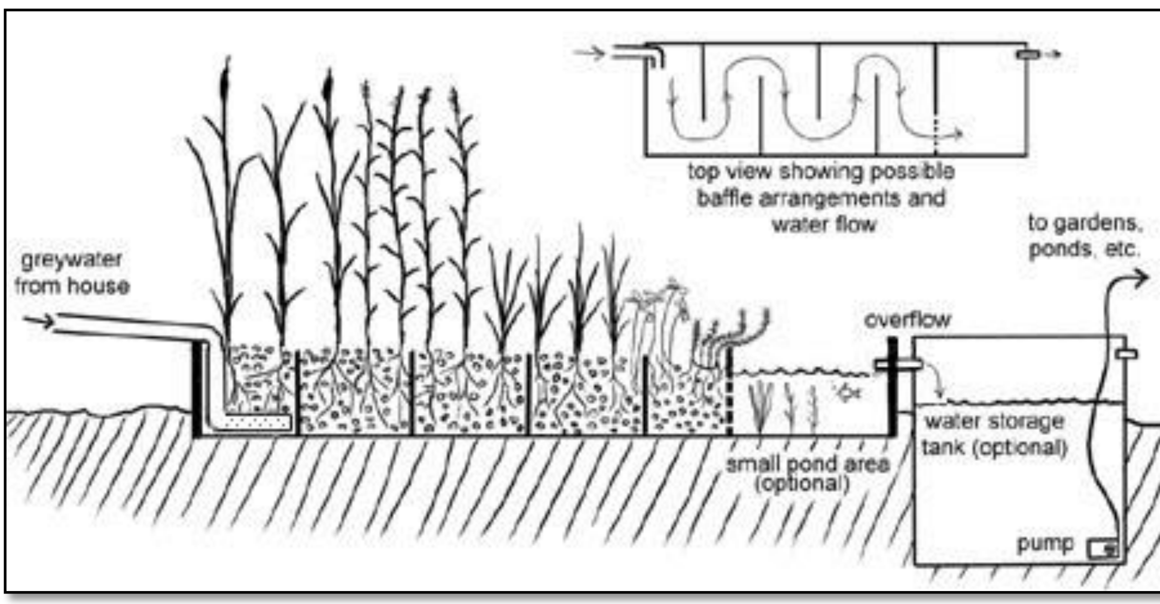

Figure1: Reed Bed Filtration System (Bradley, 2012)

Materials

- Wetland Reeds (Refer to Table 1 in additional information for list of common wetland plants in Morocco)
- Gravel
- Plastic Liner
- Dividers
- Piping

Optional Materials

- Mulch **-** as a pre-filter
- Planter Box - for above ground

Strengths	**Weaknesses**
Can use indigenous plants to filter out pollutants	Water loss to evaporation
Can be used to remove harmful contaminants that would otherwise require special filters	Must have a constant supply of water
Reeds can rejuvenate	Must tend to plants
	Industrial chemicals would kill reeds

Placement Options

Reed beds need to be placed outdoors within a water tight system. If situated within the ground, the plot should have a plastic liner to enclose the system, preventing water from seeping into the ground. Otherwise the system can be positioned above ground with a suitable planter box.

Maintenance

Due to the presence of plants in the system, which require water and nutrients, upkeep is required quieter times of the year where passive household greywater generation is not enough to sustain the reeds.

Optimal Conditions

For households that already have greywater drains installed, adding a reed bed filtration system to the outflow of the drains would be ideal, providing that the surrounding land is suitable. Reed bed filtration units need to have an active water flow for sustainable operation. One large household may not produce enough greywater regularly to effectively maintain a reed bed system. Reed bed filtration could be effectively implemented through a village wide effort, being fed with greywater flows from multiple households. This effort would require land for the system installation, piping connecting participating households to the system, as well as an effective community garden. A village-wide effort may produce enough greywater and a controlled flow of water upstream prevents a system overflow of water when water usage is high during holidays or celebrations.

Additional Information and Building Guides:

Table 1: Indigenous Wetland Reeds

Wetland plants in Morocco	**Description**
Frankenia laevis	Pink flowered herb
Arundo donax	Very tall grass used as shelter belt and along river margins
Phragmites altissima	Reedmace
Juncus acutus Pointed	Sedge
Phoenix dactylifera	Along river edge
Tamarix gallica	Pink flowered shrub

(Upson, 2012)

Appropedia.org – Subsurface flow constructed wetland for greywater

Foodforest.com.au – Designing a reed bed

Sand Filtration

Sand filtration systems function by passing contaminated water through three layers of sand. The top-most layer of sand contains an active bio-layer that naturally forms after roughly ten days of consistent use. The system uses a barrel as an enclosure, commonly made with either plastic or concrete. Within the container are three layers; fine sand, course sand, and gravel. The sand for this system is layered in a way where the fine sand is the top layer, coarse the middle, and gravel the bottom. It is also important that the outflow tubing be positioned exiting the bottom of the unit and extends upward to be parallel to the top of the fine sand, so it keeps the active bio layer wet and does not drain the system of all of its water. The active bio-layer, made up of various microbes, functions to fight pathogens and contaminants within the water and has to stay moist to avoid dying out.

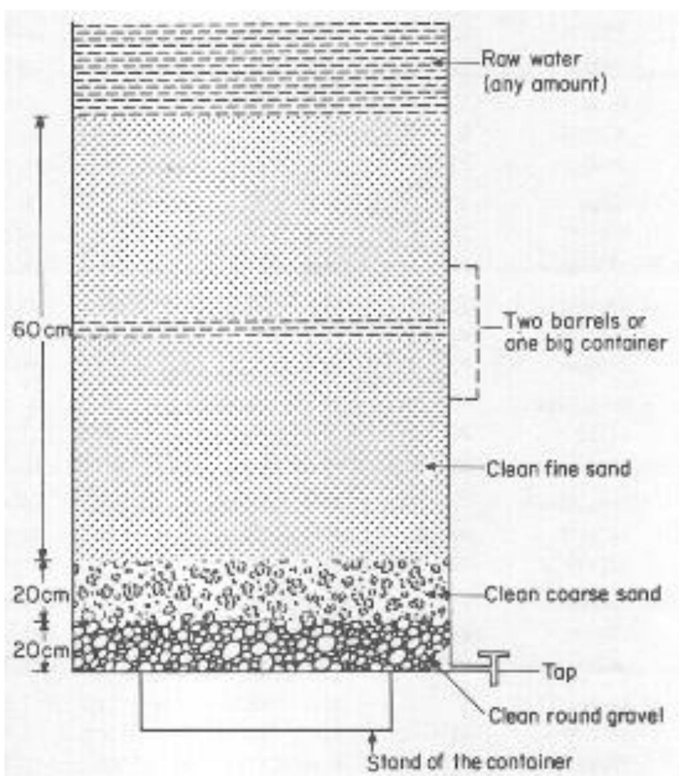

Figure 2: Diagram of a Sand Filtration System. (Dodson, 2014)

Materials

- Gravel
- Coarse Sand
- Fine Sand
- Sealable tank or barrel
- Drip plate
- Piping

Strengths	Weaknesses
Low costs to build	Large task to clean
Minimal regular maintenance	Susceptible to damage from chemicals
Versatile placement options	

Placement Options

Sand Filtration systems can be located above or in-ground. These systems are a barrel that may be placed anywhere as long as the space is available and the input and output of the system are located near the top of the system.

Maintenance

To clean the solar distillation unit, flush the basin with clean water to remove any possible buildup within the unit. Drain the water through the disposal valve instead of leaving the unit to process the liquids.

Optimal Conditions

Sand filtration units are adaptable and easy to implement system. This filtration unit can be varied to fit in almost any application. Since the unit can be placed above and below ground while being fully closed in both applications it can be located inside or outside of homes, only requiring enough space to fit the size filtration unit that has been constructed. Also because this system has the most attractive price-point it would be the best unit to implement to low income families.

Additional Information and Building Guides:

OasisDesign.net – Slow Sand Filtration

REUK.co.uk – Sand Filters for Greywater

Solar Distillation Unit

A solar distillation unit operates by evaporating the water at a lower temperature than the contaminants in the water would evaporate at, then condensing the water and capturing it. Typical solar distillation systems are a box or tray with a sloped piece of glass on top. The tray is colored black to absorb the most heat from the suns radiation. The water is pumped into the tray where it will sit and heat up as the sun's energy bypasses the clear glass and heats the tray. The water then evaporates and the resulting water vapor collects on the glass above it. After the water has condensed on the glass it beads up and rolls down the slope, where it drips into a small semi-circular tube where it is collected and ready for use.

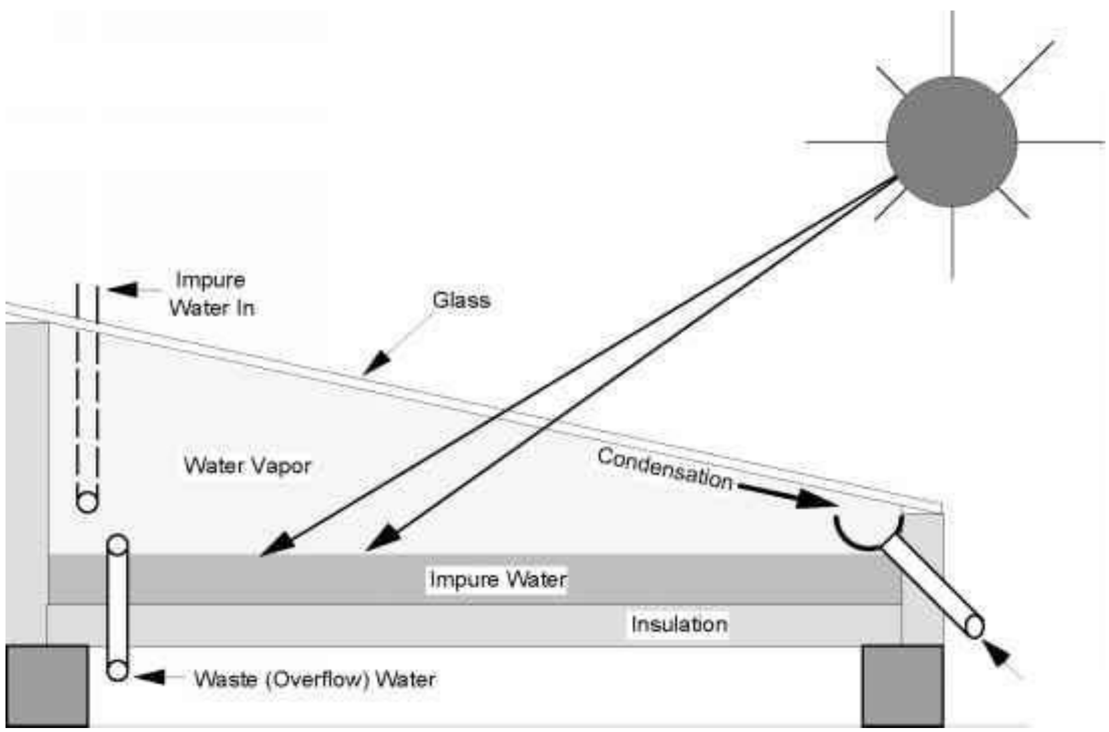

Figure 3: Solar Distillation Unit (McCracken, 2015)

Materials

- Glass Pane
- Black Trough
- Piping
- Gutter tubing
- Waterproofing bonding agent
- Frame for the still to sit on

Strengths	Weaknesses
Produces potable water	Produces chemical brine
Simple maintenance	Slow processing time
Works effectively in sunny environments	Requires large surface area
	Needs to be monitored during operation

Placement Options

Solar stills need to be placed in an outdoor location with high exposure to sunlight. This unit needs to be placed in a location that is preferably out of the path of any shadows. Depending on the desired output flow of distilled water, the units can vary in size. Large solar distillation units can take lots of space, limiting potential placement sites.

Maintenance

Operation of solar stills involves several steps. First, the greywater to be processed is poured into the bottom basin of the distillation unit. After some time has passed and the solar still has processed most of the greywater, the remaining greywater in the basin needs to be manually emptied and disposed separately. By routing a pipe from the disposal valve to nearby blackwater drainage, effort in operating the system can be reduced.

Optimal Conditions

Solar Distillation would be best implemented in a home with few people. Around two or three people's worth of greywater would be great for the capacity of this system. This family would have to be prepared to provide extra care for their recycling but would receive extra benefits from it in the form of potable water. This system would also be best suited for a home on the outskirts of a village or an isolated house, to minimize shadows that could interfere with the distilling process.

Additional Information and Building Guides:

Motherearthnews.com – How to Make a Solar Still

SolAqua.com – Solar Still Basics

i4at.org – Solar Water Distiller

Proposed Greywater System for the Dar Si Hmad House

Figure4: Dar Si Hmad House in the Bled

Three greywater recycling options have been described above and considered as designs to be applied at the Dar Si Hmad house as seen in Figure 4. Our recommendation utilizes a sand filtration unit to be implemented at the site. The reason we make this recommendation is that this system will be the easiest to maintain during the intermittent time when no one occupies the house. Sand filtration does not require the constant influx of water that the reed beds require and in the future when the test house is inhabited, the greywater recycling unit will be able to handle the increased flow of water to be processed, unlike the solar distillation. The industrial cleaning products used in the house can be monitored and avoid bleach which will keep the bio-layer of the sand system safe. This is also a low cost option with the most accessible materials, which leads it to being the optimal test system to be observed and later used for a wide scale resource in the bled.

For ease of demonstrating the placement of the system we drafted up Computer Aided Design that we could mark up with a general overview of how the system should be placed, shown in Figure 5. The option for collecting the greywater for this system would be a sink basin mounted on the wall in the courtyard and for easier accessibility, piping the greywater directly to the sand filter. For this method to function through gravitational forces only, the collection basin would need to be positioned at a higher point relative to the top of the sand filter unit. This poses the issue of deciding the placement of the sand filter. The sand filter can be partially buried into the ground, allowing the collection basin to be lower. In turn, the exiting flow of the sand unit will also be lower.

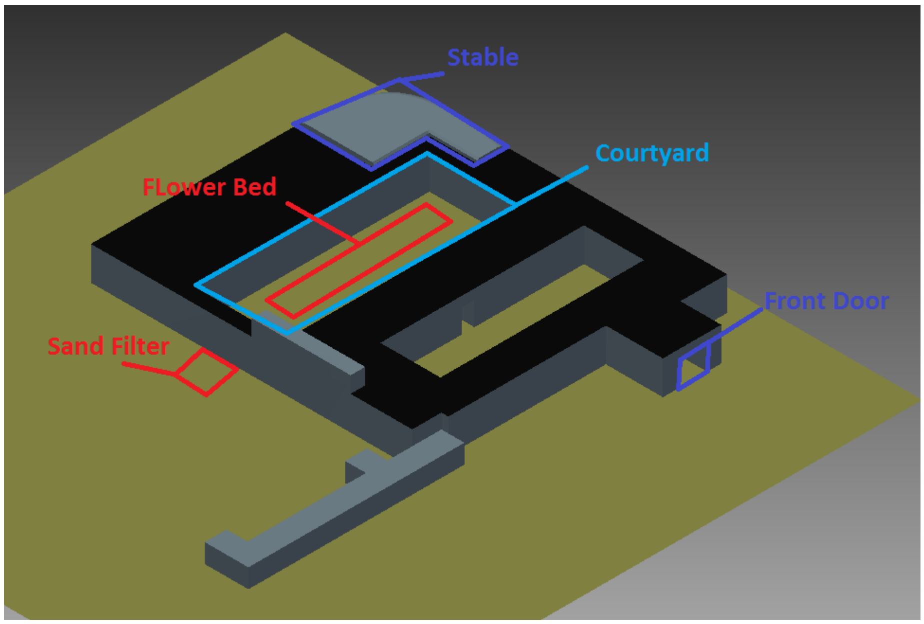

Figure5: Computer Aided Design of Dar Si Hmad House

The end use is a garden in the middle of the courtyard because this helps with the aesthetic value of the house as well as impeding growth of the bushes that are growing there currently. With no evident use for the courtyard area, a garden would be an effective use of the space, due to the increased productivity of the land as well as straightforward process to implement. Not only would a garden be useful, but it could be also used as an educational demonstration for modern and efficient permaculture practices. When no one inhabits this building there can be shrubs or other indigenous plants, in place of decorative plants, that can survive without the system constantly running. Then when the building is being prepared for full-time occupants, switching to any other plant can be sustained in the climate with proper water management. In Table 2 is a list of plants we found to grow in the bled using sufficient watering practices.

This would help the system be used intermittently because if there are no plants to soak up the greywater in the system the water will be left to stagnate in the planter.

Table 2: List of Flora Discovered in the Bled

Fruit	**Vegetable**	**Herb**	**Plant**
Date	Carrot	Basil	Argan
Eggplant	Turnip	Parsley	Bamboo
Fig		Rosemary	Cactus
Lemon			Henna
Olive			
Orange			
Plum			
Pomegranate			
Tomato			
Watermelon			
Pumpkin			

Broader Implications and Future Considerations

Introducing a greywater recycling system into the bled enables every resident to preserve and extend the use out of their newly supplied resources. Any implementation of a greywater recycling system will come with expected maintenance each household will need to perform. Solar distillation, sand, and reed bed filtration all have their strengths and weaknesses but doing case studies of each recycling system in households who are open to introducing a new concept to their lives, will assist in the long run to determine which system works best in the bled.

The end-use applications for greywater can brighten their lives by having a garden for aesthetic appeal and the residents have the benefit of choosing to grow an edible, crafting, or decorative garden. Challenges in adding greywater recycling systems would be the locations of where each system will be placed. If there is not enough room on one family's property to implement the system appropriate for them then the groundwork in placing a system within a village brings the same problems faced in the fog water project. These issues are finding a property that the owners would accept placing necessary components for a community wide greywater recycling system on their land. These villages are clustered together as seen in Figure 6, and it could be hard to actually find a location to install a greywater recycling system without it infringing on multiple families plots of land.

Figure6: A Tightly Packed Village in the Bled

Recycling greywater requires the community to be mindful of the chemicals that they have been introducing into the environment through their daily living. Educating the residents that greywater does not have to be carelessly discarded and can be filtered, treated, and used for more applications, as well in the long run saving some households money. Introducing greywater recycling to households will help close the water loop by maximizing the use of the excess water which is increasing daily.

Future research to be conducted is to test greywater produced at each household for the concentration of chemicals they contain. Specifically tests can be done looking primarily into the chemicals found in the products of Table 3. A thorough investigation of how the chemicals affect these three particular recycling systems would be required. Finding bio-friendly cleaning products available in southwestern Morocco and educating people to use them in substitution of major cleaning products found in this region would be a helpful endeavor.

Table 3: List of cleaning products used in the bled

Cleaning Materials Found in the Bled	**Uses**
Ace	Clothing, dishes, toilet
Babaria Cien	Body wash
Cadum	Personal hygiene
Care4Me Hand Wash Liquid (with aloe vera milk)	Hand soap
Essence of Musk	Toilet and remove odor (combined with water)
Exet	Bleach product
Force and Vitality Aux Oeufs	
Fraheur Shampoo	Personal hygiene
Hand Soap	
Javel Yaak	General cleaner
Magix	Dish detergent
Marvela	Liquid hand wash
O'kade soap	
Omo (laundry detergent)	Laundry Detergent
Oni	Dish detergent
Pine sol-like cleaner	
Taous	
Tide	Laundry Detergent
Top Bright	Shampoo
Traditional Bar Soap	

(Valcourt & Association Dar Si Hmad, 2015)

This recommendation leads into new opportunities for Dar Si Hmad to receive further input from the Aït Baâmrane people in what they would like to get out of a greywater recycling system. Informing the community that there are other means in maximizing their greywater is a step towards accepting recycling systems in their villages. It is inspiring to realize that the people of this region are open to new methods of improving their daily lives, and continual collaboration from the community will lead to an accelerated acceptance of greywater recycling.

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Appendix B: Interview Questions to the Amazigh Villagers

The following research questions will be asked in interviews or surveys to the stakeholders: the Amazigh people in the surrounding villages of Sidi Ifni, workers in Dar Si Hmad NGO and water managers of the fog harvesting nets.

Questions to be included in interviews pertaining to the villagers:

- How do you currently view the fog water now that this resource has been directly available to your homes?
    a. In what ways has the fog harvested water positively impacted your lives?
    b. Follow up: In what ways has the fog harvested water negatively impacted your lives?
- In what ways has routing water directly to your homes impacted your daily lives?
- How has your water---use changed since having water piped directly to your home?
- To measure the amount of water, determining the amount each household is paying for their monthly use of water.
    a. Have they used up all of their allocated water before the next monthly water cycle is available?
- In your own opinion how would water use effectiveness be achieved?
    a. Would greywater recycling be an aspect to consider in further maximizing water efficiency that you are paying money for?
- How has water demand affected food quantity, demand or trade?
- What are some challenges are you facing in handling the surplus of water to your home?

    a. Are there any water sanitation risks that you have encountered in the water supply or water set-up?

- What are your thoughts or feelings on people migrating back to these villages once they heard water has become more of an available resource?
- What are the advantages of following water management practices?
    a. What are the disadvantages?
- What are alternatives or implementations to be introduced that the community could be doing to further make best use of water?
- In what ways are you currently utilizing water that previously would have been never done before due to water availability constraints?
- In what ways do you deal with water that has already been used once before such as showering, washing your hands, or washing laundry?
- Should fog harvesting systems be installed in other locations in Morocco where fog is abundant to help alleviate water shortages concerns?
- Do you still see the greywater as your property even after it has been used it?

Appendix C: Interview Questions for Dar Si Hmad

Questions pertaining to Dar Si Hmad:

- To measure the amount of water, determining the amount each household is paying for their monthly use of water.
    - Have they used up all of their allocated water before the next monthly water cycle is available?
- What are your thoughts on whether or not there will be a community resistance in repurposing greywater into better management techniques?
- How has water demand affected food quantity, demand or trade?
- In what ways do see villagers deal with water that has villagers deal with water that have already been used once before such as showering, washing your hands, or washing laundry? Has there been a recent influx of people back to the villages since the implementations of the fog water nets?
- Has the recent instantiation of the Amazigh language pushed for learning this written language in the villages?
- Are there any readily available materials in the surround locations to attempt to incorporate?
- Is there a prototype already in production that we are to continue, or are we starting from scratch?
- What is the budget for our finalized prototype?
- Are we going to receive funding from Dar Si Hmad to develop iterations of the systems?

- Would the final deliverable be a tangible product or detailed plans to design and build a final product?
- What were some major concerns that prompted the use of greywater recycling?
- Would another education program targeted towards children be helpful to educate adults about how greywater can be reused?
- Have inter-village relationships improved since the implementation of readily accessible drinking water to each house?

Appendix D: Interview Questions for Fog Net Manager

Questions pertaining to the water manager of the fog nets:

- What are your thoughts on whether or not there will by a community resistance in repurposing greywater into better management techniques?
- How has water demand affected food quantity, demand or trade?
- What are your thoughts or feelings on people migrating back to these villages once they heard water has become more of an available resource?
- What are the advantages of following water management practices?
    - What are the disadvantages?
- In what ways do you see people dealing with water that has already been used once before, such as showering, washing your hands, or washing laundry?
- What are some of the changes that you want to see with the whole process?
- Have you seen a constant overuse of water now that it is readily available?

Appendix E: Water Pricing for Fog Water Delivery

Tarification de l'eau de brouillard

La tarification de l'eau de brouillard pour les villages de la commune d'Amellou autours de boutmezguida se base sur le modèle de l'ONEP qui comprend une redevance fixe de 19,47 DH plus un prix au mètre cube selon deux tranches.

Notre souci premier est de préserver l'eau au maximum ce qui nous a amené à définir 3 tranches, la première allant jusqu'à 6 m3 permet de fournir une quantité suffisante sachant que la moyenne consommée dans le passé était de 8 litres par personne et par jour et que l 'achat d'une citerne de 4 m3 s'élève à 300 DH.

Première tranche : de 0 à 6 m3. Redevance 20 DH, prix au m3 : 4 DH

3 m3 coûtent 20 + 3x4 = 32 DH
4 m3 coûtent 20 + 4x4 = 36 DH
5 m3 coûtent 20 + 5x4 = 40 DH
6 m3 coûtent 20 + 6x4 = 44 DH

Deuxième tranche : supérieure à 6 et inférieure ou égale à 9 m3. Redevance 20 DH, prix au m3 : 4 DH pour les premiers 6 m3 et 12,5 DH pour la quantité supérieure à 6 et inférieure ou égale à 9 m3.

7 m3 coûtent 20 + 6x4 + 12,5 = 56,5 DH
8 m3 coûtent 20 + 6x4 + 2x12,5 = 69 DH
9 m3 coûtent 20 + 6x4 + 3x12,5 = 81,5 DH

Troième tranche : supérieure à 9 m3. Redevance 20 DH, prix au m3 : 4 DH pour les premiers 6 m3 et 12,5 DH pour la quantité supérieure à 6 et inférieure ou égale à 9 m3 et 20 DH pour les quantités supérieures à 9 m3.

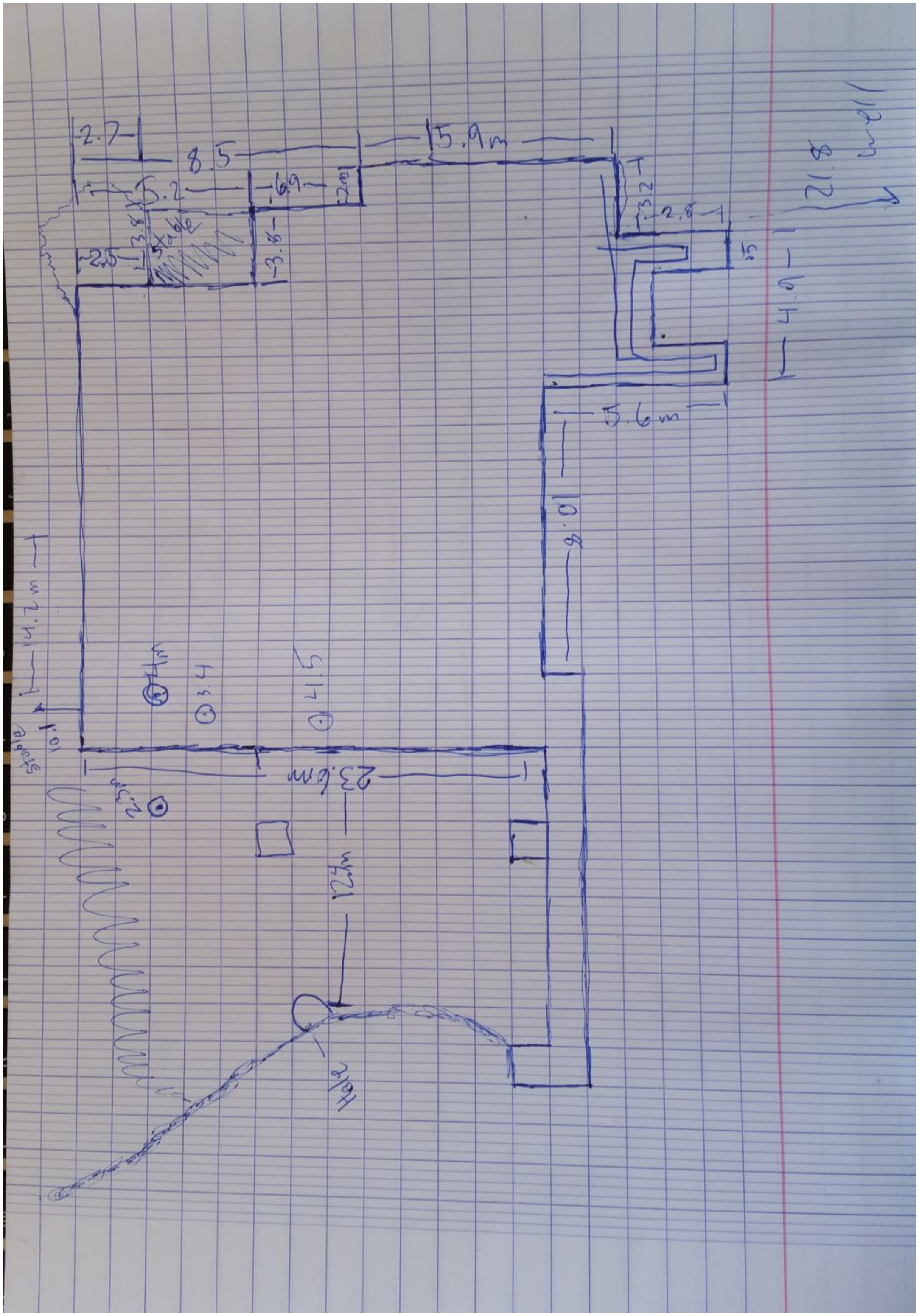
10 m3 coûtent 20 + 6x4 + 3x12,5 + 20 = 101,5 DH

11 m3 coûtent 20 + 6x4 + 3x12,5 + 2x20 = 121,5 DH
12 m3 coûtent 20 + 6x4 + 3x12,5 + 3x20 = 141,5 DH
13 m3 coûtent 20 + 6x4 + 3x12,5 + 4x20 = 161,5 DH
14 m3 coûtent 20 + 6x4 + 3x12,5 + 5x20 = 181,5 DH

etc......

Agadir le 29 octobre 2013

Appendix F: Sketch of the Dar Si Hmad Test House



Appendix G: Project Team Timeline

7 September 2015	Final Preparations of Sidi Ifni trip as a team and with the advisors over transportation, costs, and moving forward plan at Sidi Ifni
8 September 2015	Traveled to Sidi Ifni, Dar Si Hmad presentation
9September 2015	Site survey of fog nets, partial interview with sponsor, mixing station, main cistern, and Dar Si Hmad test house, Dar Si Hmad orientation
10 September 2015	Dar Si Hmad interview
11 September 2015	Water manager interview, measurements of Dar Si Hmad test house, and Head of Fog Net Project interview
12 September 2015	Breakfast at Beekeeper's house, visited greywater sink at a school, went to the women's argan coop, gathered notes
13-14 September 2015	Visited Atlas Kasbah to inquire about permaculture and traveled back to Rabat
15 September 2015	Met with advisors, transcribed notes, and re-wrote methodology
16 September 2015	Transcribed notes and wrapped up methodology, began on findings and results
17-18 September 2015	Trip to the Sahara Desert
Week of 21 September 2015	Revise Methodology, discussed recycling prototype
Week of 28 September 2015	Finish revisions on background, finish revisions on the first 3 sections of methodology, developed out findings, buy parts necessary for prototype/s, discuss house space, developed Dar Si Hmad supplemental document
8-10 October	Secondary Visit to Dar Si Hmad in Sidi Ifni, group discussion with Dar Si Hmad Executive Directors
Week of 5 October 2015	Further developed supplemental document and incorporated discussion feedback into report, expanded on findings and results, recommendation and conclusion
Week of 12 October 2015	Wrapped up IQP report and supplemental document.
15 October 2015	Project presentation
16 October 2015	IQP report & supplemental document due
17October 2015	Morocco IQP exit