A Cost-Benefit Analysis of Rainwater Harvesting at Commercial Facilities in Arlington County, Virginia

by

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Masters project submitted in partial fulfillment of the
requirements for the Master of Environmental Management degree in
the Nicholas School of the Environment and Earth Sciences
Duke University

2008

Acknowledgements

I would like to express my sincere gratitude to the following individuals: my advisor, Dr. Randall Kramer, Nicholas School of the Environment and Earth Sciences, Duke University, for his steady guidance from beginning to end of this project; Joan Kelsch, Environmental Planner, Arlington County, Virginia, who helped to formulate an interesting project; Jameson Terry, LEED AP, with Page Southerland Page and Elizabeth Floyd, AIA, LEED AP with Sustainable Design Consultants, LLC who provided case study information; and most importantly my wife Alicia Sutherland and our daughter, Zoe, who supported and encouraged me throughout this endeavor.

Abstract

Rainwater harvesting has provided a water source for communities around the world dating back to circa 1500 B.C. This ancient technology continues to serve populations today, mainly in poor, rural or dry regions of the world and island communities. Contemporary green building and stormwater management programs (e.g., Leadership in Energy and Environmental Design – LEED, Low Impact Development – LID, Better Site Design) suggest that rainwater harvesting can serve as a valuable stormwater management tool even in areas where municipal water supplies are readily available. Regardless, private developers are most apt to incorporate these systems into commercial development designs if the benefits justify the costs.

Analyses of local rainfall data and predicted potential water usage at commercial facilities in Arlington County, Virginia reveal that rainwater harvesting systems conserve potable water, protect surface water quality and minimize flood risk. However, economic analyses from the perspective of a private developer using two case studies of commercial developments in Arlington suggest that the benefits of incorporating rainwater harvesting into building designs do not justify the cost of implementing this technique. Notwithstanding, results from a sensitivity analysis indicate that charging tenants a modest price premium of one percent or less for the privilege of occupying a "green" building yields a positive return to investing in rainwater harvesting.

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Introduction

In recent years Arlington County, Virginia has strived to become a "greener", more environmentally sensitive community. Evidence of this effort appears prominently in the County through green building programs for commercial facilities as well as stormwater management programs driven by regional and federal mandates, which include: the five-state Chesapeake Bay Program; the US Environmental Protection Agency's (USEPA) National Pollution Discharge Elimination System permit program for Municipal Separate Storm Sewer Systems (MS4); and the Federal Emergency Management Agency (FEMA) flood protection requirements. While these programs vary in focus they overlap with respect to the County's stormwater management requirements for new and redeveloping building sites. Beyond these federal and regional programs, currently evolving state-level policies designed to encourage the use of "Low Impact Development (LID)" or "Better Site Design" will further promote Arlington's environmental sustainability stance in the area of stormwater management.

Arlington has pursued policies fostering suitable land development practices and building design techniques that can address the County's array of water management obligations. To that end, the County government seeks to understand the value of harvesting rainwater for non-potable, on-site building use in commercial-type facilities with the goals of: (1) conserving potable water; (2) protecting the quality of surface waters; and (3) reducing the risk of flooding in the County (personal communication with Joan Kelsch, Environmental Planner, Arlington County).

Rainwater harvesting has existed as a water supply source technique since circa 1500 B.C. (Hunt, 2006). The most basic systems require only a catchment area (typically a rooftop), a conveyance system (e.g., gutters, downspouts, plumbing) and a holding tank (e.g., rain barrel, cistern). These systems grow in complexity in order to address the quality of water captured (i.e., treatment) and the ease of its use (e.g. pumping for indoor toilet use) (LaBranche, 2007).

Captured rainwater can supply or augment both potable and non-potable uses. While captured rainwater is naturally "soft" (NVRC, 2007) it often does not meet drinking water standards (Meera, 2006). In order to serve as a potable water source some level of treatment (e.g., filtering, chlorination) must be incorporated, thus increasing the system's complexity. In lieu of treating rainwater to potable water standards, the use of untreated rainwater for non-potable uses that would otherwise be supplied by potable water ultimately conserves municipally supplied potable water (Persyn, 2004). Non-potable uses may include: toilet flushing, building or car washing, air conditioner coolant, fire suppression, industrial processes and landscape irrigation (NVRC, 2007; LaBranche, 2007). Fairfax County, Virginia, which neighbors Arlington County, claims that as much as 40% of domestic water usage during the growing season can be attributed to landscape irrigation (Fairfax County, 2005)

While rainwater harvesting systems are considered innovative building practices in Northern Virginia, several other highly developed locales routinely incorporate rainwater harvesting systems as part of normal building practice. For example, Texas and Arizona promote rainwater harvesting programs for residential use to lessen the burden on municipal potable water supplies (Texas Water Development Board, 2005; Sprouse, 2005). The island of Bermuda requires that all buildings include rainwater collection systems that harvest rainwater from a minimum four-fifths of the building roof area, and provide storage capacity equaling or exceeding 100 gallons per 10 square feet of catchment area (United Nations Environment Programme, 2007, Bermuda Public Health Regulations 1951). Similarly, on the island of St. Thomas in the US Virgin Islands, mandatory requirements ensure that every residential home collects and stores water from 112 square meter (~1200 square feet) catchments into 45 cubic meter (nearly 1200 gallon) holding tanks (Global Development Research Center website, April 12, 2008).

More locally, a 1998 Virginia Tech study evaluated the effectiveness of rainwater harvesting systems in use as the primary residential water source in the coal production region of southwestern Virginia (Younos 1998). Numerous examples such as these build the current body of research extolling the potable water supply benefits in water scarce areas and in the developing world where dispersed water supply remains the most viable water supply measure (Longland, 1983).

Green building programs such as Leadership in Energy and Environmental Design (LEED™) and sustainable development programs such as LID have gained significant momentum in recent years. Both LEED and LID aim to protect streams and water bodies from the degradation caused by unmitigated stormwater runoff. As these programs have become more mainstream, governmental agencies and advocacy groups increasingly have espoused rainwater harvesting as a key component of stormwater management for new developments and major renovations (Prince Georges County, Maryland, 1999; US Green Building Council, 2006; NC Cooperative Extension, 2006; City of Portland, 2008; Puget Sound Action Team, 2008; Nine Mile Run Watershed Association, 2008).

The goal of the present study is to assess the value of rainwater harvesting systems in regions with reliable municipal water supplies for use within commercial developments to supply or augment potable water used in toilet flushing and landscape irrigation.

Stormwater Background

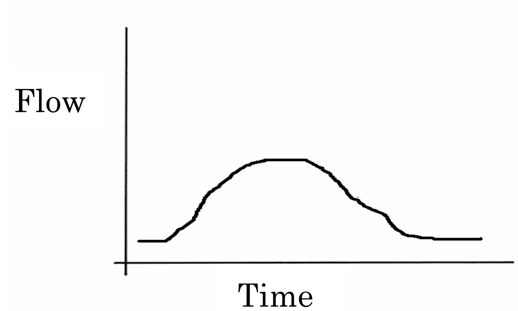
For centuries individual residences and communities have incorporated rainwater harvesting techniques to fulfill water needs; however, as an urban stormwater management tool rainwater harvesting represents an innovation in the field of stormwater management. To better understand the application of rainwater harvesting to stormwater management it is important to first examine the basic principals of stormwater management. Stormwater management covers three broad areas of focus:

- Quantity control (flooding)
- Quality control
- Stream channel protection

  (New York State Department of Environmental Conservation, 2008; Atlanta Regional Commission, 2001)

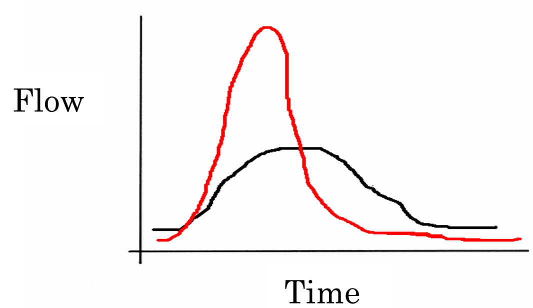
In order to understand water flow resulting from a rain event, engineers and scientists use hydrographs to visually depict the amount and timing of water passing from a watershed or drainage basin. Specifically, flows are plotted against time on a two dimensional graph. The plotted curve represents the wave of water resulting from a rain event that will pass through the bottom-most point of a particular drainage area (Dunne, 1978). Consider an undeveloped plot of land with wooded groundcover and permeable soils. A typical hydrograph describing the runoff from this undeveloped parcel might look like the following:

Figure 1. Hydrograph of a Pristine Watershed



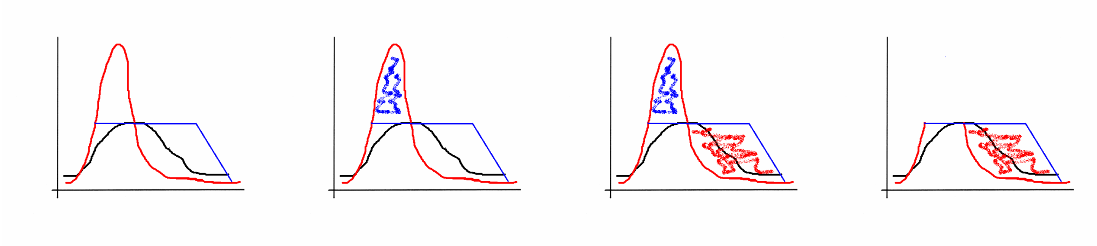
Once the site is developed the percentage of impervious groundcover increases due to the addition of roads, parking areas, rooftops, etc. This leaves less opportunity for the rainwater to infiltrate into the ground or to follow slow and winding flow paths to the edge of the site. Consequently, as depicted in Figure 2, the hydrograph evolves to a new shape, which has a higher peak, increased overall volume, and lower troughs from which stream base flow is measured (Linsley, 1994).

Figure 2. Hydrograph Comparison: Undeveloped vs. Developed Watershed



The above scenario often results in downstream flooding (NVRC, 2007). Rather than allow this to occur, engineers developed a "peak shaving" technique through onsite detention whereby the peak discharge (or peak flow) after development does not exceed the predevelopment peak flow (VADCR, 1999). Most suburban areas utilize stormwater management ponds for this purpose. In Arlington County, where the cost of land is high, most of this detention is achieved through extensive underground vaults. The following hydrographs illustrate this technique:

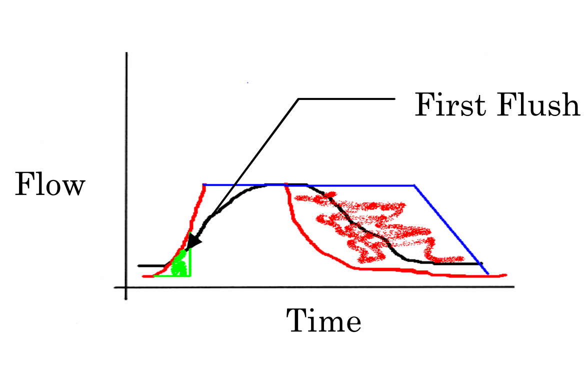
Figure 3. Detention Technique



Despite the proven success of peak shaving in protecting properties from flooding, this technique has not protected stream channels. Stream channels are shaped by the peak flows that they carry. Channel material and vegetation cover can successfully shield a stream channel from short peak flows; however, the longer duration peaks resulting from extended onsite detention have degraded many urbanized stream channels (Brown, 2001).

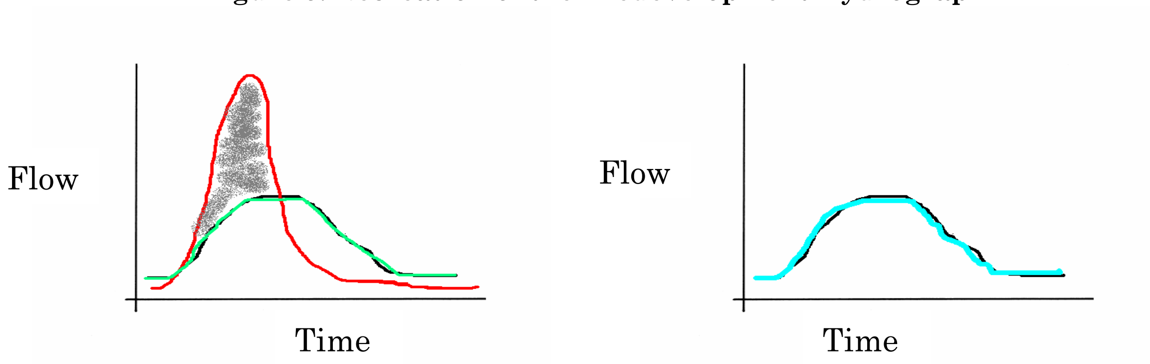
Additionally, since the 1980s, programs such as the five state Chesapeake Bay Program have paid close attention to the quality of water leaving development sites. Consequently, engineers have incorporated stormwater treatment facilities or Best Management Practices (BMPs) into project designs to filter runoff waters. These facilities focus on the first portion of runoff (i.e., the first one-half inch of runoff) since most pollutants wash away during the first flush of a storm event (VADCR, 1999). The following hydrograph depicts this portion of the storm.

Figure 4. Water Quality Component of the Hydrograph



Recent trends have suggested that the most appropriate method to achieve all three facets of stormwater management – quantity control, quality control and stream channel protection – is to recreate the predevelopment hydrograph by mimicking the rate, volume and duration of runoff occurring from the site prior to development (Prince Georges County, Maryland, 1999).

Figure 5. Recreation of the Predevelopment Hydrograph



While this concept seems intuitive, the implementation can be difficult to achieve. Recreating the predevelopment hydrograph can be approached more readily when developing greenfield sites in which ample space exists for mimicking long hydraulic flow paths and infiltrating water. This is rarely the case in an urbanized setting where land values prohibit extensive stormwater management use. Specifically, in Arlington County high groundwater tables and poor soils often preclude infiltration practices. Nonetheless, infill development and redevelopment in the urban core offer other significant environmental benefits over greenfield development including minimizing transportation infrastructure and urban sprawl.

Therefore, rainwater harvesting systems offer a promising tool for stormwater management in the urban setting. Collecting and storing rain during a storm event mitigates runoff volumes and peaks. Using the water for landscaping and toilet flushing then ensures that water quality concerns are addressed.

Objectives

This project aims to explore the economic benefit of rainwater harvesting to commercial project developers for two purposes: (1) to conserve on-site potable water use; and (2) to meet local stormwater management requirements to protect surface water quality and minimize flooding within Arlington County, Virginia.

Currently, the County has not adopted a standard approach to facilitate rainwater harvesting designs. Thus for this project, available resources combined with standard engineering techniques provide the preliminary designs for cost analysis. The designs used in this analysis consider the ultimate use of harvested water (e.g., toilet filling, landscape irrigation) as well as the volume of water necessary to positively impact surface water quality and flood risk.

Methods

The aforementioned objectives were accomplished through three stages. First, the general potential of rainwater harvesting in Arlington County was analyzed. This task examined the hydrologic potential of the region and predicted water demand based on maximum occupancy allowed under the building code. Second, preliminary engineering designs were developed for two case studies. Third, costs associated with each case study design were compiled and included in an economic analysis based on net present values.

Analysis of Rainwater Harvesting Potential

Because rainwater harvesting on commercial buildings in Arlington County represents an innovative design technique, the County has not adopted a standard approach to facilitate designers in incorporating such systems into project designs. Thus, in preparation for developing hypothetical designs, it was first necessary to establish an approach to size rainwater harvesting systems that could be repeated for both case studies. The County would then have the opportunity to adopt this methodology as a standardized approach to sizing rainwater harvesting systems. The selected sizing approach needed to address the three objectives for rainwater harvesting:

1. Conserve potable water;
2. Protect the quality of its surface waters; and
3. Reduce the risk of flooding.

The first objective, conserving potable water, follows the traditional use for rainwater harvesting and is met by on balancing water demand with supply. The final two objectives, protecting water quality and flood reduction, represent an innovative use for rainwater harvesting – that of stormwater management. In other words, the first objective, conservation of water, is achieved simply by utilizing harvested waters for uses that would otherwise be supplied by potable water. The second and third objectives are realized only if the collection and storage components are large enough to capture that part of the storm that would otherwise be treated by stormwater treatment and detention devices. By effectively meeting stormwater management obligations through an appropriately sized rainwater harvesting system, a developer realizes a financial benefit equal to the costs of constructing other facilities to meet local stormwater management requirements for water quality and flood control.

Rainwater Harvesting to Conserve Water

As a first step in developing a sizing approach appropriate for rainwater harvesting systems, the following water balance equation was considered on a monthly basis (Kinkade-Levario, 2007):

$$Supply \geq Demand$$

Where: *Supply is limited to the <u>rainwater potential</u> as defined by the rainwater depth measured across the catchment minus initial abstractions (10%); and*

Demand is the total of project uses summed over each month (e.g., toilet flushes, landscape irrigation)

To develop the supply-side of the equation, hourly rainfall data recorded at Ronald Reagan Washington National Airport (DCA) were used to develop monthly averages. The National Weather Service maintains records dating back to 1947. These hourly records were tallied to create monthly totals and averaged for each month over the period of record. Available rainwater harvesting literature and standard engineering hydrology texts suggest that the first 10% of rainwater is lost to initial abstractions (e.g., surface wetting, evaporation, transpiration) (Kinkade-Levario, 2007). Thus, study designs assumed that only 90% of rainfall could be collected. Although each month produced a unique monthly average, the array of monthly averages remained the same for all designs. Thus, supply-side quantities for each case study and the generic model differed as a function of the size of the catchment area.

The demand side of the equation was developed specifically for each project based on water demands for toilet flushing and landscape needs. Toilet fixture counts and water demand were calculated based on building code requirements. Given a lack of published information, an assumption of five toilet flushes per person per work day was assumed for this analysis. Landscape irrigation requirements were based on 1.5 inches per week minus available rainfall (personal communication with Kevin Fisher, Landscape Architect with Rhodeside & Harwell, Inc. 15-Feb-2008).

Generic Hydrologic Rainwater Harvesting Model for Arlington County

Before developing case study designs, a generic hydrological rainwater harvesting model was created based on the water balance concept. This model applies specifically to rainwater harvesting at commercial facilities in Arlington County as it accounts for county-wide rainfall conditions. This model compared estimated rainwater potential with predicted water usage for a hypothetical business development. Fitted lines modeled data that varied the building size from 1000 to 200,000 square feet in 1000 square foot increments. These estimates considered architecturally uniform buildings (e.g., box form) with roof areas equal to the floor area of a single story. The same calculations were made for buildings with multiple stories (two though six). In order to complete the water balance equations, the water demands were estimated for each building size based International Building Code maximum occupancy requirements for office spaces (e.g., 100 sq. ft. gross per occupant) and five toilet flushes per person per day. Fitted lines depicting water surplus (or deficit) versus building area were developed for each building type (i.e., single story through six stories) and graphed to show whether supply water outpaces or under paces rainwater supply.

Case Study Selection

Discussions with Arlington County environmental planning staff yielded a plan to analyze the value of incorporating rainwater harvesting systems on "typical" urban commercial developments. When considering the benefits of creating a hypothetical typical development versus a real case study, Arlington County staff expressed a preference for analyzing real case studies in order to convey the value of rainwater harvesting systems to private developers and policy makers alike.

To that end, Arlington County staff provided two commercial developments recently constructed within the County by private entities: 1812 North Moore Street (Moore Street) and the Navy League Building. Neither development included rainwater harvesting in building designs even though both building design approaches incorporated various aspects of the County's green building program. The responsible architectural firms for both development projects provided details for the facilities including building mass, footprint and gross floor area.

Case Study 1: Moore Street

The Moore Street development is a 34 story (plus two below grade garage levels) high rise office building in Arlington, Virginia. The total gross floor area of commercial space in the building equals 601,790 square feet. Aside from the street level mixed use commercial space, the first ten levels above ground are dedicated solely to structural parking. Levels 11 through 34 are dedicated to commercial office space. The 33rd floor area equals 23,387 square feet; this area instead of the 34th

penthouse floor was assumed to be the same as the roof area available for collecting rainwater, since the penthouse floor had a smaller roof area that could be drained to the 33rd floor roof area and captured. The building footprint covers the entire parcel except the street entrance to the garage and broad sidewalk areas spanning from the building to the roadway curb line. Thirteen tree boxes represent the only onsite landscaping requiring irrigation.

Case Study 2: Navy League Building

The Navy League development is located at 2300 Wilson Boulevard in Arlington, Virginia. This seven story (plus 4 below grade garage levels) office building also contains mixed use commercial space at the street level. The total gross floor area of commercial space in the building equals 212,947 square feet. The building is constructed with terraces on four of the above ground levels. Only the actual roof area was assumed useful for the purpose of rainwater catchment. Similar to Moore Street, the Navy League building footprint covers the entire parcel except the street entrance to the garage, broad sidewalk areas and sixteen total tree boxes.

Table 1 summarizes relevant building and site characteristics of the two developments selected as case studies.

Table 1. Case Study Details

Case Study	Moore St.	Navy League Bldg.
Stories	34 above ground (1-10 include garage space)	7 above ground
Gross Floor Area (GFA) (square feet)	601,790 sq. ft.	212,947 sq. ft.
Site Area	0.71 acres	1.13 acres
Predevelopment Impervious Cover (%)	96.8%	29.0%
Post Development Impervious Cover (%)	100%	99.7%

Table 2 outlines major assumptions made with respect to each case study.

Table 2. Case Study Assumptions

Case Study	Moore St.	Navy League Bldg.
Occupancy (source: 2006 International Building Code)	1 / 100 sq. ft. GFA	1 / 100 sq. ft. GFA
Total Occupants	6011	2129
Water Closets (source: 2006 International Plumbing Code)	2 plus 1 for every 50 occupants over 50	2 plus 1 for every 50 occupants over 50
Toilet Demand (source: 2006 International Plumbing Code)	1.6 gallon / flush	1.6 gallon / flush
Flushes / Occupant (assumed by author)	5 / day	5 / day
Landscape Irrigation Demand (source: personal communication with Kevin Fisher, Rhodeside & Harwell, Inc., 15-Feb-2008)	1.5 inches / week	1.5 inches / week

Case-Specific Designs

For each case study, preliminary engineering designs were developed for the rainwater harvesting systems. These designs adhere to the water balance design approach. Rainwater potential (the supply-side of the equation) utilizes the monthly rainfall averages calculated from the data recorded at the weather station at DCA minus 10% for initial abstractions. Water demands for the case study focused solely on toilet flushing and landscape irrigation. Designs were based on general guidance found in Design for Water by Heather Kinkade-Levario (2007) and included the following system components: collection, first flush diversion (to protect captured water quality), storage, distribution (piping and pumping), and water supply augmentation for dry periods.

Several additional assumptions were made to develop the case study designs:

- The system was installed during the construction of the building.
- The roof material intended in the original building design was satisfactory for a rainwater harvesting system.
- Downspouts functioned without the need for any additional periodic flushing than would be required without a rainwater harvesting system.
- A separate plumbing distribution system was needed to convey water from the rainwater harvesting storage tanks to toilets within the building.
- Captured rainwater was stored onsite in an underground tank.
- Life of the system coincides with the life of the building (i.e., 25 years).

Quantify Project Specific Costs and Benefits

Rather than applying a broad social perspective to this analysis, this economic analysis is conducted from the accounting stance of the private developer. Such an approach allows the analyst, and subsequently the County, to understand either the motivation or disincentive of a developer to incorporate rainwater harvesting into project designs.

In preparing the economic analysis costs and benefits to the developer were collected within two months in late 2007 and early 2008. Consequently, no escalation of costs/benefits was applied to the data. The analysis included the following items:

- Costs: Capital costs of the rainwater harvesting systems
- Costs: Operation costs of the rainwater harvesting systems
- Benefit: Water savings equal to municipal potable water rate ($ 3.34 / gallon, www.arlingtonva.gov, 06-Mar-2008)
- Benefit: Surface water quality protection equal to developer obligation to the County's Watershed Management Fund.
- Benefit: Flood risk reduction equal to the cost of sizing an onsite detention system.

All future costs and benefits were converted to present values using a discount rate of 7.02%. This discount rate represents an average 10-year commercial mortgage rate for office buildings prepared by RealtyRates.com (RealtyRates.com, 2008). Other assumptions made with respect to costs included the following:

- The roof material intended in the original building design was satisfactory for a rainwater harvesting system. Therefore, no costs specifically associated with the roof material were incurred as a result of incorporating a rainwater harvesting system.
- Any change in roof drainage scuppers and downspout arrangement in order to accommodate the rainwater harvesting system resulted in negligible costs.
- Costs associated with irrigation of the tree boxes with rainwater were not appreciably different than the costs that would have occurred without the rainwater system.
- Costs (Benefits) associated with flood reduction were calculated by designing a stormwater detention system capable of meeting Arlington County's detention standard for Four Mile Run. The only applicable costs associated with this stormwater detention were related to the underground tank (i.e., no additional storm drainage infrastructure was necessary than would otherwise be constructed as a part of site development).
- Costs (Benefits) associated with protecting surface water quality from each of the case studies were calculated by assuming that no onsite stormwater quality treatment facility was provided; thus, the developer would pay a onetime fee to the County's Watershed Management Fund that would completely cover the development's stormwater quality management obligation.

The final two bullets represent benefits or savings to the developer. These benefits originate from the two stormwater management objectives to use of rainwater harvesting in the County. The calculation of these benefits is described in more detail below:

Protecting Surface Water Quality

Under Arlington County's Chesapeake Bay Preservation Requirements, the County has developed a methodology by which developers pay into a Watershed Management Fund administered by the County for all or part of a development site that does not drain to an onsite stormwater quality treatment facility. The County acknowledges that the $2.50 per impervious square foot of impact area used in calculating the total developer payment represents a discounted rate for water quality preservation when compared to providing onsite stormwater management. However, the County provides a twofold defense for this lower rate:

i.) "Because most of the County is built-out, more cost effective stormwater treatment and pollutant reductions can be achieved by the County through retrofits of existing developed areas, stream restoration projects, and other watershed management programs such as street sweeping and outreach and education;" and

ii.) "To acknowledge the water quality benefits in the Potomac River and Chesapeake Bay watersheds of infill development in urban core jurisdictions like Arlington (i.e., 'smart growth' rather than sprawl)…"

(Arlington County Chesapeake Bay Preservation Ordinance Guidance, 2005, pg 13)

Costs associated with protecting surface water quality from each of the case studies were derived by assuming the absence of an onsite stormwater quality treatment facility. As a result, the developer would pay a onetime fee to the County's Watershed Management Fund to cover the development's stormwater quality management obligation.

Reducing the Risk of Flooding

With respect to flood risk, two thirds of Arlington County drains to a highly regulated stream known as Four Mile Run. Developing properties within the Four Mile Run watershed must meet one of the nation's toughest standards for flood control; that is, a redeveloping site must detain the 100-year post development event and discharge that water at a rate of no more than that of the 10-year predevelopment discharge. Therefore, calculations for these events for each case study were developed and considered for inclusion in the rainwater harvesting system. Costs associated with flood risk were equated to the costs of constructing an underground stormwater detention vault sized appropriately to detain stormwater to meet this standard.

Tables 3 and 4 contain specific cost data used to compute costs and benefits associated with each case study.

Table 3. Detailed Cost Breakdown of Rainwater Harvesting Components

	unit	quantity	unit cost	total	source
First flush filters				**$ 120.00**	
First Flush Filter	each	1	$ 120.00	$ 120.00	Safe Rain www.saferain.com.au 06-Mar-2008
Underground Tank				**$24,122.50**	
10,000 gallon	each	1	$17,372.50	$17,372.50	Darco Inc. Underground Tankage www.darcoinc.com 06-Mar-2008
Excavation	cubic yard	2700	$ 2.50	$ 6,750.00	RS Means 2007 pg 528
Plumb Tank (e.g. overflow, potable water supply, actuated valves & tank level sensors)				**$ 2,541.60**	
Overflow - 2 inch ball valve	each	1	$ 107.00	$ 107.00	RS Means 2007 pg 417
Overflow Piping 2 inch PVC	L.F.	10	$ 19.50	$ 195.00	RS Means 2007 pg 423
Overflow - Cleanout Tee (2-inch)	each	1	$ 33.60	$ 33.60	RS Means 2007 pg 418
Potable Supply - Bronze ball valve (3/4 inch)	each	1	$ 330.00	$ 330.00	RS Means 2007 Pg 417
Potable Supply - 3/4 inch Copper Tubing	L.F.	100	$ 12.80	$ 1,280.00	RS Means 2007 Pg 420
Potable Supply - 3/4 inch Backflow Preventer	each	1	$ 287.00	$ 287.00	RS Means 2007 Pg 425
Potable Supply - 3/4 inch Actuated Valve	each	1	$ 309.00	$ 309.00	Grainger, Inc www.grainger.com 05-Mar-2008
Tank Pump				**$ 3,378.00**	
Pump (3/4 HP, 3 phase)	each	1	$ 533.00	$ 533.00	Grainger, Inc www.grainger.com 05-Mar-2008
Level Control	each	2	$ 83.00	$ 166.00	Grainger, Inc www.grainger.com 05-Mar-2008
Pump Panel	each	1	$ 1,734.00	$ 1,734.00	Grainger, Inc www.grainger.com 05-Mar-2008
Pump Installation for Pump (3 person crew)	crew/ hour	5	$ 189.00	$ 945.00	RS Means 2007 Pg 638

Table 4. Detailed Cost Breakdown of Rainwater Harvesting Components (Continued)

	unit	quantity	unit cost	total	source
Floating Intake				**$ 256.00**	
	each	1	$ 256.00	$ 256.00	Safe Rain www.saferain.com.au 06-Mar-2008
Distribution Piping - Installed				**$ 12.80**	
3/4 inch Copper Tubing	L.F.	1	$ 12.80	$ 12.80	RS Means 2007 Pg 420
Booster Pump				**$ 1,478.00**	
Dayton Centrifugal Pump (model 4TU40)	each	1	$ 533.00	$ 533.00	Grainger, Inc www.grainger.com 05-Mar-2008
Pump Installation for Pump (3 person crew)	crew/ hour	5	$ 189.00	$ 945.00	RS Means 2007 Pg 638

A second economic analysis was performed as a sensitivity analysis to determine the effect of a price premium paid by tenants to occupy a "green building" on the total net present value. It was assumed that the premium was achievable only during the first five years of building occupancy. Beyond the initial five years, a market advantage reaping a price premium for the developer over other available real estate was assumed unlikely.

Results

This analysis considers the feasibility of meeting water demands of modern commercial buildings in Arlington, Virginia using rainwater harvested on-site. To accomplish this task, the physical practicality of such a system must be examined through a water balance analysis (i.e., is there sufficient rainwater to meet building demands?). A second feasibility concern is that of the economic viability of harvesting rainwater versus using municipal potable water supplies (i.e., do the benefits associated with the system justify their costs?). While this study focuses largely on two recent commercial developments as case studies for analysis, the first part of the results section reveals results applicable to all rainwater harvesting projects in Arlington County.

Monthly Rainfall for Arlington County

The National Weather Service (NWS) maintains weather stations across the U.S. Those stations vary in complexity and therefore in the data that they collect. NWS maintains a station at Ronald Reagan Washington National Airport (DCA) in Arlington County. Among other data, the station records hourly precipitation data, which are made available electronically on the internet from the National Climatic Data Center (NCDC). The NCDC database contains nearly 8000 records describing hourly precipitation at the DCA station dating back to 1947. Using the daily totals for records from Water Year 1948 through Water Year 2007 an average was calculated for each month (Note: A water year coincides with the federal fiscal year running from October 1st of the previous calendar year through September 30th of same nominal calendar year). Table 4 presents the monthly average rainfall during this period.

Table 5. Monthly Average Rainfall between Water Year 1948 and 2007

Month	Average Rainfall (inches)
January	2.84
February	2.59
March	3.51
April	2.92
May	3.64
June	3.47
July	3.81
August	3.80
September	3.55
October	3.09
November	3.04
December	3.07
Total	39.32

Since the above averages are based on historical data, they do not reflect periodic fluctuations or trends that could result from effects related to climate change.

Generic Hydrologic Rainwater Harvesting Model for Arlington County

In preparation for designing the hypothetical rainwater harvesting systems for the two case studies, a generic hydrologic rainwater harvesting model specific to Arlington County was created. This model generally applies to rainwater harvesting at all commercial facilities in Arlington County.

Figure 6 shows the efficacy of harvested rainwater water supply versus demand. Fitted lines illustrate water supply (Rainwater Potential) versus building water demand (toilet flushing only).

Figure 6. Rainwater Surplus or Deficit by Building Area

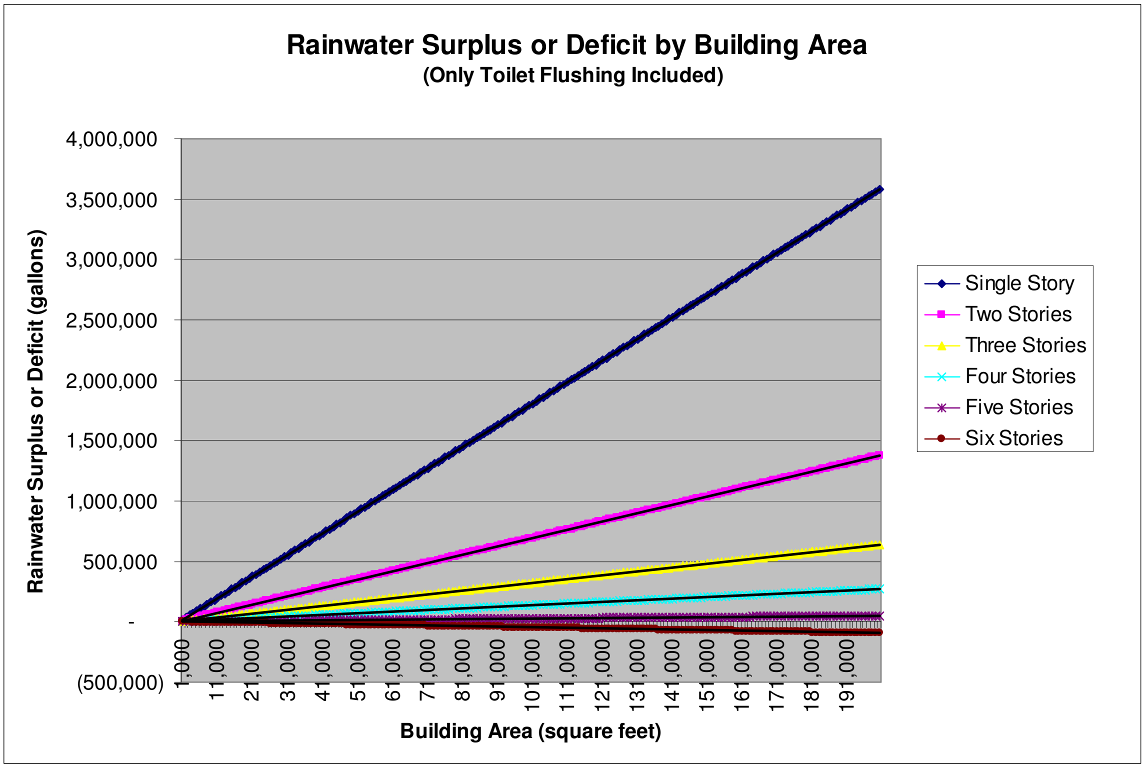


Table 6 lists the slopes for each fitted line.

Table 6. Fitted Lines for Water Balance Estimates for Office Buildings

Building Type	Slope (gallons / square foot)
Single Story	17,896
Two Stories	6,868
Three Stories	3192
Four Stories	1354
Five Stories	251.19
Six Stories	-484.01

As illustrated in Figure 6, positive slopes for the fitted curves represent situations in which more than adequate rainwater can be harvested than utilized through predicted toilet flushing within the building. Thus, a surplus of rainwater will be available. The negative slope for a six story building indicates more water is demanded by predicted toilet flushing than can be supplied by the rainwater potential in Arlington County. In general, buildings with more than five stories will require augmentation of rainwater stores to meet the water demands of toilet use, whereas buildings with five or fewer stories can meet the water demands of toilet flushing through rainwater harvesting alone.

Case Study 1: Moore Street

Table 7 presents a monthly water balance for the Moore Street Building. The water balance accounts for rooftop rainwater potential, toilet flushing and irrigation of the 13 street level tree boxes.

Table 7. Water Balance for Moore Street

Month	Rainfall (inches)	90% of precipitation over 23,387 sq ft (gallons)	Toilet Water Demand (gallons)	Irrigation Demand (1.5 inches / week) (inches)	Tree Box Area (gallons)	Surplus or Deficit (gallons)
January	2.84	37,252	1,041,907	4	742	(1,005,396)
February	2.59	33,986	1,041,907	4	792	(1,008,713)
March	3.51	46,089	1,041,907	3	605	(996,422)
April	2.92	38,335	1,041,907	4	725	(1,004,296)
May	3.64	47,699	1,041,907	3	580	(994,788)
June	3.47	45,545	1,041,907	3	614	(996,976)
July	3.81	49,974	1,041,907	3	545	(992,478)
August	3.80	49,821	1,041,907	3	548	(992,633)
September	3.55	46,545	1,041,907	3	598	(995,960)
October	3.09	40,486	1,041,907	3	692	(1,002,113)
November	3.04	39,850	1,041,907	3	701	(1,002,759)
December	3.07	40,241	1,041,907	3	695	(1,002,361)

According to the above data, the water demands for irrigation represent less than 0.1% (0.07%) of the total water demand for this case study. Notwithstanding, significant shortfalls exist (i.e., approximately 1,000,000 gallons every month) between the rainfall potential and the water demand derived from toilet flushing in the building and landscaping needs. This aligns with the predictions of the generic rainwater harvesting model. Nonetheless, a rainwater harvesting system could be constructed and supplemented with potable water to cover this water deficit. Under this assumption, preliminary engineering designs were developed for the case study. Table 8 depicts the costs specific to the rainwater harvesting system components, which total $178,800.50.

Table 8. Capital Costs for the Rainwater Harvesting System at Moore Street

Capital Costs ***Item***	***Unit***	***Cost***	***Count***	***total***
First flush filters	each	$ 120.00	6	$ 720.00
Underground Storage Tank (10,000 gallon)	each	$ 24,122.50	5	$ 120,612.50
Plumb Tank (e.g. overflow, potable water supply, actuated valves & tank level sensors)	each	$ 2,541.60	5	$ 12,708.00
Pump	each per tank	$ 3,378.00	5	$ 16,890.00
Floating Intake	each per tank	$ 256.00	5	$ 1,280.00
Distribution Piping - Installed	linear feet	$ 12.80	1,500	$ 19,200.00
Booster Pumps -Installed	each per tank	$ 1,4780.00	5	$ 7,390.00
Roof Material (No Extra Cost)	square foot	$ -	23,387	$ -
Downspout/Piping Installed (No Extra Cost)	linear feet	$ -	4,160	$ -
				$ 178,800.50

Table 9 shows the results of an economic analysis conducted using the derived cost and benefit values for the Moore Street case study. As designed, this project fails to meet a positive net present value (i.e., it has a NPV of -$105,375). The costs of constructing this system thus outweigh the benefits of doing so as tabulated. Given this result, a developer has no economic incentive to include a rainwater harvesting system on this development site.

Table 9. Economic Analysis for Moore Street

Item	**Cost Per Event/Item**	**Present Value**
Capital Costs		
Rainwater Harvesting System	$ 178,800.50	$ 178,800.50
Operating costs		
Mucking Tank (every 5 years)	$ 1,500.00	$ 2,757.91
Pump Replacement (every ten years)	$ 16,890.00	$ 12,918.40
Minor fittings replacement (every 5 years)	$ 1,500.00	$ 2,757.91
Booster Pump replacement (every 10 years	$ 1,478.00	$ 5,652.28
Capital Benefits		
SWM Quality	$ 10,022.25	$ 10,022.25
Flood Control (1000 cf detention structure)	$ 50,000.00	$ 50,000.00
Operating Benefits		
No maintenance of SWM facility (yearly)	$ 1,500.00	$ 17,448.93
Water Bill Savings (Yearly)	$ 1,722.85	$ 20,041.22
Net Present Value		-$ 105,374.60

Case Study 2: Navy League Building

Similar to the computations for the Moore Street case study, Table 10 presents a monthly water balance for the Navy League Building. The water balance accounts for rooftop rainwater potential, toilet flushing and irrigation of the 16 street level tree boxes.

Table 10. Water Balance for the Navy League Building

Month	Rainfall (inches)	90% of precipitation over 212,947 sq ft (gallons)	Toilet Water Demand (gallons)	Irrigation Demand (1.5 inches / week) (inches)	Tree Box Area (gallons)	Surplus or Deficit (gallons)
January	2.84	40,994	369,027	4	912.73	(328,946)
February	2.59	37,399	369,027	4	974.81	(332,602)
March	3.51	50,719	369,027	3	744.79	(319,053)
April	2.92	42,186	369,027	4	892.15	(327,733)
May	3.64	52,490	369,027	3	714.19	(317,251)
June	3.47	50,119	369,027	3	755.14	(319,663)
July	3.81	54,994	369,027	3	670.96	(314,704)
August	3.80	54,825	369,027	3	673.88	(314,876)
September	3.55	51,220	369,027	3	736.12	(318,543)
October	3.09	44,552	369,027	3	851.28	(325,326)
November	3.04	43,852	369,027	3	863.37	(326,038)
December	3.07	44,283	369,027	3	855.93	(325,600)

According to the above data, the water demands for irrigation represent less than 1% (0.2%) of the total water demand for this case study. However, the water balance yields a deficit of over 300,000 gallons every month. Nonetheless, a system could be constructed and supplemented with potable water to cover the water deficit. Under this assumption, preliminary engineering designs were developed for the case study. Table 11 provides the costs specific to the rainwater harvesting system components, which total $179,424.58.

Table 11. Capital Costs for the Navy League Building

Capital Costs Item	Unit	Cost	Count	total
First flush filters	each	$ 120.00	12	$ 1,440.00
Undergound Storage Tank (10,000 gallon)	each	$ 24,122.50	4	$ 96,490.00
Plumb Tank (e.g. overflow, potable water supply, actuated valves & tank level sensors)	each	$ 2,541.60	4	$ 10,166.40
Pump	each per tank	$ 3,378.00	4	$ 13,512.00
Floating Intake	each per tank	$ 256.00	4	$ 1,024.00
Distribution Piping - Installed	linear feet	$ 12.80	4,321	$ 55,314.18
Booster Pumps -Installed	each per tank	$ 1,4780.00	1	$ 1,478.00
Roof Material (No Extra Cost)	square foot	$ -	25,736	$ -
Downspout/Piping Installed (No Extra Cost)	linear feet	$ -	1,594	$ -
				$ 179,424.58

Table 12 presents the results of an economic analysis conducted using the derived cost and benefit values for the Navy League Building case study. As designed, this project fails to meet a positive net present value (i.e., it has a NPV of -$54,246). The costs of constructing this system outweigh the benefits of doing so. Given this result, a developer has no economic incentive to include a rainwater harvesting system on this development site.

Table 12. Economic Analysis for the Navy League Building

Item	Cost Per Event	Present Value
Capital Costs		
Rainwater Harvesting System	$ 179,424.58	$ 179,424.58
Operating costs		
Mucking Tank (every 5 years)	$ 1,500.00	$ 2,757.91
Pump Replacement (every ten years)	$ 13,512.00	$ 10,334.72
Minor fittings replacement (every 5 years)	$ 1,500.00	$ 2,757.91
Booster Pump replacement (every 10 years	$ 1,478.00	$ 1,130.46
Capital Benefits		
SWM Quality	$ 52,656.25	$ 52,656.25
Flood Control (1000 cf detention structure)	$ 50,000.00	$ 50,000.00
Operating Benefits		
No maintenance of SWM facility (yearly)	$ 1,500.00	$ 17,448.93
Water Bill Savings (Yearly)	$ 1,895.89	$ 22,054.17
Net Present Value		-$ 54,246.22

Sensitivity Analysis Considering a Price Premium

Given that the economic analysis yields negative net present values, a developer has no economic incentive to pursue incorporating rainwater harvesting systems as designed in this study. However, if the building owner could effectively market the building under a "green" profile, tenants might be willing to pay a price premium to lease space in this building. Table 13 reveals the effect that a potential price premium could have on the economics of incorporating rainwater harvesting systems into these case studies.

Table 13. Consideration of a Price Premium on Rental Rates

Case Study	Moore Street	Navy League Bldg.
Gross Floor Area (GFA) (square feet)	601,790	212,947
Assumed Useful Square Footage (Assumed at 50% GFA)	300,895	106,474
Yearly Rent (based on $30.20 / sq. ft.)[A]	$ 9,087,029	$ 3,215,500
1% Price Premium (per year)	**$ 372,386**	**$ 32,155**
Recalculated Economic Analysis with Price Premium Included	$ 267,012	$ 77,525
Previous BCA without Price Premium	- $ 105,375	- $ 54,246

[A] $30.20 per square foot represents the 2007 average cost to rent office space in Arlington, Virginia (www.officefinder.com, 07-Mar-2008).

After applying a 1% price premium to the average Arlington County 2007 rental cost for office space, the Moore Street net present value reverses from negative $105,375 to positive $267,012 – a $372,387 swing. Similarly for the Navy League Building, a $131,771 swing moves the net present value from negative $54,246 to positive $77,525.

Discussion

The results presented above provide insight into the broad applicability of rainwater harvesting systems in Arlington County in general as well as specific information regarding the hypothetical use of rainwater harvesting in two real world case studies. The County's reasonably constant rainfall over the course of a year makes planning for seasonal dry periods easily managed. As shown in Table 14, monthly rainfall ranges from 2.84 inches in January to 3.81 inches in July, deviating less than 16% from the average monthly rainfall. Note that these data present long-term averages and thus do not reflect the extreme years in which rainfall deviates substantially from the average.

Table 14. Rainfall Statistics for Arlington County, Virginia

	Value	Difference from Average
Average Monthly Rainfall	3.28 inches	---
Maximum Monthly Rainfall	3.81 inches	15.8%
Minimum Monthly Rainfall	2.84 inches	-13.4%

In contrast to Arlington County, regions with wet and dry seasons such as the southwest require large amounts of rainwater storage to provide water during dry months. Holding land, material and labor costs constant from one region to another, rainwater systems developed for use in Arlington County are therefore more cost effective simply because the rainwater available for capture is relatively constant throughout the year.

In terms of the Generic Hydrologic Rainwater Harvesting Model for Arlington County, commercial buildings built with roof areas to floor areas corresponding to ratios of 1:5 or greater can be supplied with sufficient rainwater to serve building toilet flushing without the need for an additional water supply. This model was based on the maximum occupancy allowed by the International Building Code (the applicable code in Arlington County), which states that each occupant in an office building requires no less than 100 gross square feet. A building's gross square feet includes hallways, stairways, mechanical rooms, etc. However, it is highly unlikely that any office space in Arlington County would be so densely packed with occupants. Thus, captured rainwater would likely serve buildings with smaller than 1:5 roof to floor area ratio without the need for additional supply water for toilet flushes.

Another assumption included in this model is the number of flushes per work day per person. For this analysis, the number was assumed to be five. While information can easily be found regarding how much water a particular fixture uses (e.g., 1.6 gallons per flush) and use per capita (150 to 200 gallons per day) neither of these values directly applies to water use applicable to toilets in an office building. For example, a single toilet potentially could be flushed every time it fills throughout the workday. Also, of the 150 gallons per capita per day, the proportion of water used during the work day versus at home is unknown. In the absence of such an estimate, five flushes per person per day was utilized for this analysis based on the study author's judgment. If the actual number of flushes is four or even three this could have significant impacts to the water demand side of the equation (i.e., 20 to 40%). In other words, if the true number of flushes is less than five per person per work day, then captured rainwater could more readily meet water demands for buildings with smaller roof to floor area ratios. The converse would also be true, that if occupants flushed the toilet six or more times per day then the captured rainwater would fail to adequately supply 1:5 roof to floor ratios.

A final assumption made in the generic model and carried into the case study designs was that aside from the initial abstractions and the first flush diversion, all of the rainwater landing in the catchment area (i.e., roof) could be captured by the rainwater harvesting system. This assumption may be valid only some of the time. For instance, if one rain event follows another within a short period of time (e.g., 24 hours) the storage tanks may already be significantly full. The available tank volume would then be insufficient to capture additional rainwater, thus the second rain event would be lost. Further examination of the hourly rainfall record could provide information on the quantity of rain per event and the typical time between events (interevent time). This information could help an analyst better judge the reasonableness of the assumption that all rain can be captured.

With respect to the case studies, it may be possible to design the rainwater harvesting system more economically if done as part of the original design. If this could be accomplished, then the economic analysis might show a positive net present value. Both Moore Street and the Navy League Building yielded negative economic analysis results, \$105,374.60 and \$54,246.22, respectfully. The analyses were heavily burdened by the capital cost of the rainwater harvesting system (i.e., \$178,800.50 for Moore Street and \$179,424.58 for the Navy League Building). With this in mind, it should be acknowledged that the efforts to design the systems included herein represent preliminary designs not intended for construction. The case study designs were not developed by an engineering / architectural team fully competent in building design. Nor were the case study designs developed as an integral part of the planning for the building and site layout from the outset. Rather, the case study designs were based on an assumption that a rainwater harvesting system would fit into the building designs as they exist today. Therefore, it can be stated with confidence that the case study designs and their associated costs represent a preliminary estimate. As such the costs included in this analysis could be too high or even too low. Regardless, both designs resulted in relatively similar capital costs for similar roof areas.

The inputs to the economic analysis for the case study designs differed significantly with respect to two items: (1) the number of booster pumps required to convey water at sufficient pressure to the higher floors of the building; and (2) the costs associated with stormwater quality management. With respect to booster pumps, a different design could utilize captured rainwater to serve for toilets only for the lower floors and provide municipal potable water for toilets on higher floors. A system serving only the lower floors of a building would provide a more efficient design for two significant reasons. First, this would save in costs associated with booster pumps and distribution piping because the same potable plumbing service to the lavatories, water fountains, etc. on upper floors could also serve the toilets on those floors, thus negating the need for a separate distribution network serving only toilets. Second, such a system could maximize the use of rainwater without the need to augment supplies with potable water.

The water balance developed in the Generic Hydrologic Rainwater Harvesting Model revealed that rainwater supplies can only adequately meet the demands of the first five floors. Creating a distribution network for the rainwater harvesting system when insufficient rainwater potential exists results in inefficient design. Nonetheless, the booster pump costs for Moore Street total only $ 5,652.28 over the life of the project. Thus, lessening or even removing booster pumping over the life of the project makes little difference when compared to the $105,374 negative present value resulting from the economic analysis.

Another significant difference between the two analyses centers on the calculated stormwater quality capital benefit as presented in Table 15. Following the Arlington County guidelines for calculating a developer contribution to the County's Watershed Management Fund, the stormwater quality capital benefit for Moore Street was calculated at $10,222.25. In contrast the benefit for the Navy League Building was calculated at $52,656.25. The reason for this significant difference is primarily a function of the predevelopment land cover. Specifically, the Navy League Building increased impervious cover through site development by 70.7%, whereas, the Moore Street project only increased impervious cover by 3.2%. Thus, a development that substantially increases the impervious cover on a parcel through development has the most to gain from employing a rainwater harvesting system in lieu of addressing stormwater management separately.

Table 15. Comparison of Stormwater Quality Benefit

	Predevelopment Impervious Cover	**Post-development Impervious Cover**	**Difference**	**Stormwater Quality Benefit**
Moore Street	96.8%	100%	3.2%	$10,222.25
Navy League	29.0%	99.7%	70.7%	$52,656.25

Finally, the price premium sensitivity analysis showed that even a modest premium paid by building tenants during the initial years of the project has the potential to significantly alter the results of an economic analysis. In the analysis, the price premium was carried only for five years. This reflects the consideration that as newer buildings become available they are also more likely to have rainwater harvesting systems, discounting the market differentiation that rainwater harvesting systems bring to buildings now. However, if developers were able to continue the price premium beyond five years the economic returns to investment in rainwater harvesting would be even greater.

Certainly, commercial developers are conscious of the current average market rate for similar buildings and do not want to extend the expenses beyond their ability to recoup them. Nonetheless, developers must market their properties to fill them. By simply altering the emphasis of their marketing materials to target more "green" minded leasers, developers could potentially reap a price premium that more than makes up for the cost of installing a rainwater harvesting system.

In conclusion, if Arlington County desired to encourage developers to incorporate rainwater harvesting systems, the County could choose among the following policy options:

- Mandate the incorporation of rainwater harvesting systems.
- Provide grants or subsidies equal to the negative value of the economic for the project.
- Provide partial subsidies with the understanding that buildings with rainwater harvesting systems receive a price premium for their green approach to water management.

Under the first scenario, the County runs the risk of seeming unfriendly to business. While such a command and control approach ensures that all new developments incorporate rainwater harvesting systems, the County may injure their ability to attract new development which could result in the loss of potential tax revenue. The second option will likely provide an eager queue of developers desiring County monies. However, County administration of a system whereby each developer must present an economic justification might prove tenuous. Moreover, the subsidies might become overly burdensome to tax payers. The third alternative would presumably require less cash investment (or deferred tax revenue) on the County's part. At the same time the County could leverage the power of the market to encourage the growth of these systems.

<u>Conclusion</u>

Rainwater harvesting in Arlington County, Virginia holds the potential to conserve on-site potable water use, protect surface water quality, and reduce the risk of flooding within the County. Examination of the rainfall record at Ronald Reagan Washington National Airport (located within the County) reveals an average annual rainfall of approximately 40 inches, with the drier months receiving only 15% less rain than the average monthly rainfall. This relatively constant rainfall means that rainwater harvesting system designs need not address the large swings from wet to dry seasons that occur in the southwestern portion of the US.

In considering geometric uniform building shapes and maximum occupancy ratings allowed by the applicable building code, the local hydrology will provide sufficient rainwater to serve a five story office building. Developers of buildings with more than five stories can plumb a distribution network for higher floors on the assumption that building occupancy likely will not reach the code maximum; and during any periods with insufficient rainfall municipal supplies could augment the rainwater harvesting system. However, a more efficient design might plumb only the first five stories, leaving the remaining stories to traditional municipal supplies.

Results from the two case studies examined in this paper did not readily show a positive economic cash flow even though a system could be constructed to effectively harvest rainwater and distribute it throughout the building. Notwithstanding, sites that negatively impact the environment by increasing impervious cover through site development stand to benefit most by incorporating a rainwater harvesting system into the building design. Finally, if even a modest price premium can be achieved for a given project the economic analysis drastically changes to a positive return to investing in rainwater harvesting.

References

Arlington County. *Arlington County Chesapeake Bay Preservation Ordinance Guidance Manual, Version 2.1.* January 2005.

Arlington County Public Utilities website. http://www.arlingtonva.us/departments/EnvironmentalServices/uso/EnvironmentalServicesUsoAccountsUtilities.aspx (Accessed March 6, 2008)

Arlington County Website, http://www.arlingtonva.us/DEPARTMENTS/EnvironmentalServices/epo/EnvironmentalServicesEpoGreenBuildings.aspx . (Accessed September 14, 2007)

Armstrong, James E., William R. Barry, Robert F. Cox, Roy F. Gilley, Kenneth K. Humphreys, Patricia L. Jackson, Martin F. Joyce. 2007. *RS Means Building Construction Cost Data, 65th Annual Edition.* Kingston, Massachusetts. RS Means Construction Publishers & Consultants.

Atlanta Regional Commission. 2001. *Georgia Stormwater Management Manual.* http://www.georgiastormwater.com/ (Accessed April 20, 2008)

Brown, Ted, Deb Caraco. November 2001. *"Channel Protection"* Water Resources Impact. September 2001, Vol. 3, No. 5. pp 16 – 19.

Center for Watershed Protection. 2007. *Urban Stormwater Retrofit Practices. Manual 3.* http://www.cwp.org/PublicationStore/USRM.htm#usrm3

City of Portland, Oregon website.

http://www.portlandonline.com/osd/index.cfm?print=1&c=ecbbd&a=bbehfa

(Accessed January 16, 2008)

Darco, Inc. Underground Tankage website. www.darcoinc.com (Accessed March 6, 2008)

Davis, Carter, Scott, Ltd., *1812 North Moore Street, Project Designs*. September 5, 2006. Prepared for Arlington County, Department of Environmental Services.

Dunne, Thomas, Luna B. Leopold. 1978. *Water in Environmental Planning.* New York, New York. W. H. Freeman and Company.

Fisher, Kevin, Landscape Architect, Rhodeside & Harwell, Inc. Personal Communication February 15, 2008.

Floyd, Elizabeth, AIA, LEED AP, Personal Communication (February 26, 2008) Sustainable Design Consulting, LLC, Silver Spring, Maryland.

Global Development Research Center website. www.gdrc.org. (Accessed February 24, 2008)

Grainger Industrial Supply website. www.grainger.com (Accessed March 5, 2008)

Hicks, P.E., William D., 2004. *Flood Frequency Analysis for Four Mile Run at USGS Gaging Station 1652500.* Northern Virginia Regional Commission.

Hunt, Ph.D., P.E., William F. and Laura L. Szpir, 2006. *Urban Waterways, Permeable Pavements, Green Roofs and Cisterns, Stormwater Treatment Practices for Low-Impact Development.* NC State University and NC A&T University Cooperative Extension.

Kelsch, Joan, Envionmental Planner, Arlington County. Virginia. Personal Communication (September 14, 2007)

Kindade-Levario, Heather. 2007. *Design for Water*, Gabriola Island, British Columbia, Canada. New Society Publishers.

Kloss, Christopher, Crystal Calarusse. 2006. *Rooftops To Rivers: Green Strategies for Controlling Stormwater and Combined Sewer Overflows.* Washington DC. Natural Resources Defense Council.

LarBranche, Adrienne, Hans-Otto Wack, David Crawford, Ed Crawford, Nickolas J. Sojka, Cabell Brand. 2007. *Virginia Rainwater Harvesting Manual.* Salem, Virginia. The Cabell Brand Center.

Linsley, Ray K., Joseph B. Franzini, David L. Freyberg, George Thobanoglous, 1992. *Water Resources Engineering, Fourth Edition.* New York, New York. McGraw-Hill, Inc.

Longland, F., 1983. *Filed Engineering, An introduction to development work and construction in rural areas, compiled and edieited by Peter Stern and others, from an original work by F.Longland.* London. Intermediate Technologies Publications.

Meera, V. M. Mansoor Ahammed. *Water Quality of Rooftop Rainwater Harvesting Systems: A Review*. Journal of Water Supply: Research and Technology – AQUA. 55.4, 2006.

National Climatic Data Center website. *Hourly Precipitation Records for Washington Reagan Airport National Weather Station, ID 448906.* http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI%7EStnSrch%7EStnID%7E20027254 (Accessed February 12, 2008).

New York State Department of Environmental Conservation. April 2008. *New York State Stormwater Management Design Manual.* http://www.dec.ny.gov/chemical/29072.html (Accessed April 20, 2008)

Nine Mile Run Watershed Association website. http://www.ninemilerun.org/programs/rainbarrel/index.htm (Accessed January 23, 2008)

Northern Virginia Regional Commission. Draft Northern Virginia LID Supplement. http://www.novaregion.org/lid/ (Accessed December 15, 2007)

OfficeFinder website. www.officefinder.com (Accessed March 7, 2008)

Persyn, Russell A., Dana O. Porter, Valeen A. Silvy. 2004. *Rainwater Harvesting*. Texas Cooperative Extension, Texas A&M University System.

Prince Georges County Maryland, Department of Environmental Resources. 1999. *Low-Impact Development Design Strategies, An Integrated Design Approach.* http://www.epa.gov/OWOW/nps/lidnatl.pdf [1]

Public Health (Water Storage) Regulations 1951. Bermuda Statutory Instrument, Title 11, Item 1. 1989 Revision.

Puget Sound Action Team website. http://www.psat.wa.gov/Publications/LID_studies/rooftop_rainwater.htm (Accessed January 16, 2008)

RealtyRates.com website. www.realtyrates.com (Accessed February 24, 2008)

SafeRain website. www.saferain.com.au (Accessed March 6, 2008)

Smullen, James, Terry Meeneghan, Mark Loehlein, Khalid Khan. 2005. *Nine Mile Run Rain Barrel Initiative: Analysis Report*. Pittsburg, PA. CDM. Inc.

Sprouse, Terry, Amy McCoy, Joaquin Murrieta. 2005. *A Guide: Rain Barrel Water Harvesting*. Nogales, Arizona. Sonoran Institute.

Terry, Jameson, LEED AP. Project Designer, PageSoutherlandPage, Arlington, Virginia. Personal Communication (February 1, 2008)

[1] This manual is often referred to as the "National LID Manual"

Texas Water Development Board. 2005. *The Texas Manual on Rainwater Harvesting*. Austin, Texas.

United Nations Environmental Programme. *Examples of Rainwater Harvesting and Utilisation Around the World* http://www.unep.or.jp/ietc/Publications/Urban/UrbanEnv-2/9.asp (Accessed September 30, 2007)

US Green Building Council. 2006. *LEED for New Construction Version 2.2 Reference Guide.*

US Green Building Council. 2005. *Green Building Rating System for New Construction and Major Renovations*.

US Green Building Council website http://www.usgbc.org/DisplayPage.aspx?CMSPageID=75&#rs (Accessed September 30, 2007)

VIKA, Inc., *Navy League Building, Project Designs*. February 6, 2003. Prepared for Arlington County, Department of Environmental Services.

Virginia Department of Conservation and Recreation (VADCR). 1999. *Virginia Stormwater Management Handbook, Volumes 1 and 2, First Edition.* http://www.dcr.virginia.gov/soil_&_water/stormwat.shtml (Accessed April 21, 2008)

Younos, Tamim, Rebecca Bohdan, Eric Anderson, Kelly Ramsey, Nicole Cook, Blake Ross, Theo Dillaha. 1998. *Evaluation of Rooftop Rainfall Collection – Cisterrn Storage Systems in Southwest Virginia*, Blacksburg, Virginia. Virginia Polytechnic Institute and State University.