VIRGINIA WATER RESOURCES RESEARCH CENTER

Analysis of Water and Energy Conservation of Rainwater Capture System on a Single Family Home

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Disclaimer

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Summary

Adequate water supply is crucial to the economic growth and welfare of global societies. Conventional centralized water supply systems are inefficient and energy intensive. There is a need for developing sustainable and decentralized systems such as rainwater harvesting systems. Throughout the history of mankind, rain has been harvested through various innovations to provide water for countless communities. Today, residential and commercial use of rainwater is growing rapidly. This report contains a detailed review of various aspects of rainwater harvesting systems.

The overall goal of this research is to analyze and compare the efficiency of two decentralized water systems, i.e., groundwater and rainwater harvesting systems that are implemented in a single household. Specific research objectives are:

(a) Determine energy efficiencies of groundwater and rainwater harvesting systems
(b) Determine the specific energy required to run the dual system, i.e., the rainwater capture as well as the groundwater system
(c) Compare costs of each system including installation, maintenance, and daily usage.

The case study site for this study is a single family residential house located in Montgomery County, Virginia. The groundwater is pumped from an aquifer 174 feet below the house. The rainwater system collects the rooftop rainwater in an underground storage tank and is equipped with a U.V. disinfection unit. Rainwater is used for outdoor use and all indoor uses including drinking water.

Efficiency analysis is based on amount of rainfall at the study site and through the specific efficiencies of both rainwater and groundwater systems. Overall energy efficiency is evaluated as a relationship between all facets of both systems that include initial investment and consumption savings.

This study shows that for this specific site, groundwater system is more efficient and cost-effective. However, it is concluded that energy efficiency of either system depends on pump efficiency. It was also noted that both systems are more cost efficient and energy efficient comparing to extending the public water line to the house.

The report discusses several advantages of decentralized systems. Water quality analysis for groundwater and rainwater samples collected at the study site are documented in the appendix. The report also includes a list of online sources for information on rainwater harvesting systems.

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1. Introduction

Water is one of the most important natural resources. Many anticipate that freshwater resources will become widely unavailable in coming decades (Furumai 2008). The exponential increase in population and subsequent urbanization of countries around the world has caused a major strain on waterways including complete loss of rivers and natural watersheds in order to provide more space (Furumai 2008). In addition to the loss of watersheds due to development, the increase in urbanization dramatically affects the amount of runoff created by impervious surfaces. This increase in impervious surfaces causes decrease in natural groundwater recharge resulting in less available groundwater to meet increased water demand.

Virginia has also witnessed the decrease in available water coinciding with the increase in population, especially throughout the past decade. With a rise in population of nearly eight percent between 2000 and 2006, the state has seen the development of over 450,000 new homes (Census Virginia 2007). The increase in development leads to an increase in impervious surfaces causing more harmful runoff polluting surface waters.

Rainwater harvesting is an excellent tool which, with proper use, could dramatically reduce the continual strain on watersheds. Rainwater harvesting is not only useful in rural areas but it can provide numerous benefits for urban ecosystems by managing stormwater runoff. It can also provide communities with another option for stormwater management in places such as the Chesapeake Bay watershed where there are laws enacting the proper maintenance of stormwater runoff (Cabell Brand Center 2007).

In order to utilize resources and sustain the intensely water driven agriculture practices, various technologies have been implemented to harness rainwater. The techniques currently employed including infiltration pits, tied ridges, and the use of channels as methods of collecting surface runoff (Kudakwashe 2004). Varying from agricultural use, most residential and commercial practices utilize a rooftop, a gutter and downspout system, a collection tank or cistern, and a water distribution pump for harvesting rainwater. In both cases, the amount of harvestable rain is based on the surface area of collection, the ridges and pits of agricultural practices and the rooftop, as well as the average rainfall in the area.

Utilizing rainwater for indoor and outdoor uses is fast becoming more common. Rainwater can be used for both potable and non-potable uses. The majority of rainwater harvesting currently only uses the rainwater for non-potable uses such as irrigation, landscaping and flushing toilets. Potable uses include drinking water and dishwashing. In order to use rainwater for potable uses, a water treatment unit is usually required. Since rainwater harvesting for potable use is much less common and technologies are still being developed, many states, counties, and cities have different restrictions and mandates constraining the implementation of indoor systems. In Virginia, a code has just been enacted stating that the indoor use of rainwater must be not only be filtered and designed according to the Virginia Rainwater Manual, it must also be sampled and tested for approval by the Virginia Department of Health (Division of Engineering and Building 2008).

While it is evident that rainwater capture can greatly reduce the strain of runoff into the environment and can conserve resources by using rain for several uses, it is still undetermined if rainwater capture can save energy as well as water. Rainwater harvesting has the potential to relieve many communities of inevitable water pressures by allowing individual businesses and residences to become decentralized. The collection process of rainwater capture is completely energy free since the environment and gravity harness the rain. The distribution process however, requires energy usually through a pump. Also, if rainwater harvested for potable use, energy is required throughout the filtration process.

2. Literature Review

The available literature pertaining to rainwater harvesting includes information about specific rainwater technologies, cost considerations and incentives, and water quality issues. Rainwater harvesting technologies have evolved tremendously in the recent years so that most systems run on 95% efficiency (Rainwater Management Solutions, Inc 2007). Cost comparisons are difficult to pinpoint and vary with each system, but the general cost of rainwater harvesting components, as well as current government incentives provide useful for this study. Water quality issues are highly debatable and very specific to location but several studies have been conducted for the southwest Virginia area.

2.1 Rainwater Technologies

Rainwater harvesting is a basic practice of catching rain that was implemented largely for agricultural use in ancient civilizations (Boers and Asher 1981). There are various technologies and practices associated with rainwater harvesting for agricultural use including utilizing channels, dams, diversion systems and many more (Boers and Asher 1981). For this study, Rainwater harvesting is defined, not as the method of collecting surface runoff for agriculture, but as a method for collecting rainwater from rooftops through a gutter or downspout system into a cistern or holding tank for future use.

One of the foremost rainwater harvesting companies, Rainwater Management Solutions, located in Salem, Virginia has greatly contributed to the rainwater harvesting development in Virginia and provided valuable information for this study. This company was also designed the rainwater system to the Shawsville case study site described in detail in section 5 of this report.

Rainwater harvesting systems are very flexible and alterable based on specific site needs. The main components for each system include a catchment area (rooftop), a gutter or downspout system, a cistern or holding tank, and a pump to redistribute the water (Rainwater Management Solutions Inc 2007).

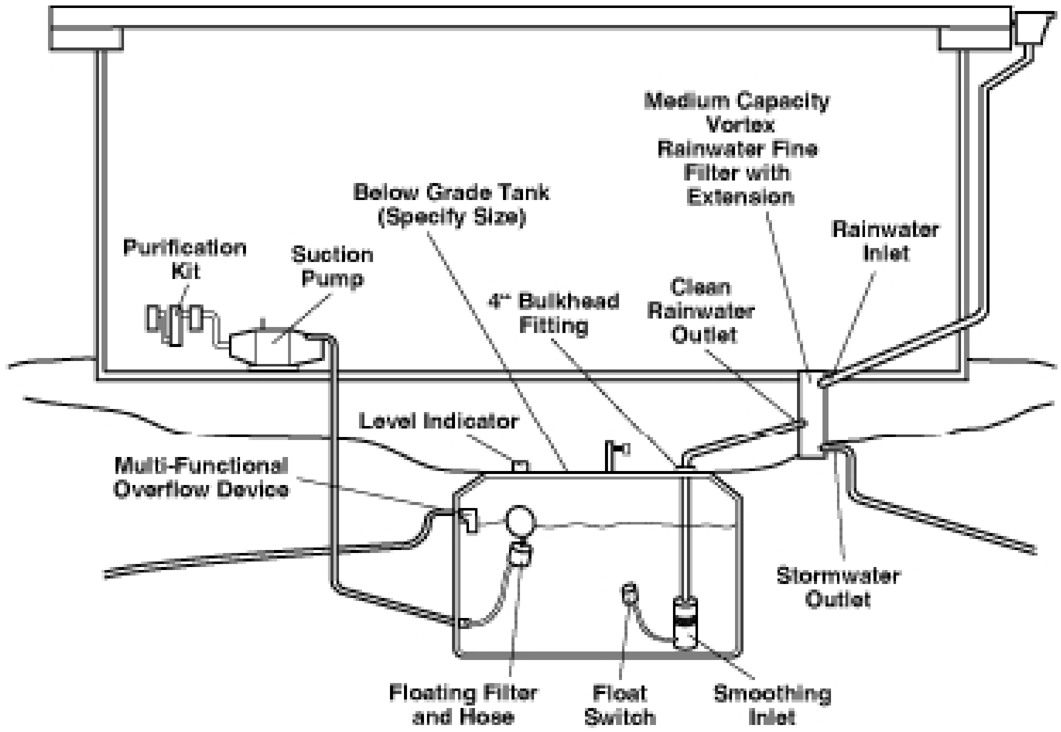

Figure 1. Typical rainwater harvesting system for residential and commercial potable and non-potable water use (Source: www.rainwatermanagment.com)

Residential systems are most commonly gutter/downspout systems that allow the rain to be collected through gravity into a storage tank. Before the rain reaches the tank it is filtered through a membrane that prevents large debris from entering the cistern. The tank size is determined by the rooftop area, the average rainfall and water use at the site as described in section 5.2. From the tank, the water is pumped to treatment unit to be treated for potable use and non-potable use.

Potable uses for rainwater include: drinking water; cooking; bathing, and washing dishes Non-potable uses for rainwater include household cleaning; irrigation; toilet flushing; pond/landscape use; fountains; vehicle washing (Cabell Brand Center 2007).

Rainwater harvesting systems design is based on the potential for rainwater capture and the use of the water. In addition, use of water treatment technologies in conjunction with rainwater harvesting is also becoming more prominent as the use for rainwater continues to grow. Most of the systems that are installed for landscape irrigation and non-potable uses do not require treatment technologies. Recent rainwater harvesting systems that provide water for potable as well as non-potable are equipped with filtration and water treatment at least a UV light treatment component. Combining rainwater harvesting with low water consumption appliances has been projected as a viable duel solution in many case studies (Villarreal and Dixon 2004).

2.2 Cost considerations and incentives

With the increase in population and commercial use of rainwater capture practices, countries, states, cities, and counties are all beginning to enact restrictions and regulations to control the usage of these new systems. Texas, one of the leading states of rainwater capture, published a Rainwater Harvesting Manual in 2005 (TWBD 2005). Leading the country in state mandates, this manual provides valuable information for legislators, citizens, and company owners to better comprehend various aspects of the systems. These aspects include everything from basic knowledge about the components for the most common systems, to the state and federal drinking water regulations. Now widely used, the Manual provides guidance for rainwater harvesting system design. In addition to the valuable the manual provides readers with information adequate for estimating and reducing indoor water usage. Once water use is calculated, the effectiveness of the system can be evaluated by comparing the potential rainwater captured to total water needed for daily use. A table, found in Appendix A of the Manual, details the calculations for evaluating indoor water use. This table is formatted for low impact appliances but can be expanded based on site specifications (TWDB 2005).

Following suite, many other states began to construct rainwater manuals much like Texas. The Virginia Rainwater Manual was published in 2007. The manual interprets many of the information collected for the Texas text and adds more useful data for the state of Virginia. This manual is also more "reader friendly" than the Texas Manual. The Virginia Rainwater Harvesting manual also adopts design procedure similar to Texas Manual to calculate harvestable water based on roof size and average rainfall (TWDB 2005, Cabell Brand Center 2007).

Because of the fast increase in implementing rainwater harvesting systems, the state of Virginia has enacted a preliminary code to regulate the use of rainwater. This code requires all systems to be designed based on the technologies outlined in the Virginia Rainwater Manual. It also requires all waters to be tested to determine the quality and usage of the water. In accordance with the Environmental Protection Agency, all waters used for potable use must meet all of the Federal Drinking Standards.

In addition to state and federal codes, rainwater harvesting is influencing sustainable building regulations and tax exemptions. Internationally, Australia and Germany have rainwater harvesting economic incentive programs. In one region of Australia, Queensland, rebates for up to $1,500 are available (Queensland, Australia www.nrw.qld.gov.au). A second region of Australia, Gold Coast, requires the instillation of rainwater harvesting for some non-potable uses (Gold Coast, Australia www.goldcoastwater.au). In addition to governments providing residents with incentives, utilizing rainwater harvesting can save millions of dollars and delay construction of new water supply infrastructure by decades, as shown through recent studies in Australia (Coombes 2002). In Germany there is currently a rain tax which residents pay based on how much rain runs off of the residents property, influencing runoff and stormwater management (Colwell, www.kstate.edu […]). Germany has tax programs available for rainwater harvesting that lower the rain tax for a resident based on how much rain the resident is collecting. Additionally, all across Europe there are subsides available for implementing rainwater harvesting to promote residential greywater resuse systems (Gould 1994). Apart from Europe and Australia, Japan is providing financial incentives for both residential and commercial implementation of rainwater harvesting technologies (Lye 2002). In Japan, rainwater harvesting technologies have been in practice on both small scale residential sites as well as large scale sites including the Tokyo Dome (Furumai 2008).

In the United States, rainwater harvesting systems can count towards the LEED, Leadership in Energy and Environmental Design, certification (United States Green Building Council 2008). While the LEED certification offers no immediate tax incentives, this certification often increases the property value of the site and is becoming more popular in cities such as Austin, Texas and Seattle, Washington which now requires some level of LEED certification on all new public buildings (Department of Planning and Development, Seattle 2000). Arizona, New Mexico, Oregon, and Texas are the leading states in government incentive programs. Arizona has several grants available for installation of rainwater harvesting systems. Arizona also provides residents with a tax credit of 25% of the cost of the rainwater system and for builders the state provides up to $200 per residence unit constructed (Arizona, www.azdor.gov). Several counties in New Mexico also have specific regulations for rainwater harvesting such as the Santa Fe County mandate for all new residential and commercial buildings over 2,500 sq ft to have a rainwater system in place (Santa Fe, New Mexico www.santafecounty.org). Oregon incentives include a possible 100% discount on rainwater harvesting system if the system is helping to protect local watersheds and groundwater from the effects of stormwater runoff (Portland, Oregon www.portlandonline.com). Finally, the state of Texas allows rainwater harvesting systems to be exempt from both property and sales tax with specific incentive programs in cities such as Austin (Texas, www.twdb.state.tx.us).

In the state of Virginia a cost analysis study has been performed on several case study sites in Arlington County (Hicks 2008). This analysis provided insight into the detailed cost breakdown of the rainwater harvesting system components. It also established a theory that rainwater harvesting is more cost efficient when the system is planned with the construction of the building, and not installed after. This study only analyzed the costs of commercial systems and did not make connections or assumptions as to the cost effects of residential systems. For the two sites described Arlington study it was not cost effective to implement rainwater capture systems based on the water needs of the buildings.

2.3 Water Quality Issues

Harvested rainwater quality can be affected by several factors. The major factors that affect water quality are site location and climate, as well as the nature of the catchment system (Langdon 2007). Location impacts the water quality of the rain, for example if the area is prone to acid rain or if there is a high amount of pollution in local watershed. The harvested rainwater quality is also affected by rooftop material. For residential and commercial rainwater capture, roofing material can become a serious source of nonpoint source pollution (Chang 2004). The water quality is also affected by air pollution and potential contamination of rooftop water by plants or animals (Langdon 2007). In the state of Virginia, there have been only a few studies that describe the quality of rainwater. A study of Dickenson County cisterns in 1997 (Younos et al. 1998) showed that only fifty percent of the cisterns sampled met all of the federal drinking water standards. Most of these cisterns failed in regard to total coliform contamination. All samples met drinking water standards for heavy metals. These cisterns were also analyzed based on possible contamination with over 30% within 200 ft of a septic tank system. When properly maintained, the contamination of cisterns is expected to be much lower than that found in the study.

Not only is the water quality of the rainwater a major concern, but the use of rainwater to effect the water quality of stormwater drainage is also a factor in the implementation of rainwater systems. Like with water quality of the rainwater, stormwater drainage quality is influenced tremendously by location. In Virginia, using the National Atmospheric Deposition Program information, the Feasibility of Rainwater Harvesting Report found that if rainwater harvesting is utilized for both indoor and outdoor (potable and non-potable) use then the total nitrate load reduction of the stormwater drainage has the potential to reach nearly 25% (Gowland and Younos 2008).

The majority of the resources, available specifically about rainwater capture, focus on new technologies or on water quality. Water from various sites around the world has been tested compiling data proving everything from very poor water quality through very safe and drinkable water quality. The technologies for this developing system are countless. In today's world every building from a small residential home to an international commercial business can be outfitted for rainwater capture. The majority of feasibility lies in the amount of annual rainfall of the area as well as the various possible filtration methods of the rainwater. The efficiencies of these new technologies can also be analyzed based on how much water is collected and used. There is, however, little information about how these new systems compared to traditional water systems on energy efficiencies. There is even less data about the comparison of water systems in completely decentralized settings. This poses numerous questions for many but is especially crucial for rural areas outside or far away from public water supplies.

3. Research Objectives

The overall goal of this case study is to analyze and compare overall cost, energy requirements of two decentralized water systems, i.e., groundwater and rainwater harvesting in a single household. Specific objectives include:

> (a) Determine energy efficiencies of two different decentralized water systems; rainwater harvesting and groundwater capture
> (b) Determine the specific energy required to run the rainwater capture system as well as the groundwater system
> (c) Compare economic costs of each system including installation, maintenance, and daily usage.

4. Research Approach

4.1 The Case Study Site

The case study is a single family house located in Shawsville Virginia (Figure 2). The house was originally built as a weekend cottage. The house is located in Sweet Spring Hollow at an elevation of nearly 1500 feet above sea level. The hollow is in a valley between River Ridge and Pond Hill. The valley creates a prime setting for stormwater runoff. There are two creeks on this property. One of the creeks is routed under the property in between the house and the septic system. The other creek lies parallel to the house and the road nearly fifty feet below the house. Both creeks maintain constant flow throughout the year and flow increase only during severe storms.

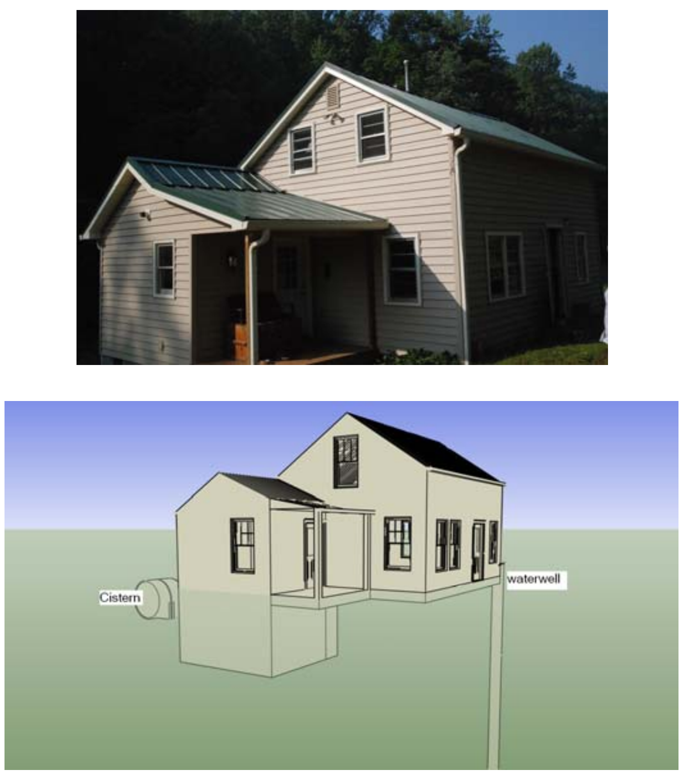

Figure 2. Rendering of rainwater cistern and groundwater well locations

The groundwater table is about 174 ft. below ground surface. The aquifer is source of water for several homes in the area. A submersible pump is used to withdraw water and feed to indoor plumbing system. In 2007 a rainwater capture system was designed and installed. When the rainwater system was installed, a small addition was also constructed on the house. This addition includes a new bathroom and a cellar where the rainwater system pump and UV filter are located. Details of groundwater and rainwater systems are provided below. Water quality for selected parameters is documented in Appendix A.

4.2 Groundwater System

The groundwater system is supplied from a 174ft well tapped into an aquifer below the house. Water is drawn from the well by a ½ horse power submersible pump unit installed in 2001 (Figure 3). Originally, the groundwater did not go through any treatment before consumption. When the rainwater harvesting system was installed, the pluming was re-routed so that the groundwater could be filtered through the UV disinfection light installed with the rainwater system. The groundwater system has supplied all water for potable and non-potable use since the house was constructed. Previous to this study, the water was not tested for any possible contaminants.

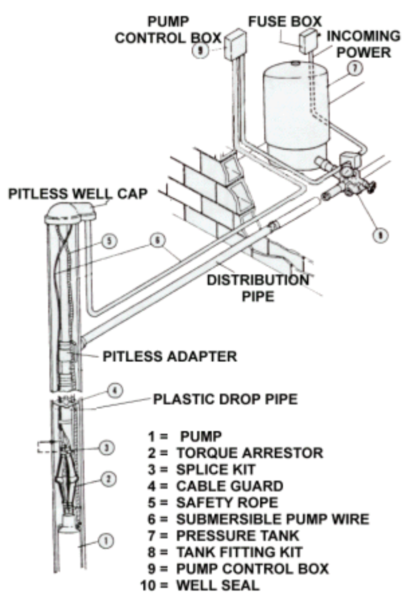

Figure 3. Typical groundwater well with Submersible Pump
Source: http://www.precisionwell.com/

4.3 Rainwater Harvesting System

Rainwater collection potential (gallons/month) for study area (Table 1) is calculated from monthly rainfall (Table 1) using the following equation (Cabell Brand Center 2007):

Gallons/Month = Roof area * monthly average rainfall * .62 * collection efficiency
Note: house rooftop area is 818.75 sq-ft; collection efficiency is 95%

Table 1. Monthly average rainfall (http://www.idcide.com/weather/va/shawsville.htm) and potential rainwater collection for the study house

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (inch)	3.21	2.84	3.43	3.44	3.96	3.51	3.71	3.16	3.23	2.87	2.85	2.67
Collection potential (gallons)	1548	1370	1654	1659	1910	1693	1789	1524	1558	1384	1374	1288

The total water use (demand) for the study household was estimated as 21,746 gallons per year. This was calculated using a record of the resident's normal daily water usage (drinking, cooking, bathing, toilet use) and the potential water usage by household appliances (washing machine and dishwasher). The appliance water usage data are available from the Texas Rainwater harvesting manual and the Virginia Rainwater Harvesting manual (Cabell Brand Center 2007) (see Appendix B). A comparison of water use (21,746 gallons/year) and available rainwater show that the collected rainfall (18,750 gallons/year) can compensate for 84% of the water needs of the household. As shown in Figure 4, the average rainfall to meet the household water needs exceeds only during one month of the year (May).

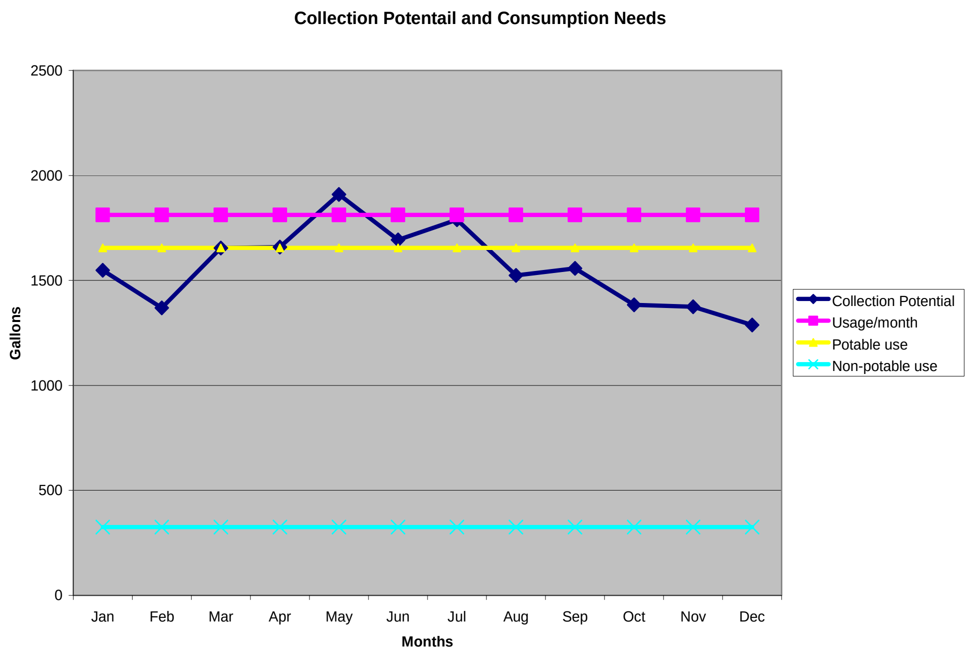

Figure 4. Potential rainwater collection and water use

Components of the system in study house are shown in Figure 5 (rooftop and gutter), Figure 6 (UV water treatment unit), Figure 7 (800 watt rainwater pump to pressurize water), Figure 8 (dual pipe system) and Figure 9 (1,700 gallon underground storage tank).

Figure 5. Roof and Gutter System Section

Figure 6. UV light treatment unit

Figure 7. Grundfos 800 watt rainwater pump

Figure 8. Pipe and valves for dual operation

Figure 9. Underground storage tank

4.4 Methods of Energy Measurement

Data and relevant information from the case study site was collected to provide energy and cost data for analysis. Electricity is the source of power for both systems in order to use the pump which draws the water from its source to the point of use. The energy required to power both systems was determined by the pump used to pressurize the water for in-house distribution.

The specifications of the pumps provided enough information to calculate the total watts needed to run the pump for water treatment (UV light) and in-house water distribution. In order to check these specifications this study used a standard watt meter (Figure 10). The watt meter was connected in between the unit where electricity is used and the electricity source.

Figure 10. Appliance watt meter

Because of the nature of the submersible pump unit, watt meter was not used to measure the watts required to run the groundwater pump. In an attempt to determine the actual running watts of the groundwater pump a test trial was attempted. This trial included running the groundwater for a period of time and monitoring the house electricity meter until the unit changed 1 kWh (kilo-watt hour). Because of the low watts used to run the pump, after running the groundwater for one hour the trial was stopped as to not waste more water. Slight error is attributed to the inability to measure electric current through the unit below ground surface.

5. Results and Discussion

This case study evaluated two decentralized energy systems, i.e., groundwater and rainwater harvesting systems for energy efficiency and costs of the system. Figure 11 show the energy flow diagram for the study house.

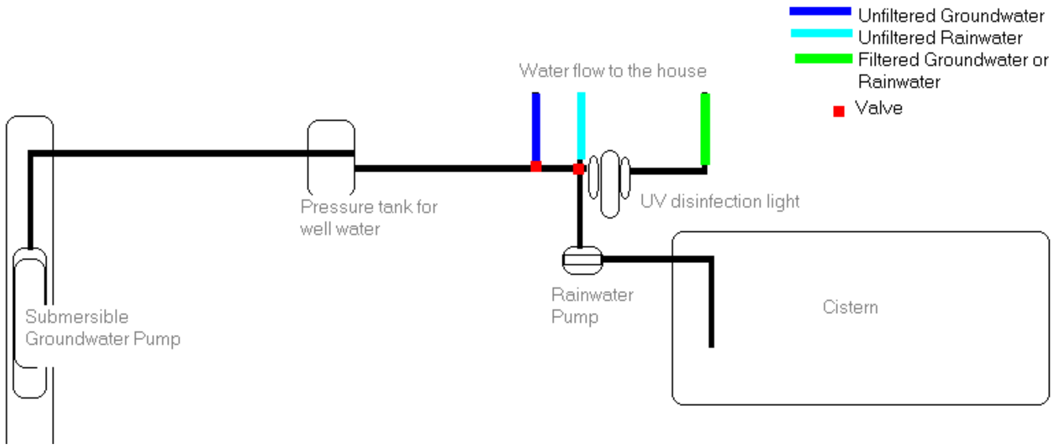

Figure 11 Energy flow in the house

5.1. Energy Analysis

Table 2 shows energy use corresponding to maximum flow rate of major system components based on unit specifications. Table 3 also includes the energy use in kWh based on both systems running for the same amount of time (estimated 30 minutes/day).

Table 3 shows the energy use of the rainwater pump and the UV light as shown through the appliance load tester.

Table 2. Energy information on water system pumps

	Energy Use (watts)	Max Flow Rate (gal/min)	Maximum Water Pressure (psi)	Energy Use (kWh)	Energy Estimate water at gal/min
Groundwater pump	372.85	10	30	0.1864	37.2 watt/gal/min
UV light	90	-			
Rainwater pump	800	22	51	0.4	36.36 watt/gal/min

Table 3. Appliance load tester trials

	Trial 1	Trial 2	Trial 3
UV light	90 watts	91 watts	90 watts
Rainwater Pump	801 watts	808 watts	808 watts

To compare the efficiencies of the two systems calculations were made in order to see total watts needed to provide water at the same flow rate. Dividing the watts by the flow rate yielded watts needed to provide water at 1gallon per minute. This calculation yielded system efficiency shown in the last column of Table 3. This calculation was made solely for comparison between the two systems and flow rate for distribution is determined by the pressure tank and by the source at which the water is being distributed. For example, a faucet will always run at the same flow rate and common faucet flow rate is 5gal/min (Cabell Brand Center 2007). In testing the flow rate, the faucet was found to run at a flow rate of 4gal/min. Both systems still use the full watts to run even when providing water at lower than the maximum flow rate.

5.2. Cost Estimation

Basic costs to consider for evaluating each system are installation costs and usage or operating costs. The installation costs of installing decentralized systems vary site and specifications of each system. For this case study, the installation of the rainwater harvesting system was known, since the system was installed very recently. The water well has been in place for many years and the cost of installation is not known and only speculated. Also, the cost for installation of a well system greatly varies based on how deep the well must be drilled as well as type of soil and rock the well is being dug through.

The cost of the components of the rainwater harvesting system for this case site totaled $4880.56 excluding installation cost. For this case study site the transportation costs were $200 from Salem, Virginia. These transportation costs include a truck delivering all of the components of the system including the large 1,700 gallon cistern tank. The cost for installation was unknown because the company who sold the rainwater harvesting system did not install the system. The rainwater harvesting system was installed by the owner with help from local plumbers. Because the instillation was done in conjunction with house renovations, an hourly labor rate was not available. The local drilling company, Fenton Drilling, provided an estimate of $2,800 for the drilling of a 175ft well in Shawsville area (Fenton, 2008). This price includes the casing, drilling, grouting, and well cap for the well but does not include the well pump. The total cost for the submersible pump unit and labor cost in 2001 was $1,087.50. For both systems, pump is the most costly component and can greatly alter the total cost of the system depending on type of pump. Overall, the rainwater system installation cost was $5080.50, not including instillation costs. The groundwater system estimated cost was $3887.50 including instillation.

A cost comparison was made if the public water supply line is extended to the house which is located about two miles from the public water line. The Montgomery County Public Service Authority (PSA) provided a cost estimate of $100 to $125 per foot to lay a new water line. Therefore the estimated cost for extending the new 12,000 ft water line is $120,000 to $150,000.

Because both systems in this case study are decentralized, the only operating cost is the electricity cost needed to run each system. There are two main facets of consideration for this cost when comparing the two systems. The first is the kWh used to run each system as displayed in section 5.1. The second facet of cost consideration that could alter the overall electricity used is the time needed for each system to provide the same amount of water to the source. Because each system provided water to the source at the same rate and pressure, the second facet was negated when it was proven to be the same for each system. The cost information displayed in Table 4 shows the minimal operating cost of each decentralized system. The operating cost for the rainwater pump is nearly twice of the amount for groundwater pump. As described in section 5.1, the only component contributing to electricity use is the pump, and the operating cost will be affected if a more efficient pump is used. .

Table 4. Annual operating cost of each decentralized system

	watts	hours/day	hours/yr	kWh	annual cost
rainwater pump	800	0.4	140	112	$7.84
groundwater pump	372.85	0.4	140	52	$3.65

Source for price per kWh: Appalachian Power Company

Again to make a comparison between these decentralized systems and public water supply, centralized water is much more costly when taking into consideration water usage. According to Montgomery County PSA, at present, water cost to customer is $0.003/gallon. Therefore, for this particular house for 21,746 gallons/year use the customer cost will be $65.24/year. There will also be a yearly cost of roughly $200 dollars in service charges in addition to basic water costs.

6. Conclusions

The energy information based in section 5.1 displayed that the only unit responsible for the energy efficiency of both the groundwater and the rainwater systems is the pump. The UV disinfection light also uses some energy running at 90watts but the UV light can be turned on and off and can be used to disinfect the water of both systems; therefore, it does not contribute to the economy of one system or the other. Theoretically, based on energy calculations, the rainwater harvesting system is slightly more efficient, if running without the UV disinfection light. But in practice the groundwater pump is about half as energy intensive as the rainwater pump. However, it would be wise to filter the groundwater for potable use as well, even though it has been used unfiltered in the past.

In comparing the energy efficiencies of the two systems, because the major factor in determining energy was solely based on the pump unit, the efficiency could have easily been changed with a different or more efficient pump. In theory, a rainwater harvesting system would be more energy efficient because water capture and storage requires no energy whereas to withdraw water up from a well is thought to be much more energy intensive. This however is not necessarily the case as shown through this site study. Appendix C contains a table with several pumps types currently available on the market. Using a different pump could make either of these systems more energy efficient or more energy intensive.

Cost evaluation shows that for this particular site groundwater system is more cost efficient as a direct result of lower energy use. The cost of instillation for groundwater system is lower as well. However, well installation cost is site specific depending on well depth, geology and other conditions described in section 5.2.

When comparing decentralized systems to centralized drinking water systems, both groundwater and rainwater harvesting systems provide major advantages and benefits. As shown through the cost comparison of this case study site, not only would it be very costly to extend new water lines from the public water supply to an isolated area there is t also significant energy requirement to pump water to isolated area through water distribution system. The enormous energy savings of decentralized systems can be one major reason to promote decentralized water systems in rural and low population communities. Decentralized systems such as rainwater harvesting can greatly conserve public water supply if implemented on a large scale. In favor of centralized systems; however, because decentralized systems are not regulated the absence of filtration system in most cases could present a health risk to users of these systems. Public education will be needed to lower health risks associated with decentralized systems. Using rainwater is a viable option in many parts of the world and even if rainwater is not the only source of water, it can prove to be very valuable when used in conjunction with a groundwater well or other source. In some locations, excess harvested rainwater can be a significant source for groundwater recharge to protect groundwater aquifer for possible use during drought conditions.

In order to conserve diminishing water supplies the government could help promote decentralized drinking water systems by providing various incentives. Currently the most common government initiative used in several states and other countries is providing a tax rebate for implementing the rainwater harvesting system. As described in the Literature Review, governments could also require the implementation of rainwater harvesting for certain uses on new construction. Even if rainwater harvesting was implemented on a large scale just for non-potable use, it could greatly transform and preserve water supplies throughout the country.

7. Recommendations for Future Research

This study provided applicable results for small scale residential rainwater harvesting and groundwater systems. In order to better understand the energy use of these systems in comparison to one another, a similar study could be performed on other residential sites where both the rainwater harvesting and the groundwater capture are in place. Also, other case studies could be performed to evaluate the energy consumption of these systems with sites that have access to both public water and decentralized water so a comparison to a centralized public water supply system can be more accurately performed.

In a more applied setting, energy efficiencies of large scale rainwater harvesting systems should be analyzed to help determine the future of rainwater harvesting as a valuable technology for providing water, a crucial resource that is becoming more depleted with the ever increasing population and water demand.

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9. Online Sources

Dara Colwell, Green Roofs:
http://www.kstate.edu/waterlink/graphics/reports/green%20Roofs.pdf
Green Building Pages: http://www.greenbuildingpages.com/links/weblinks_LEED.html

American Rainwater Catchment Systems Association, http://www.arcsa-usa.org/

Southern Australian Water Corporation, http://www.sawater.com.au/sawater

Queensland, Australia Government Rebate Program:
http://www.nrw.qld.gov.au/water/saverscheme/rebate_schemes

Gold Coast Australia Government Rebate Program:
www.goldcoastwater.com.au/rainwatertanks

Arizona State Government: www.azdor.gov

Santa Fe, New Mexico Government Development Guidlines:
http://www.santafecounty.org/about_us/documents/development_guidelines.pdf

Portland, Oregon Government Rebates for Stormwater Managment:
https://www.portlandonline.com/bes/index.cfm?c=41976
Texas Tax Incentives: http://www.twdb.state.tx.us/iwt/rainwater/faq.html#08

United States Environmental Protection Agency List of Primary and Secondary Contaminants: http://www.epa.gov/OGWDW/contaminants/index.html

Precision Well Inc: http://www.precisionwell.com

Weather Information for Shawsville: http://www.idcide.com/weather/va/shawsville.htm

Rainwater Management Solutions Inc: http://www.rainwatermanagement.com/

Appendix A – Water Quality of Study Site

As shown through literature review, the water quality of both rainwater and groundwater are dependent on location and can be influenced by many sources. Water samples were collected from groundwater, rainwater, and filtered rainwater, and from the creek which runs parallel to the back of the house. These samples were analyzed in the laboratory for nitrates, metals, organic material, and bacterial contamination in the form of Eschericha coli (E-coli) and Fecal Coliform. In addition, pH and conductivity were measured in the field. Water quality results are summarized in Tables 1 to Table 3.

Table A1 describes the amount of nitrate, ammonium, and phosphate found in each of the water samples. Nitrate nitrogen was present in all water samples but concentrations were well below USEPA drinking water standards of 10 mg/L (USEPA www.epa.gov). Ammonium nitrogen was only found in the rainwater samples in small amounts in both filtered and unfiltered samples. Low concentrations of Ortho-Phosphate were detected in rainwater storage tanks.

Table A1. Water quality analysis results for nitrate, ammonium and phosphate

	Nitrate +	**Ammonium**	**O-Phosphate**
	nitrite as N	**as N**	**as P**
	mg/L	mg/L	mg/L
Detection Limit	*0.002657186*	*0.008730694*	*0.004033903*
Groundwater1	0.086	<.008731	<.004034
Groundwater2	0.074	<.008731	<.004034
Cistern Rainwater1	0.714	0.16	0.059
Cistern Rainwater2	0.699	0.163	0.065
Filtered Rainwater1	0.487	0.167	<.004034
Filtered Rainwater2	0.529	0.16	<.004034
Creek1	0.526	<.008731	<.004034

Table A2 displays concentrations of metals measured in each water sample. Measured metals include cadmium (Cd), copper (Cu), lead (Pb), Silicon (Si) and zinc (Zn). Except for silicon (all samples) and zinc (rainwater unfiltered and filtered), metal concentrations were below detection level. For Zinc, the USEPA suggested maximum allowable concentration is 5.0 mg/L. Observed values in rainwater samples are well below suggested values. Zinc in rainwater samples may have originated from rooftop material. This speculation was not verified in this study. The harmful effects of silicon in drinking water have yet to be fully known and the USEPA has not issued guidance as yet.

Table A2. Metal concentrations in groundwater and harvested rainwater

Analyte	Cd	Cu	Pb	Si	Zn
Wavelength (nm)	228.802	327.395	220.353	288.158	206.2
Detection Limit	0.018415596	0.012628909	0.022655	0.015729	0.026439
	mg/L	mg/L	mg/L	mg/L	mg/L
Groundwater1	<0.018416	<0.126289	<0.02266	5.305630	<0.02644
Groundwater2	<0.018416	<0.126289	<0.02266	5.222690	<0.02644
Cistern Rainwater1	<0.018416	<0.126289	<0.02266	0.072030	0.039726
Cistern Rainwater2	<0.018416	<0.126289	<0.02266	0.068709	<0.02644
Filtered Rainwater1	<0.018416	<0.126289	<0.02266	0.152044	<0.02644
Filtered Rainwater2	<0.018416	<0.126289	<0.02266	0.125196	0.029827
Creek1	<0.018416	<0.126289	<0.02266	4.508310	<0.02644

While collecting samples, total dissolves solids (TDS), conductivity, and temperature were measured and are displayed in Table A3. Like Zinc, measurement of total dissolved solids is a secondary concern for water quality (USEPA, www.epa.gov). An elevated level of TDS is not specifically harmful to the health of humans but can be an indicator of an increased level of other harmful contaminants. The USEPA still suggests a TDS level of below 500mg/L

Table A3. Conductivity Observations

Trial 1	Groundwater	Cistern	Filtered
Total Dissolved Solids	374 mg/L	23 mg/L	14 mg/L
Conductivity	555 mu/cm	34.8 mu/cm	11.2 mu/cm
Temperature	16.4 C	18.4 C	19.6 C

Trial 2	Groundwater	Cistern-Top	Cistern-Bottom	Filtered
Total Dissolved Solids	375 mg/L	14 mg/L	65 mg/L	17 mg/L
Conductivity	558 mu/cm	20.8 mu/cm	97 mu/cm	28 mu/cm
Temperature	16.6 C	19.1 C	16.9 C	19.7 C

Appendix B. Appliance Water Usage

	A. Water consumption using conserving fixtures	B. Assumptions from AWWA Residential End-Use Study	C. Adjustments to assumptions (adjust up or down according to actual use)	D. Number of persons in household	E. Household monthly demand A x (B or C)x D x 30
Toilets (use only appropriate type)					
ULFT	1.6 gal/flush	6 flushes/ person/day			
Dual Flush	1 gal/flush liquids 1.6 gal/flush solids	6 flushes/ person/day			
Baths & showers					
Showerhead	2.2 gal/min	5 minutes/ person/day			
Bath	50 gal/bath	NA			
Faucets (personal hygiene, cooking, and cleaning of surfaces)	2.2 gal/faucet/min	5 minutes/ person/day			
Appliances or uses which are measured on a per-use basis (not a per-person basis):					
Clothes washer Front-loading (horizontal-axis)	18–25 gal/load	2.6 loads/week			
Dishwasher	8 gal/cycle	0.7 cycles/day			
Miscellaneous other					
Total					

Table for Calculating Indoor Water Usage from Texas Manual using water saving appliances

Appendix C. Pump Efficiency Data

Goulds pumps for rainwater harvesting systems

Series	HP	Volts	Max amps	Watts
1SC51C0AA	0.5	115	10.6	372.85
1SC51C1AA	0.5	230	4.5	372.85
1SC51C3AA	0.5	230	3	372.85
1SC51C0FA	0.5	115	10.7	372.85
1SC51C1FA	0.5	230	4.5	372.85
1SC51C3FA	0.5	230	3	372.85
1SC51D1BA	0.75	230	5.4	559.27
1SC51D3BA	0.75	230	3.5	559.27
1SC51D1GA	0.75	230	5.3	559.27
1SC51D3GA	0.75	230	3.5	559.27
1SC51E1CA	1	230	6.4	745.7
1SC51E3CA	1	230	4.1	745.7
1SC51E1HA	1	230	6.8	745.7
1SC51E3HA	1	230	4.3	745.7

Source: ITT Goulds Pumps Inc. Residential Water Systems
Specifications provided by Rainwater Management Solutions Inc.