VIRGINIA WATER RESOURCES RESEARCH CENTER

Final Report

Feasibility of Rainwater Harvesting BMP for Stormwater Management

Submitted to:
Ms. Krystal Coxon
Virginia Department of Conservation and Recreation

Submitted by:
Dr. Tamim Younos

Authors:
Dana Gowland
Tamim Younos

VWRRC Special Report No. SR38-2008

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
BLACKSBURG, VIRGINIA

May 2008

Acknowledgments

Funding for this project was provided in part by the Virginia Department of Conservation and Recreation Mini-Grant Contract # 319-2005-34-SR (VT # 08-0950-11).

Lee Hixon, Engineer, Town of Blacksburg, provided information about the case study site - Blacksburg Motor Company Building. Adrienne LaBranch and David Crawford, Rainwater Management Solutions and Cabell Brand Center, Salem, Virginia provided reports of case studies and assisted with design parameters and cost estimates of the case study site.

****

Disclaimer

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the Virginia Water Resources Research Center, Virginia Tech or Virginia Department of Conservation and Recreation. The mention of commercial products, trade names, or services does not constitute an endorsement or recommendation.

****

Virginia Water Resources Research Center
210 Cheatham Hall (0444)
Virginia Tech
Blacksburg, VA 24061
(540)231-5624
FAX: (540)231-6673
E-mail: water@vt.edu
Website: http://www.vwrrc.vt.edu

Stephen Schoenholtz, Director

Executive Summary

Rainwater harvesting – the collection and use of rainfall – has been practiced since ancient times. In modern times, rainwater harvesting has been used mostly as a low-cost technology for water supplies in rural areas. Collecting rooftop rainwater in barrels for landscape irrigation is a common practice for many single-family households in the United States. In recent years, indoor use of harvested rainwater in commercial buildings has been promoted. In the context of this project, rainfall harvesting is considered a *Low Impact Development* (LID) *Best Management Practice* (BMP) to help achieve the goal of the *municipal separate storm sewer system* (MS4) stormwater management program.

The major goal of this project is to study the feasibility of rainwater harvesting for stormwater management. The project has six objectives:

(a) Conduct a literature review of material relevant to rainwater harvesting
(b) Identify case studies of modern rainwater harvesting systems
(c) Select a case-study site to investigate the effect of rainwater harvesting on stormwater management
(d) Design a rainwater harvesting system for the selected site
(e) Estimate the stormwater-reduction volume to the drainage system that is attributable to rainwater harvesting
(f) Estimate the effects of rainwater harvesting on the water quality of stormwater runoff.

The approach for this project consists of two components: 1) a review of literature and existing case studies of rainwater harvesting systems; and 2) the design of a rainwater harvesting system for a case-study site that will enable estimating possible water-volume reductions to the stormwater drainage system.

The reduction of water volume to the stormwater drainage system is an expected advantage to using a rainwater harvesting system. For the case-study site, Blacksburg Motor Company (BMC) building, the planned outdoor use for landscape irrigation (rain barrels) will reduce the rainwater volume and nitrate-nitrgen load to the stormwater-drainage system by about 10%. If indoor use (e.g. toilet flushing) were also implemented (not planned at this time), the rainwater volume and nitrate load to the stormwater-drainage system would be reduced by 25%, A second advantage of using rainwater harvesting systems is the reduction in the use of potable water for non-potable-water needs. At the BMC case-study site, if indoor and outdoor uses of rainwater are implemented, about 51,000 gallons of potable water could be saved each year.

At first glance, the stormwater runoff reductions and potable water savings from rainwater harvesting appear insignificant. If rainwater harvesting is implemented at the watershed scale (for example, assume 100 buildings in the watershed), the reduction in stormwater volume and savings of potable water would be significant. Rainwater substituted for potable water would also reduce energy requirements because less potable water would need to be treated and transported.

Table of Contents

1. Introduction

Rainwater harvesting – the collection and use of rainfall – has been practiced since ancient times. For example, the ancient Carthaginian-Roman civilization in Sardinia used rainwater cisterns to provide for public and household needs in the 9th century BC (Crasta et al. 1982). In recent times, rainwater harvesting has been used a low-cost technology for water supply in rural areas where other appropriate water sources are unattainable and where surface water and groundwater sources are either expensive to utilize or are inadequate for consumption (Michaelides and Young, 1983; Yaziz et al. 1989). Rooftop rainwater harvesting practice and potable rainwater use is common in the coal-mining regions of the United States such as coalfields of southwest Virginia where groundwater is not available or contaminated and/or constructing conventional drinking water infrastructure is cost prohibitive (see Figure 1, Younos et al. 1998).

Figure 1. Household rooftop rainwater collection and cistern in Dickenson County, Virginia

At present, collecting rooftop rainwater in barrels to be used for landscape irrigation is a common practice in many single households in the United States. Indoor use of harvested rainwater in commercial buildings such as toilet flushing is becoming more acceptable.

A modern rainwater harvesting system consists of a rainfall collection system (rooftop), a water conveyance system (gutters and downspout pipes), a water storage system (storage tank or cistern), and a water pumping system (Figure 2a). A pump is used to distribute rainwater from the storage tank for indoor potable use or non-potable use such as flushing toilets or outdoor non-potable uses such as fountains, landscape irrigation, and groundwater recharge (Figure 2b). The indoor potable use of rainwater will require installation of a water treatment unit.

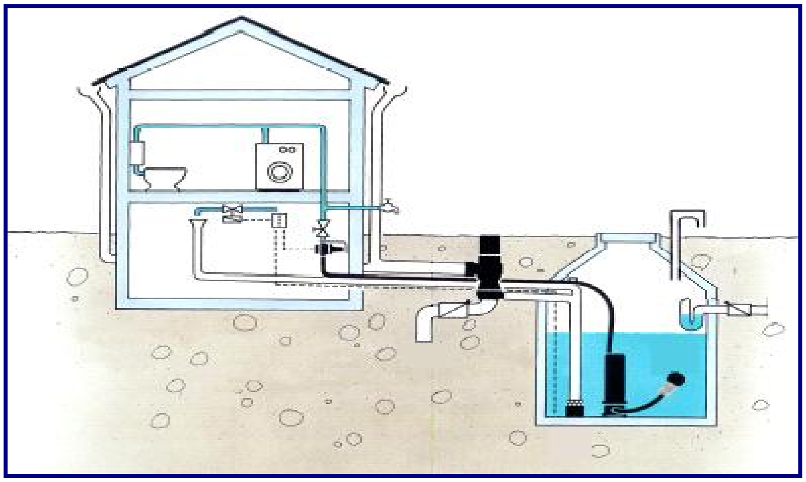

Figure 2a. Typical Rainwater Harvesting System
Source: Rainfall Management Solutions
http://rainwatermanagement.com/

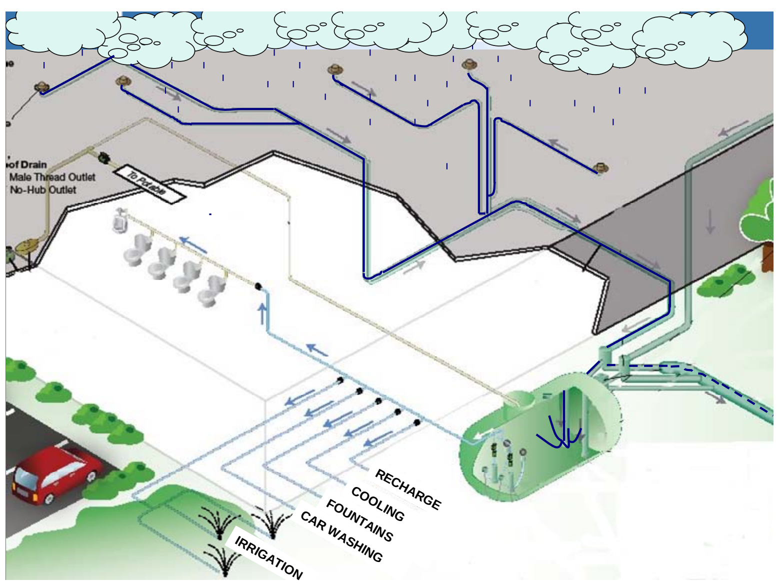

Figure 2b. Rainwater Harvesting System- Uses of Water
Source: Rainfall Management Solutions –
http://rainwatermanagement.com/

In the context of this project, rainfall harvesting is considered a *Low Impact Development* (LID) *Best Management Practice* (BMP) to help achieve the goal of the *municipal separate storm sewer system* (MS4) stormwater management program that was established by the Stormwater Phase II Rule. The goal of MS4 program is to reduce the quantity of pollutants (sediment, nutrients, bacteria, metals) in urban runoff entering surface waters through reduced MS4 discharge into nearby waterways. It is expected that rainwater collection from building rooftops will reduce the water volume that enters a stormwater drainage system. Also, because pollutant concentrations in harvested rainfall are lower than runoff generated from the ground surface, rainwater harvesting is expected to contribute lower amounts of pollutants to stormwater drainage and eventually receiving surface waters.

2. Project Objectives

The major goal of this project is to study the feasibility of rainwater harvesting for stormwater management. The project has six objectives:

(a) Conduct a literature review of material relevant to rainwater harvesting
(b) Identify case studies of modern rainwater harvesting systems
(c) Select a case-study site to investigate the effect of rainwater harvesting on stromwater management
(d) Design a rainwater harvesting system for the selected site
(e) Estimate the stormwater-reduction volume to the drainage system that is attributable to rainwater harvesting
(f) Estimate the effects of rainwater harvesting on the water quality of stormwater runoff

3. Approach

The approach for this project consists of two components: 1) a review of literature and existing case studies of rainwater harvesting systems; and 2) the design of a rainwater harvesting system for a case-study site that will enable estimating possible water-volume reductions to the stormwater drainage system.

4. Literature Review

Two areas of interest in this project are literature relevant to water quantity impacts of rainwater harvesting and literature relevant to water quality issues. Less information is available on water quantity impacts of rainwater harvesting. A rich body of literature is available on water quality issues of rainwater harvesting.

4.1 Water Quantity Impacts of Rainwater Harvesting

Study by Herrmann and Hasse (1997) describe the development and performance of rainwater utilization systems in Germany. The study specifically looks into rainwater harvesting system efficiency and the impact of rainwater harvesting systems on reducing potable water demand and reduction of stormwater volume entering the combined sewer system. Study results show that rainwater harvesting reduces demand on potable (drinking) water. Also it concludes that rainwater harvesting is most effective for the stormwater drainage system when it is applied in multi-storey buildings and densely populated districts. In a follow up study Herrmann and Shmida (1999) reported that for a private household, depending on the consumption habits, roof area, and size of storage tank, the average water (drinking water) saving will be between 30% to 60%.

Coombes at al. (2002) developed a series of models that determine the economic and environmental benefits of water source controls on centralized municipal water providers in New South Wales, Australia. Source control measures in the model include rainwater harvesting tanks, infiltration trenches, grassed swales, detention basins and constructed wetlands. These control measures can be used in housing allotments and subdivisions to reduce stormwater and supplement domestic water sources. Model developed for household water demand, satisfied in part from rainfall and in part from municipal water. Household use estimate was based on roof area and number of occupants. Municipal water use estimates was based for all potable uses and to supplement rainwater in times of drought. Study results show that that rainwater harvesting tanks can reduce water demand by being used for toilet flushing and outdoor uses. It concludes that reduced demand on central water providers can delay the requirement of new infrastructure and reduce the cost and size of infrastructure improvements.

Crowley (2005) reported results of a neighborhood-level rainwater catchment analysis in Portland, Oregon. The a major study objective was to determine the total amount of stormwater that could be collected to if all single family residences used a rainwater harvesting system. A second objective was to identify the ideal cistern size, and indoor water use to maximize amount of water diverted from stormwater system while keeping system cost low. Results were reported for various cistern sizes (110, 500, 1500 or 4500 gallons) and different water uses (all indoor uses, toilet flushing and clothes washing, or toilet flushing only). It was shown that any cistern size will reduce stormwater directed to the combined sewer systems (CSS) immediately. No cisterns failed, although all were full to capacity during the wettest months. Reduction in volume to CSS ranged from 30% to 68%. The least overall reduction occurs when water is used for toilet flushing only (30 35%). Even the smallest cistern size (110 gallons) had significant impact on stormwater volume (~30%/year). Most successful cistern size is the 4,500 gallon, however 1,500 gallon cisterns are the most size efficient for in town homes (more cost efficient and size appropriate).

4.2 Water Quality Issues of Rainwater Harvesting

Atmospheric deposition and organic sources, including animal feces and deposition of tree leaves, are sources of contamination of rainwater harvesting systems. Water quality from different rooftop catchment systems are affected by the surrounding environment, climatic conditions, and roof material (Thomas and Green 1992). Microbial and chemical contamination of rooftop runoff is considered potential issues of rainwater harvesting water quality.

Microbial Contamination

Storage tanks and cistern water may contain high levels of microbes of great variety including protozoa, algae, invertebrates and insects (Lye 1992). Bacteria that are commonly found in cistern water supplies are coliform, fecal coliforms (thermotolerant *Escherichia coli*), eugonic bacteria, dysgonic bacteria and hemolytic and/or cyotoxic bacterial activity (Lye 1987; Lye 1992). Other bacteria including non-fecal sources of contamination and pathogenic organisms that are not commonly found in cistern water supplies, but still raise grave concern, are *Pseudomonas, Aeromonas, Legionella, Legionella pneumophila*, *Salmonell*, *Salmonella arechevalata*, and other heterotrophic bacteria (Lye 1992). Lye (1987) reported on several studies related to microbial contamination of harvested rainwater. After surveying the bacterial content of 30 rural northern Kentucky cistern systems, it was found that coliforms and heterotrophic bacteria are common to cistern storage systems. In general, levels of bacteria in cistern water supplies are high enough to be unsuitable even though they are generally lower than that of surrounding surface waters and higher than those found in rainfall (Lye 1992). A study of 83 cistern in Nova Scotia (Lye 1987) showed that 50 percent of the cistern systems contained coliforms, 8 percent contained fecal coliforms and 95 percent contained *Pseudomonas*. Another study of the bacterial quality of 100 rainwater cistern supplies in the Virgin Islands (Lye 1987) indicated that 64 percent of cistern tanks contained coliforms, fecal streptococci was detected in 39 percent, 11 percent contained *Salmonell*, and *Shigella* was detected in 44 percent of cisterns. Evans et al. (2006) reported that bacterial loads in roof runoff are source dependent and therefore influenced by weather patterns, wind speed and direction in conjunction with other factors such as relative source location.

Chemical Contamination

Natural and anthropogenic sources of toxic metals and other inorganic compounds contaminate water supplies, including cistern water supply systems (Amirtharajah and Jones 1995). Chemical contamination sources include particulates from auto emission, industrial manufacturing emissions, and from airborne soil, corrosion of chemical from within the distribution system, corrosion of roof paints and material, and dissolution of chemicals from sediments in storage tanks. Indicators of chemical contamination include asbestos fibers, pH, suspended solids, and very important, heavy metals- cadmium (Cd), copper (Cu), lead (Pb), zinc(Zn), chromium (Cr) (Lye 1992; Quek and Forster 1993).

Several studies report on chemistry of rooftop runoff collected in cistern and water storage tanks. Thomas and Green (1992) analyzed water quality of collected rainwater from different roofs in rural, urban and industrial areas in Australia to ascertain its appropriateness for domestic use. They reported that the rainwater collected from roof catchments was mainly polluted from atmospheric deposition and that the number of antecedent dry days affects water quality, meaning the quality of rainwater collected decreased with and increase of number of antecedent dry days. The two roof types influenced the runoff quality where the concrete tile roof catchment had higher turbidity, conductivity, and pH levels, while the galvanized iron roof catchments had higher zinc concentrations. Industrial area roof catchments had higher concentrations of lead in the suspended solids due to emissions from motor vehicles and zinc and turbidity. Urban area roof catchments also had high levels of lead due to motor vehicle emission, but were less than industrial concentrations. Rural area roof catchments were affected by agricultural activities and had higher concentrations of nitrate and pH. The study concluded that galvanized iron roof catchments provide the best water quality and that surrounding environment conditions greatly affect water quality. Yaziz et al. (1989) reported that acid rain causes leaching of zinc from galvanized-iron roofs.

Several studies have reported on the chemical composition of roof catchment water of cistern systems, primarily the metal content. Young and Sharpe (1984) analyzed the impact of atmospheric deposition on the water quality of 40 roof catchment cistern systems in rural Clarion and Indiana counties, PA. They studied the inflow of the heavy metals lead, cadmium and copper in the precipitation and in the water distribution system. The study showed that lead did not meet drinking water standards in bulk precipitation samples and corrosiveness predominated bulk precipitation samples (incoming rainwater samples). Corrosiveness was also present in cistern water samples and mean lead, cadmium and copper concentrations were below drinking water limits of cistern water samples. Lead and cadmium concentrations exceeded drinking water limits in the cistern bottom sediment/water amassed from the metal deposits on the roof catchments. Also, the study found that the corrosive bulk precipitation was moderated in all cement-based cisterns construction materials due to the dissolution of $CaCO_3$ from cistern walls and floors except those vinyl-lined. Vinyl-liners prevent the dissolution of $CaCO_3$ and thus the water stored in vinyl-lined cisterns was almost as corrosive as the bulk precipitation. Notable reduction of sediment metal contamination of cistern was noted when roof water filters were employed. It was concluded that cistern systems had several drinking water problems at the tap and were considered a hazard to its users due to the acidic precipitation that corroded the household distribution system and the atmospheric deposition of the metals lead, cadmium and copper that accumulated in cistern bottom sediments.

Another study was conducted on 46 roof catchment cistern systems of single-family dwellings in St. Maarten, Netherlands Antilles to determine heavy metal concentrations, Cd, Cr, Pb, and Zn (Gumbs and Dierberg 1985). They found that heavy metal concentrations were well below US drinking water limits in most cases. There was higher levels of Zn, Pb, and Cd at the tap water due to the increased dwelling time of the water in the pressure tanks which caused the corrosion of galvanized metal parts. The removal of dissolved heavy metals was facilitated in the surface waters of the cistern due to increased pH, calcium, and alkalinity due to the dissolution of the cistern masonry by the corrosive rainwater. Good (1993) reported on the source of metal and aquatic toxicity in storm water of roof runoff of sawmill on the coast of Washington. It was observed that the collection of atmospheric deposits on roof-tops contributed to the relationship between Zn concentrations in roof runoff and the antecedent dry days between storm events. Zn concentrations were detected throughout the storm event due to the leaching of Zn from the galvanized roof surface and were considered to be toxic to aquatic life but, not human life. It was concluded that roof runoff was a source of pollutants, including high Zn concentrations, that exceed water quality limits for marine water and may be a source of and aquatic toxicity and storm water contamination. The rapid corrosion of galvanized metal roofs and leaching of zinc were attributed the acid rain and the coastal climate of Washington.

Chang (2004) reported that roofs can be a serious source of nonpoint source pollution. Of eight roof runoff quality variables studied, only pH, EC, and Zn were significantly affected by the types of roofing materials. However, concentrations of Al, Mn, Cu, Pb, Zn, and pH in roof runoff exceeded the national quality standards at least 5% of the time. Zn and Cu concentrations most often violated standards. Chang (2004) also noted that wood shingles are the least desirable roofing material. Most wood shingle and shake roofs are made from western red cedar (Thuja plicata), red wood (Sequoia sempervirens), and cypress (Taxodium distichum). Chang (2004) cited other studies that indicate these materials are often impregnated with preservative chemicals such as copper naphthenate, copper octoate, and zinc naphthenate, and fungi killing chemicals most notably zinc sulfate, copper sulfate, and zinc chloride and therefore a possible source of water contamination.

Davis et al. (2001) reported that industrial and commercial roofs have much higher concentrations of metals than residential roofs. They speculated that copper sheeting in flashing, trim, and gutters likely influenced concentrations of copper due to prevalence in commercial and industrial buildings. They also noted, in terms of lead and copper, that fiberglass and asphalt roofs tend to have better runoff quality than those using slate tile, rubber and galvanized metal.

5. Case Studies of Modern Rainwater Harvesting Systems

Examples of rainwater harvesting systems can be found around the globe. The International Rainwater Harvesting Alliance website: http://www.irha-h2o.org/ presents rainfall case studies in several countries.

The Rainwater Harvesting in Delhi, India is found on the website: http://www.ecotippingpoints.org/indepth/indiaurbanrain.html. The website: http://www.unep.or.jp/ietc/Publications/TechPublications/TechPub-8c/index.asp provided information on United Nations Rainwater Harvesting in Developing and Transitional Countries, Latin America and the Caribbean. Australian states have passed legislation which requires or encourages rainwater catchment. The Building and Sustainability Index (BASIX) is a building regulation in New South Wales which requires a 40% reduction in mains water usage via low flow fixtures and use or rainwater tanks for outdoor, toilet and laundry water use. New homes in Victoria are required to have either a rainwater tank or a solar hot water heater to reduce water or energy demand. Rainwater catchment is encouraged in Queensland in the Development Code, which outlines standards for system installation. For more information see the Southern Australian Water Corporation website: http://www.sawater.com.au/sawater.

American Rainwater Catchment Association (http://www.arcsa.org/gallery.html) provided a gallery of rainwater harvesting systems in the United States. Texas appears to be at the forefront of incorporating rainwater catchment systems into new development through property and sales tax incentives (TWDB 2005). Information on Texas rainwater harvesting is provided in the Rainwater Harvesting, Complete Rainwater Solutions website: http://www.rainharvesting.com.au/rain_water_harvesting.asp.

The Lady Bird Johnson Wildflower Center near Austin, Texas: http://www.wildflower.org/ is a major educational and demonstration site for rainwater harvesting where annually 300,000 gallons of rooftop harvested rainwater is used for wildflower garden landscaping. Information on rainwater harvesting in Seattle can be found on the website: http://www.seattle.gov/util/Services/Yard/Natural_Lawn_&_Garden_Care/Rain_Water_Harvesting/index.asp.

The City of Portland, Oregon, Office of Sustainable Development website provides rainwater harvesting information in Portland, Oregon: http://www.portlandonline.com/OSD/index.cfm?a=114750&c=42113. Other rainwater harvesting information in the U.S. can be found on the website: http://www.buildinggreen.com/. Additional resources are provided in the Appendix A of this report.

In Virginia, rainwater harvesting for various uses is increasing. Table 1 shows summary of a few case studies of rainwater harvesting projects in Virginia that were designed by Rainwater Management Solution (http://rainwatermanagement.com/). Hicks (2008) conducted a cost-benefit analysis of two case study sites of rainwater harvesting at commercial facilities in Arlington County, Virginia.

Table 1. Typical Existing Rainwater Harvesting Case Study Sites in Virginia
Source: Rainwater Management Solution website: http://rainwatermanagement.com/

Site Name	**Building Purpose**	**Location**	**Roof Area (sq. ft.)**	**Annual Rainwater Volume (gallons)**	**Annual Rainfall (in)**	**Water Use**
Western Virginia Regional Jail	Correctional Facility	Roanoke County	225,000	4,600,000	41	Laundry Facilities
Oscar Smith Middle School	Public School	Chesapeake City	170,000	3,730,000	44	Landscaping, Toilet Flushing
Claude Moore Education Complex	Culinary School	Roanoke City	10,000	200,000	41	Toilet Flushing
Eggleston Services	Laundry Facility	Norfolk City	29,450	646,000	44	Laundry Facilities

6. Feasibility of Rainwater Harvesting for Stormwater Management

6.1 Site Description: Blacksburg Motor Company Building

Recently, the Town of Blacksburg (TOB) purchased an historic building, adjacent to the Town Hall, known as Blacksburg Motor Company building (BMC) located at 400 South Main Street, Blacksburg. The building is being renovated to house TOB planning and engineering departments. TOB is using this opportunity to create Green Building that will meet goals of the Sustainable Blacksburg and demonstrate green building techniques to the local engineering, development and building communities. As a part of the overall renovation plan, TOB is planning to install rainwater harvesting BMP on this building for stormwater management and water conservation purposes. In the vicinity of the site, TOB will also install bio-retention cells (rain gardens) for stormwater management. A rainfall harvesting system, along with the bio-retention cell, is expected to significantly reduce stormwater runoff impacts. TOB in collaboration with Virginia Tech and Cabell Brand Center will use the "Green Building" as a "Good Practices" demonstration site for K-12 and citizen educational programs. University researchers will use the site as research facility to monitor effects of LID BMPs on water quantity/quality and energy conservation. Figures below show the BMC building and site plan. Figure 3a and Figure 3b show the BMC building and the artist view of site plan, respectively.

Figure 3a. Blacksburg Motor Company Building

Figure 3b. Artist view of renovated BMC building site plan
Source: Town of Blacksburg. "Blacksburg Motor Company Building Renovation." *http://www.blacksburg.va.us/Index.aspx?page=473*

The engineering site plan (C1.3) for the BMC building is attached in Appendix B. Figure 4 shows details from the engineer's plan (C1. 3) (it shows the location of one rain-barrel and one nearby bio-retention cell).

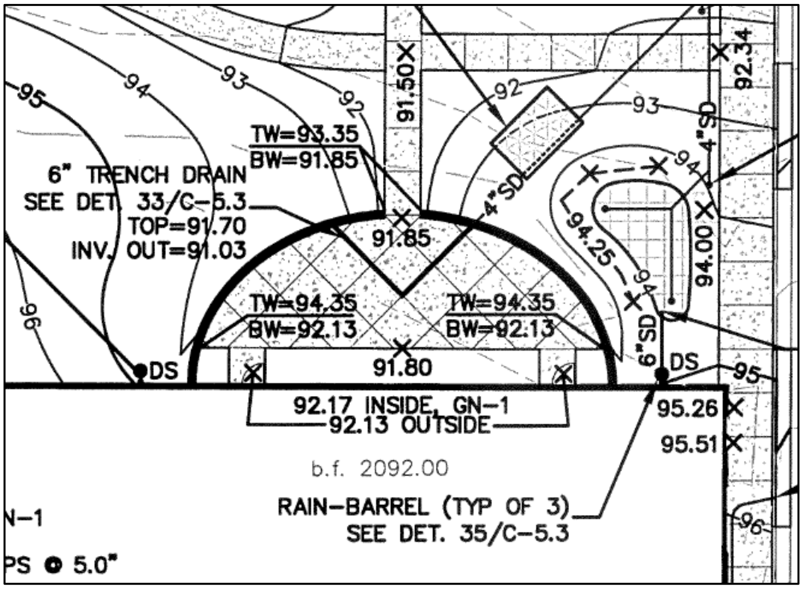

Figure 4. Details of stormwater management plan for Blacksburg Motor Company Building. *Source: Spectrum Design. "Blacksburg Motor Company Building Renovations C1.3."*

6.2 Basic Design Parameters

Basic design parameters for a rainfall harvesting system are rooftop area and expected available rainwater volume. Rooftop area can be estimated from building dimensions or aerial photographs. Available rainwater volume can be estimated from average monthly rainfall depth over rooftop area using the following equation:

ARV (gallons/month) = Roof-Area (sq-ft) x Average Rainfall (inch/month) x C x 0.6233 where, HRV is available rainwater volume, C is collection efficiency (usually 0.8) – compensates for losses due to splash and evaporation - and 0.6233 is conversion factor to estimate in water volume in gallons.

Information on indoor and outdoor water demand is needed to harvest the available rainwater effectively. Indoor and Outdoor water usage can be calculated from expected monthly indoor and outdoors usage. Indoors water usage for the building is estimated from the number of people who work and reside in the building on a daily basis. Outdoor water usage for landscape irrigation can be estimated from expected irrigation application rate and irrigation frequency.

6.3 Estimating Available Water from Rainwater Harvesting – BMC Building

The rooftop area for the BMC building is 10,000 square-ft. Table 2 shows monthly and annual average rainfall amount for Blacksburg, Virginia.

Table 2. Average monthly and annual normal precipitation in Blacksburg, Virginia

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual**
Rainfall (inch)	3.37	3.02	3.83	3.83	4.39	3.39	4.17	3.68	3.39	3.19	2.96	2.87	42.63

Source: http://www.idcide.com/weather/va/blacksburg.htm

Table 3. Estimated Available Water for BMC Building, Blacksburg

Month	**Monthly Av. Rainfall (inch)**	**Available Rainwater (gal)**
January	3.37	16,810
Feb	3.02	15,063
March	3.83	19,104
April	3.83	19,104
May	4.39	21,897
June	3.93	16,909
July	4.17	20,800
August	3.68	18,356
September	3.39	16,909
October	3.19	15,912
November	2.96	14,764
December	2.87	14,315
Av. Monthly		17,495
Total Annual	42.63 (inch)	209,943 (gal/year)

Note: 1 gallon = 0.1337 cubic-ft

Table 3 shows the estimated rainwater volume that can be harvested from the Blacksburg Motor Company Building. In a normal year, nearly 210,000 gallons (~ 2,800 cubic-ft) of rainwater is available from the BMC rooftop. In a dry year, if total annual rainfall in Blacksburg is assumed about 35 inches, the annual available water volume from BMC rooftop will be approximately 175,000 gallons (~ 23,000 cubic-ft).

6.4 Estimating Water Demand for the BMC Building

Indoors water usage, in this case limited to flushing toilets, can be estimated from the building occupancy. It is assumed that on a daily basis, 25 people will be utilizing the BMC building (estimated by TOB Planning Department). It is also assumed that each person will be flushing the toilet 3 times per day. With the low flow toilets to be installed, estimated indoor water use is 120 gallons/day (2,500 gallons per month excluding weekend days).

Planning for outdoor water usage for landscape irrigation in Blacksburg provides insurance about possible drought condition during summer month when evapotransiration rate is high. Outdoor usage can be estimated from expected depth of water application (inch) over the area (square-ft) to be irrigated and irrigation frequency (e.g. weekly). Approximate landscape area in the vicinity of BMC building to be irrigated is 1,000 square-ft. If it is assumed that about 1.0 inch/week water application will be needed during the peak of the summer dry months when evapotranspiration is highest, a 1,000 sq-ft. landscaped area would require approximately 3,000 gallons per month. If irrigation water is applied April to October (7 month period), required water volume for landscape irrigation will be about 25,000 gallons. This value may be overestimated as it is based on peak demand.

Table 4. Estimated Water Demand for the BMC Building, Blacksburg

Month	**Available Rainwater (gal) from Table 3**	**Monthly Indoor Use (gal)**	**Monthly Outdoor Use (gal)**
January	16,810	2,500	-
Feb	15,063	2,500	-
March	19,104	2,500	-
April	19,104	2,500	3,000
May	21,897	2,500	3,000
June	16,909	2,500	3,000
July	20,800	2,500	3,000
August	18,356	2,500	3,000
September	16,909	2,500	3,000
October	15,912	2,500	3,000
November	14,764	2,500	-
December	14,315	2,500	-
Av. Monthly	17,500	2,500	
Total Annual	210,000 (gal/year)	30,000 (gal/year)	21,000 (gal/year)

Note: 1 gallon = 0.1337 cubic-ft

The following observations can be made from Table 4. In a normal year, the BMC rooftop can yield nearly 210,000 gallons of water (about 2,800 cubic-ft). The annual irrigation water demand for landscaping is 21,000 gallons/year that corresponds to 10% of total available rooftop water. Total water demand (indoor plus outdoor) use for the BMC building is about 51,000 gallons/year, or about 25% of total available water. This means that: 1) if the BMC building total water demand is met in a given year, the water volume to stormwater drainage will be at least reduced by 25% - will be higher if storage tanks are full all the time; and 2) since normally, potable water from public water supplies is used for flushing toilets and landscape irrigation, 51,000 gallons/year less water from public water supplies will be used for those purposes.

6.5 Estimating Storage Requirement

The goal of rainwater harvesting is to make the harvested water available for various uses. To meet that goal, some type of water storage is required. Rain barrels and storage tanks are two options investigated in this report.

6.5.1 Rain Barrel Storage for Rainwater Harvesting at BMC Building

The use of rain barrels for landscape irrigation is a common practice. Use of 3 rainwater barrels (each 55 gallon capacity) with a total capacity of 165 gallons has been planned for the BMC building. These barrels will receive water from three downspouts. Table 3 shows available rainwater and possible monthly and daily water use for landscape (1,000 sq-ft) irrigation of the BMC building.

Table 5. Water Use for Landscape Irrigation

Month	Available Rainwater (gal) from Table 3	Monthly Outdoor Use (gal)	Rain Barrel Storage Capacity (gal)
January	16,810	-	165
Feb	15,063	-	165
March	19,104	-	165
April	19,104	3,000	165
May	21,897	3,000	165
June	16,909	3,000	165
July	20,800	3,000	165
August	18,356	3,000	165
September	16,909	3,000	165
October	15,912	3,000	165
November	14,764	-	165
December	14,315	-	165
Av. Monthly	17,500		
Total Annual	210,000 (gal/year)	21,000 (gal/year)	

Note: 1 gallon = 0.1337 cubic-ft

The following observations can be made from Table 5. Based on average monthly available water (17,500 gallons), daily available water is about 580 gallons. Therefore, 165gallon/583gallon indicates that only about 28% of rainwater can be captured per average rain event (assuming empty barrels). A smaller percentage of available water will be captured during larger rain events. Also, using the monthly irrigation demand and barrel capacity (165gal/3000gal/month demand x 30 day/month) the average storage capacity of barrels is 1.65 days. Therefore, it can be concluded that during dry times (no rainfall events) the storage capacity of barrels will most probably be insufficient to provide adequate water for landscape irrigation at 1,000 square-ft BMC site.

6.5.2 Storage Tank Design for Rainwater Harvesting at BMC Building

For the BMC building, the current architect plan includes provision for only rain barrels where the rainwater will be used solely for landscape irrigation. The storage tank capacity design provided here is for comparative purposes and/or in case the Town of Blacksburg decides to implement indoor use of water. The most effective storage tank size for a building is usually determined by water consumption. According to the Virginia Rainwater Harvesting Manual (www.cabellbrandcenter.org/), an area which receives 40 inches of rain per year with a roof area of 4,000 square feet or more need a water holding capacity of 10,000 gallon to capture sufficient rainfall for indoor use. On this particular site, for cost saving purposes, installation of two 2500 gallon tanks (total storage capacity 5,000 gallons) is proposed. Table 6 shows estimated water use and tank capacity for the BMC building. Cost estimate provided by Rainwater Management Solutions is provided in Appendix C.

Table 6. Water Use for Indoor Use and Tank Storage Capacity

Month	Available Rainwater (gal) from Table 3	Monthly Indoor Use (gal)	Storage Tank Capacity (gal)
January	16,810	2,500	5,000
Feb	15,063	2,500	5,000
March	19,104	2,500	5,000
April	19,104	2,500	5,000
May	21,897	2,500	5,000
June	16,909	2,500	5,000
July	20,800	2,500	5,000
August	18,356	2,500	5,000
September	16,909	2,500	5,000
October	15,912	2,500	5,000
November	14,764	2,500	5,000
December	14,315	2,500	5,000
Av. Monthly	17,500	2,500	
Total Annual	210,000 (gal/year)	30,000 (gal/year)	

Note: 1 gallon = 0.1337 cubic-ft

The following observations can be made from Table 6. Based on average monthly available water (17,500 gallons), daily available water is about 580 gallons. The tank storage capacity is adequate to capture the rainwater from average rain event (assuming empty tanks). Also, using the monthly indoor water demand and tank capacity (5,000gal/2,500gal/month demand x 30 day/month) the average storage capacity of two storage tanks is 60 days. Therefore, it can be concluded that the storage capacity of tanks can be sufficient to provide adequate water for indoor use at BMC building. If irrigation demand is included, during summer month the total water demand would be 5,500 gallons. Therefore, available water storage when tank is full would be 5,000 gallon (tank capacity)/5,500 gallon/month = 0.91 x 30 days/month = 27.2 days. Inclusion of rainwater barrels (165 gallon capacity) will only slightly increase available storage capacity.

6.6 Disposal of Excess Rainwater

Usually, rooftop rainwater is directed to gutter and connected to stormwater drainage. In the absence of rainfall harvesting system the whole 210,000 gallons (100%) will flow into the storwater drainage system annualy. Outdoor and indoor use of rainwater will reduce the water volume to stormwater drainage system. Table 7 shows if both barrels and storage tanks are used the maximum contribution to stormwater drainage system will 96,603 gallons or 46%. The reduction will be 25% if only barrels are installed (assuming barrels are maintained as full all the time).

Table 7. Summary of Water Use and Excess Rooftop Water for Disposal

Month	Available Rainwater (gal) from Table 3	Monthly Outdoor Use (gal)	Monthly Indoor Use (gal)	Rain Barrel Storage Capacity (gal)	Storage Tank Capacity (gal)	Excess Rooftop Rainwater (gal)
January	16,810	-	2,500	165	5,000	8,515
Feb	15,063	-	2,500	165	5,000	7,398
March	19,104	-	2,500	165	5,000	11,439
April	19,104	3,000	2,500	165	5,000	8,439
May	21,897	3,000	2,500	165	5,000	11,232
June	16,909	3,000	2,500	165	5,000	6,244
July	20,800	3,000	2,500	165	5,000	10,135
August	18,356	3,000	2,500	165	5,000	7,961
September	16,909	3,000	2,500	165	5,000	6,244
October	15,912	3,000	2,500	165	5,000	5,247
November	14,764	-	2,500	165	5,000	7,099
December	14,315	-	2,500	165	5,000	6,650
Av. Monthly	17,500		2,500			
Total Annual	210,000 (gal/year)	21,000 (gal/year)	30,000 (gal/year)			96,603 (46%)

Note: 1 gallon = 0.1337 cubic-ft

Table 7 shows that under the best circumstances, at least 46% of the rooftop water be disposed of. Directing the excess water to bio-retention cells or infiltration trenches is the best option for reducing the water volume contribution to stormwater drainage system. However, as Table 8 shows 3 bio-retention cells designed for the BMC building have limited capacity that can handle only runoff from certain impervious areas that does not include the rooftop surface area.

Table 8. Bio-Retention Cells for BMC Building (Source: SPECTRUM DESIGN, P.C.)

BMC Bio-Retention Cells	Actual Area (Sq-ft)	Required Area (Sq-ft)
Bio-Cell 1	410	320
Bio-Cell 2	202	146
Bio-Cell 3	165	224
Total Area	777 Sq-ft	690 Sq-ft

The difference between Actual (available) area (777 sq-ft) and Required (Design) Area (690 Sq-ft) is 87 Sq-ft. This is the only available capacity to accept rooftop rainwater. Rooftop area is 10,000 Sq-ft (0.23 acres). Required bio-cell area (using 90% rule) for this is 0.23 x 0.05 x 43560 = 501 Sq-ft. Therefore, only a fraction of the excess water from rain barrels can be directed to existing bio-cells. Design information about infiltration trend is not available as yet. It’s possible that a significant portion of the unused rooftop runoff can be absorbed by the onsite infiltration trenches.

6.7 Water Quality Effects of Rainwater Harvesting on Stormwater Drainage

A final objective of this study is to estimate reduction in pollutant load to stormwater drainage attributed to rainwater harvesting. In general, nitrogen and phosphorus are pollutants of interest. To do this estimate, information on pollutant concentration in rainwater is needed. National Atmospheric Deposition Program (NADP) website: http://nadp.sws.uiuc.edu/sites/sitemap.asp?state=va was consulted to retrieve nutrients data. The NADP database provides precipitation-weighted mean concentrations for nitrate nitrogen only (phosphorus concentration is not available). Horton’s Station (VA13) in Giles County is the nearest NADP station near Blacksburg, Virginia. Average annual nitrate concentration in rainwater calculated from year 2006 monthly means measured at station VA13 is 0.942 mg/L (max 1.794 mg/L in March, min 0.380 mg/L in November). It is estimated that nitrate nitrogen in available rainwater (210,000 gallons) from BMC building rooftop (Table 3) is 1642 lb/year. Rainwater use (21,000 gallons) for outdoor landscaping will result in reducing 164.2 lb/year nitrate (10%) reduction to stormwater drainage. Rainwater use for indoor toilet flushing (30,000 gallons/yr) will result in 234.56 lb/year or 14% nitrate reduction to stormwater drainage. If both indoor and outdoor uses of available rainwater are implemented, total nitrate reduction to stormwater drainage will be about 25%. Nitrate load to stormwater drainage will be further reduced if portions of rooftop runoff are directed to bio-retention cells. It should be noted that, in these calculations, it is assumed that nitrate load source is solely from rainwater and the amount of nitrate on the rooftop from other possible sources such animal droppings is insignificant.

Literature review related to water quality effects of rainwater harvesting presented in Section 4.2 of this report show the importance of rooftop material on water quality of rooftop runoff. Characteristics of rooftop material are rather different from other paved surfaces and therefore the resulting runoff water quality and its effects on storm drainage systems will be different than other paved areas. Depending on roof material, concentration of some metals in rooftop runoff and consequently in stormwater drainage can be increased. Estimating metal loading from rooftop rainwater requires further research and a discussion is beyond the scope of this project.

7. Conclusions

A major advantage of a rainwater harvesting system is possible reduced water volume to stormwater drainage system. However, this can be achieved only by planning increased indoor and outdoor uses of water. For the case study site, Blacksburg Motor Company building, the planned outdoor use for landscape irrigation (rain barrels) will reduce the rainwater volume to stormwater drainage by about 10%. If indoor use (e.g. toilet flushing) is implemented (not planned at this time), the rainwater volume to stormwater drainage will be reduced an additional 25%. It was also estimated that nitrate load reduction to stormwater drainage system will be about 25%.

The reduction of water volume to the stormwater drainage system is an expected advantage to using a rainwater harvesting system. For the case-study site, Blacksburg Motor Company (BMC) building, the planned outdoor use for landscape irrigation (rain barrels) will reduce the rainwater volume and nitrate-nitrgen load to the stormwater-drainage system by about 10%. If indoor use (e.g. toilet flushing) were also implemented (not planned at this time), the rainwater volume and nitrate load to the stormwater-drainage system would be reduced by 25%, A second advantage of using rainwater harvesting systems is the reduction in the use of potable water for non-potable-water needs. At the BMC case-study site, if indoor and outdoor uses of rainwater are implemented, about 51,000 gallons of potable water could be saved each year.

At first glance, the stormwater runoff reductions and potable water savings from rainwater harvesting appear insignificant. If rainwater harvesting is implemented at the watershed scale (for example, assume 100 buildings in the watershed), the reduction in stormwater volume and savings of potable water would be significant. Rainwater substituted for potable water would also reduce energy requirements because less potable water would need to be treated and transported. Further research is needed to evaluate the energy efficiency of rainwater harvesting systems.

It is recommended that for best results and effectiveness, rainwater harvesting systems be designed in conjunction with other low impact design BMPs such as bio-retention cells and infiltration trenches so drainage of rooftop water to stormwater can be minimized.

Water quality information related to rainwater harvesting in Virginia is lacking. More information is needed on rainwater quality and rooftop runoff quality. This information will improve our understanding of the impact of rainwater harvesting on stormwater drainage water quality and consequently impact on receiving waters.

8. References Cited

Amirtharajah, A., and C. Jones. 1995. Drinking Water Treatment. The Engineering Handbook, CRC Press Handbook and IEEE Press, 1995.

Chang, M. M. W. McBroom and R. S. Beasley. 2004. Roofing as a source of nonpoint water pollution. *Journal of Environmental Management* 73 (2004) 307-315.

Coombes, P. J., G. K. Jetse, D. Kalma and J. R. Argue. An evaluation of the benefits of source control measure at the regional scale. *Urban Water* 4 (2002) 307-320.

Crasta, F. M., C. A. Fasso, F. Patta, and G. Putzu. 1982. Carthaginian-roman cistern in Sardinia. Proceedings of the International Conference on Rain Water Cistern Systems, Honolulu, Hawaii, June 1982.

Crowley, B. J. 2005. Neighborhood level analysis of rainwater catchment in Portland, OR. Master of Science in Geography, Portland State University.

Davis, A. P., M. Shokouhian, and S. Ni. 2001. Loading estimates of lead, copper, cadmium, and zinc in urban runoff from specific sources. Chemosphere 44: 997-1009.

Evans, C.A, P.J. Coombes, R.H. Dunstan. 2006. Wind, rain and bacteria: The effect of weather on the microbial composition of roof-harvested rainwater. *Water Research* 40: 37-40.

Good, J. C. 1993. Roof Runoff as a diffuse source of metals and aquatic toxicity in stormwater. *Water and Science Technology*, vol. 28, no. 3-5: 317-322.

Gumbs, A. F. and F. E. Dierberg 1985. Heavy metals in the drinking water from cisterns supplying single-family dwelling. *Water International*, vol. 10: 22-28.

Herrmann, T. and K. Hasse. 1997. Ways to get water: rainwater utilization or long distance water supply, Water Science Technology 36 (8 - 9), Pergamon, New York, pp. 313 - 318.

Herrmann, Thilo, Uwe Shmida. 1999. Rainwater utilization in Germany: efficiency, dimensioning, hydraulic and environmental aspects. *Urban Water* 1: 307-316.

Hicks, B. 2008. A cost-benefit analysis of rainwater harvesting at commercial facilities in Arlington County, Virginia. Master of Environmental Management Degree in Environmental and Earth Sciences, Duke University. 49 pp. http://dukespace.lib.duke.edu/dspace/bitstream/10161/512/1/MP_wdh11_a_200805.pdf

Lye, D. J. 1987. Bacterial levels in cistern water systems of northern Kentucky. *Water Resources Bulletin*, vol. 23: 1063-68.

Lye, D. J. 1992. Microbiology of rainwater cistern systems: A Review," *Journal of Environmental Science and Health*, A27(28): 2123-2166.

Michaelides, G. and R. J. Young. 1983. Rainwater harvesting for domestic use in rural areas. *Ekistics*, vol. 303, pages 473-476.

Quek, U. and J. Forster 1993. Trace metals in roof run-off, water. Air and Soil Pollution, vol.68, no. 3-4: 373-389.

Simmons, G., S. Jury, C. Thornley, D. Harte, J. Mohiuddin and M. Taylor. 2007. A Legionnaires' disease outbreak: A water blaster and roof-collected rainwater systems. Water Research.

Thomas, P. R. and G. R. Greene. 1993. Rainwater quality from different roof catchments. *Water and Science Technology*, vol. 28, no. 3-5: 291-299.

TWDB. 2005. Texas Water Development Board. *The Texas Manual on Rainwater Harvesting."* 3rd Edition. Austin, Texas. http://www.twdb.state.tx.us/publications/reports/RainwaterHarvestingManual_3rdedition.pdf.

Young, E.S. and W.E. Sharpe. 1984. Atmospheric deposition and roof-catchment Cistern water quality," *Journal of Environmental Quality*, vol. 13: 38-43.

Yaziz, M. I., H. Gunting, N. Sapari and A. W. Ghazali. 1989. Variations in rainwater quality from roof catchments," *Water Research* 23: 761-765.

Younos, T., R. Bohdan, E. Anderson, K. Ramsey, N. Cook, B.B. Ross and T. Dillaha. 1998. Evaluation of rooftop rainfall collection-cistern storage systems in southwest Virginia. VWRRC Special Publication SP3-1998. Virginia Water Resources Research Center, Virginia Tech, Blacksburg, VA. 41 pp. http://www.vwrrc.vt.edu/special_reports.html#1998.

Appendix A.

Additional Reading and Online Sources

Cullis, A. and A. Pacey. 1986. Rainwater Harvesting, The Collection of Rainfall and Runoff in Rural Areas, Intermediated Technology Publications, Londond, UK.

Schiller, E.J. 1982. Rooftop Rainwater Catchment systems for Drinking Water Supply, Water Supply and Sanitation in Developing Countries, Edited by E.J. Scheiller and R. L. Droste, Ann Arbor Science Publishes, Ann Arbor, Michigan.

Kindade-Levario, H. 2007. Design of Water, Gabriola Island, British Columbia, Canada. New Society Publishres.

The Sustainable Sites Initiative, http://www.sustainablesites.org/
Standard & Guidelines: Preliminary Report. November 1, 2007

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

Stormwater Solutions Handbook. Environmental Services, City of Portland.
http://www.portlandonline.com/shared/cfm/image.cfm?id=129056

Buildinggreen.com, collection of residential, industrial, and municipal case studies.
http://www.buildinggreen.com/

Domestic Roofwater Harvesting Programme,
http://www.eng.warwick.ac.uk/dtu/rwh/links.html

GARNET, Global Applied Research Network, roof water harvesting,
http://info.lut.ac.uk/departments/cv/wedc/garnet/tncrain.html

International Rainwater Harvesting Alliance, http://www.irha-h2o.org/

Sourcebook for Green and Sustainable Building,
http://www.greenbuilder.com/sourcebook/Rainwater.html

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

United Nations Rainwater Harvesting in Developing and Transitional Countries, Latin America and the Caribbean,
http://www.unep.or.jp/ietc/Publications/TechPublications/TechPub-8c/index.asp

Appendix B. Detailed Site Plan for the Blacksburg Motor Company Building

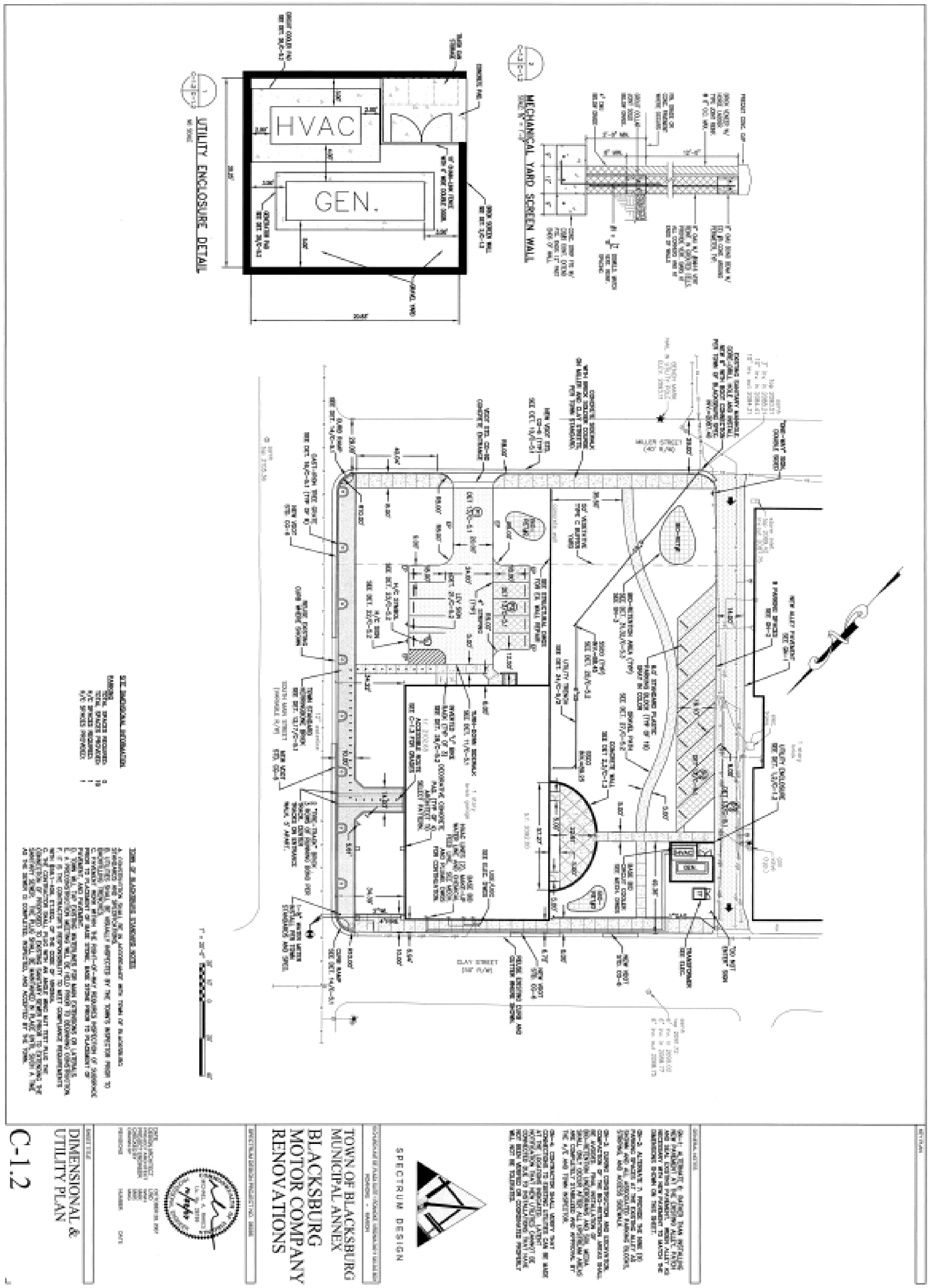

Table of Contents

RAINWATER MANAGEMENT SOLUTIONS
1260 West Riverside Drive
Salem, VA 24153
540-375-6750

Estimate

Date	Estimate #
1/21/2008	FL1008-106

Name / Address
Town Of Blacksburg

Project

Description	Qty	Rate	Total
2500 gallon below ground tank	2	2,800.00	5,600.00
Vortex 150 filter w Extension tube (5500sq ft. roof)	2	948.05	1,896.10
Multisiphon with drain back flow prevention and small animal protection	1	417.00	417.00
Goulds 1 hp cistern pump with 7' 2" suction hose, SZ 99991 2" floating filter, coarse	1	995.00	995.00
tank 4"gasket	4	14.00	56.00
Bulkhead fitting 2"	4	12.00	48.00
Man hole Extension	2	58.27	116.54T
Alliance/ 20 micron String wound, 20" big blue	1	35.00	35.00
Upstream 30 gpm, 75%, UV light 1.5" inlet/outlet	1	2,300.00	2,300.00
Alliance/ 20 micron String wound, 20" big blue	1	35.00	35.00
Bracket for big blue housing	1	30.99	30.99
20" big blue housing 1" fitting	2	96.00	192.00
Bracket for big blue housing	2	30.99	61.98
1 hp 230V Booster Pump	1	560.00	560.00
Goulds 1hp cistern pump 230 volt	1	555.00	555.00
Smoothing Inlet	2	168.00	336.00
Shipping fees out	1	2,800.00	2,800.00
fittings	1	400.00	400.00
Managing the Installation of Rainwater Systems	1	16,000.00	16,000.00

Subtotal	$32,434.61
Sales Tax	$5.83
Total	$32,440.44