VIRGINIA WATER RESOURCES RESEARCH CENTER

A Study of Water Infrastructure and Sustainability at Local Level

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Summary

Increased population and land use development greatly effect water supply/wastewater systems by increasing the amount of water infrastructure and energy used. Moving towards a pipe-less society will help reduce energy use of treating/delivering residential water and transporting/treating wastewater. Implementing decentralized water systems can help preserve water resources and prevent climate change by reducing the carbon footprint of water. Decentralized storm water management systems can help restore water quality while reducing the need for increased infrastructure. Objectives of this study were to: 1) estimate energy use attributed to potable and wastewater systems at a selected study site; 2) estimate the impact of implementation of two hypothetical decentralized systems (i.e. rainwater harvesting and onsite wastewater treatment) on energy use at the selected study site; and 3) estimate and compare carbon footprint attributed to centralized and decentralized water systems at the study site. Results show the study site's carbon footprint of water consumption can be reduced if rainwater harvesting/use is implemented and the study site's carbon footprint of wastewater discharge would be increased if a complete decentralized filtration wastewater system replaces the current hybrid decentralized filtration wastewater system. This study highlights the potential for water and energy conservation by using certain water supply/wastewater systems within a local neighborhood that could potentially assist in mitigating climate change.

Key Words: water conservation, energy conservation, carbon footprint, rainwater harvesting, onsite wastewater treatment

INTRODUCTION

The United States Environmental Protection Agency reports that the rate of urban land use development across the country is twice the rate of population growth for the past two decades. Between 1982 and 1997, 25 million acres were developed, resulting in a 34 percent increase in land development and only a 15 percent increase in population. The U.S. population is expected to increase by 22 percent by 2025, meaning an additional 68 million acres of land will develop within this period if recent trends continue (EPA 2007). Many urbanized areas depend on conventional water supply plants and wastewater treatment systems for their water delivery and treatment of wastewater and discharge. More than 60,000 water supply plants and 15,000 wastewater treatment plants operate within the United States and the demand for electricity at these facilities is 75 billion kWh per year – about 4% of total energy consumption in the U.S. (Oliver and Putnam 1997). These systems prove to be energy intensive and have high infrastructure cost. Decentralized water systems are considered an attractive alternative or complement conventional systems for water and energy conservation and green technologies in rural and urbanizing environments. Decentralized systems are small-scale water systems that use local water and land resources for water supply and wastewater disposal. The United States Department of Energy has reported that most states will have water shortages within ten years due to groundwater levels dropping (USDOE 2006). Decentralized water systems help to conserve water and energy. Moving towards a pipe-less society will protect water resources; use less energy, thereby reducing carbon emissions; and thus, may potentially help mitigate climate change.

The objectives of this study were to: 1) estimate energy use attributed to potable and wastewater systems at a selected study site; 2) estimate the impact of implementation of two hypothetical decentralized systems (i.e. rainwater harvesting and onsite wastewater treatment) on energy use at the selected study site; and 3) estimate and compare carbon footprint attributed to centralized and decentralized water systems at the study site.

RESEARCH METHODS

Study Site

Tom's Creek Village, located in Blacksburg, Virginia, was selected as the study site (Figure 1). Tom's Creek Village was chosen due to 1) data availability and contained neighborhood, 2) rural character and topography; and 3) proximity to Virginia Tech. Blacksburg has mountainous terrain making water delivery and discharge more energy intensive and implementing decentralized systems an attractive option. The Tom's Creek Village constructed in 1999 contains 223 residential units; 60 of those are townhouses and 163 of those single-family homes. Roughly 250 people live in the village (Graham 2009). Tom's Creek Village receives water supplies from the Blacksburg-Virginia Tech Water Authority and depends on Blacksburg's conventional wastewater treatment plant, the Blacksburg-VPI Sanitation Authority to treat its wastewater. Two sewage pump stations serve Tom's Creek Village and are responsible for distributing wastewater to a main sewage pipe. In 2004, Tom's Creek Village was renovated with a STEP/STEG (Septic Tank Effluent Pump/ Septic Tank Effluent Gravity) hybrid system. A STEP/STEG system supplies each residential unit with a septic tank that conducts primary treatment before wastewater enters the collection system. These systems are part-decentralized systems that benefit the community by allowing for the use of smaller pipes, fewer manholes, and less reliance on minimum slopes. These systems create lower energy costs and prevent blockages that normally occur from solids settling in a collection system (Scheim 2010).

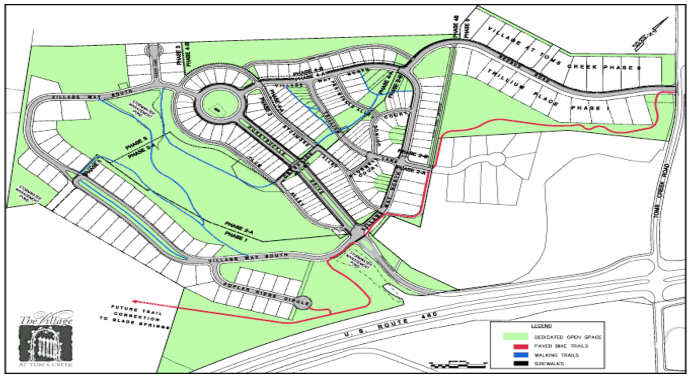

Figure 1. Study Site, Tom's Creek Village, Blacksburg, Virginia

Blacksburg's Centralized Water System: A Closer Look

Potable Water: Water consumption in Blacksburg and Virginia Tech is approximately 3.0 million gallons per day (MGD). The water facility: Blacksburg-Virginia Tech Water Authority is located 7 miles from the Town of Blacksburg. Raw water is pumped from the New River intake (350 ft lift) and transported to a conventional water treatment facility located about 2 miles from the river intake. Once treatment is finished, water is pumped to a high head storage tank (2.0 capacity) and delivered to Blacksburg (Younos et. al 2009).

Wastewater: Blacksburg contains 22 sewer pump stations total. Blacksburg's wastewater is pumped through various pipes to the main sewage pipe, located beneath the Drillfield, and then by gravity is transported to the Blacksburg-VPI Sanitation Authority where wastewater is treated. Wastewater goes through primary and secondary treatment. The secondary treatment uses microorganisms to further cleanse the water through processes including biological treatment, nitrification/ denitrification. The treated wastewater is disinfected in chlorine tanks before being discharged into the New River. While other plants choose to rid of their residue sludge by re-applying it to land for purposes such as fertilization, the Blacksburg VPI Sanitation Authority chooses to incinerate their sludge (Epperly 2009).

The Blacksburg- VPI Sanitation Authority serves the Town of Blacksburg, Virginia Tech, and portions of Montgomery County. The design capacity of the wastewater treatment plant is 9.0 MGD. In 2008, the estimated wastewater discharge volume from Blacksburg to Sanitation Authority was 4.85 MGD (Epperly 2009). About 2-3% of wastewater discharge originates from Montgomery County. This conventional wastewater system uses energy when transporting, treating the water, and in its incineration of sludge (Epperly 2009).

Figure 2. Town of Blacksburg Sewer Pump Stations

Estimate energy use attributed to potable and wastewater systems at a selected study site
Potable Water: Tom's Creek Village receives potable water from Blacksburg-Christiansburg-VPI Water Authority. Energy is required to treat and deliver water to point of use. Previous research estimated the energy required to treat and deliver water to Blacksburg and Virginia Tech is 1.67 kWh/1,000 gallons (Chen et al. 2007). This figure was used to estimate electricity use attributed to water consumption at Tom's Creek Village.

Wastewater: Tom's Creek Village depends on Blacksburg's conventional wastewater treatment plant, the Blacksburg-VPI Sanitation Authority to treat its wastewater. Energy is required to transport wastewater to a treatment facility. Using flow rate and energy use data received from the Blacksburg-VPI Sanitation Authority, the estimated energy required to transport wastewater from Blacksburg and Virginia Tech is approximately 2.7 kWh/1,000 gallons (incorporating both Blacksburg VPI Sanitation Authority and Blacksburg Pump Station energy use). This figure was used to estimate the annual electricity use attributed to wastewater discharge at Tom's Creek Village and was calculated as:

Table 1. Blacksburg VPI Sanitation Flow Rate, Energy Use, and Blacksburg Pump Station Energy Use

Year	Flow Rate (MGY) (Epperly 2009)	Energy Blacksburg VPI Sanitation Authority (kWh) (Epperly 2009)	Energy Blacksburg Pump Station (kWh) (Epperly 2009)	Energy Combined (kWh)
2008	1,770,042,000	4,332,000	490,968	4,822,968

$$\frac{4{,}822{,}968 \text{ kWh}}{1{,}770{,}042{,}000 \text{ MGY}} = \mathbf{2.7\ kWh/1{,}000\ gallon}$$

where 4,822,968 kWh is the energy required to transport wastewater from VPI Sanitation Authority + Blacksburg Pump Station (Table 1). Because Tom's Creek Village uses a STEP/STEG hybrid system, less total gallons are sent to the treatment facility than would be required for a centralized system. Primary treatment has already occurred, at Tom's Creek Village, before any wastewater is transported to facility, making the amount less and therefore less energy required.

Estimate the impact of implementation of two hypothetical decentralized systems (i.e. rainwater harvesting and onsite wastewater treatment) on energy use at the selected study site

Potable Water: Rooftop rainwater harvesting and use, is a water conservation method that could reduce electricity use at Tom's Creek Village. Harvestable rainwater can be estimated using the following equation (Virginia Rainwater Harvesting Manual 200):

$$\text{URV(gallons/yr)} = \text{Roof Area (sq ft)} \times \text{Avg Rainfall (in/month)} \times C \times 0.6233 \times 12 \text{ month/1 yr} \quad \text{(Eq. 1)}$$

URV is usable rainwater volume, C is collection efficiency (approximately 0.8 due to splash and evaporation resulting in loss of water), and 0.6233 is the conversion factor to estimate water volume in gallons ((1 ft/12 in) x (7.48 gal/1 ft^3)). Long-term average monthly rainfall data is used to estimate harvestable rainwater (Table 2). The average rooftop area per residential unit in Tom's Creek Village is 2,400 sq ft (Stolte, 2009).

Table 2. Thirty Year Average Monthly Precipitation in Blacksburg, Virginia

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (inches)	3.37	3.02	3.83	3.83	4.39	3.93	4.17	3.68	3.39	3.19	2.96	2.87

Source: National Weather Service Total Annual Rainfall: 42.63
www.idcide.com/weather/va/blacksburg.htm.

The total amount of indoor and outdoor water use attributed to harvested rainwater on buildings is equivalent to potable water savings in theory. With the rainwater harvesting system capture and use, energy is conserved because less energy is used to supply, treat, and distribute water.

Wastewater: Tom's Creek Village already benefits from a part-decentralized (STEP/STEG) system that requires less energy. The purpose of this research was to determine if using a complete onsite wastewater management system would use less electricity than the part-decentralized/centralized system already in place. A proposed location for possible implementation of a decentralized wastewater management system was made in cooperation with Meredith Jones, Project Manager and Engineer of Tom's Creek Investors L.C and can be seen in Figure 3 below. The hypothetical location of the onsite treatment area is at the lowest point of Tom's Creek Village. The effluent could be transported by gravity to the treatment center, therefore requiring no pumps or energy for transporting water. The type of treatment center proposed is a recirculating sand filter like one from Orenco, Inc (http://www.orenco.com/) that requires pumps for the recirculation of water.

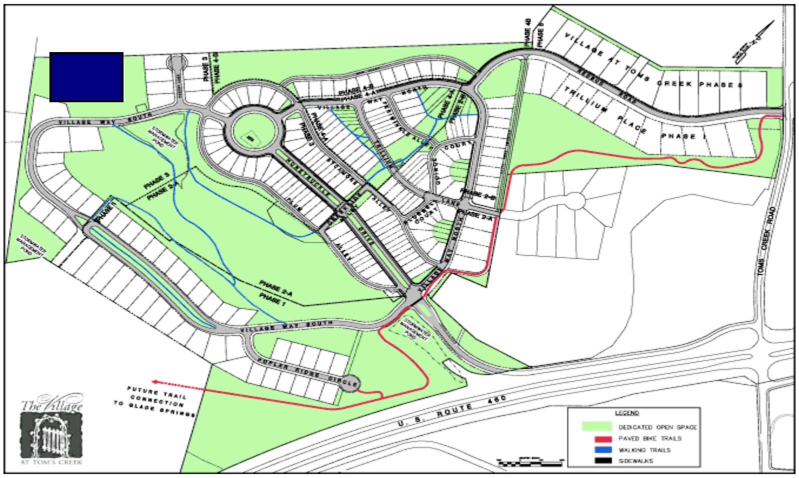

Figure 3. Location of Onsite Wastewater Treatment at Tom's Creek Village

A recirculating sand filter was customized for Tom's Creek Village, a neighborhood with a little over 200 residential units using an average of 100 gallons/day. The sand filter requires12 pumps, each using 5.8 kWh/day totaling 69.6 kWh/ day (Espinosa 2010).

Estimate and compare carbon footprint attributed to centralized and decentralized water systems at the study site

The carbon footprint can be estimated from carbon emissions attributed to electricity using an energy conversion coefficient. Blacksburg's energy coefficient is 1.985867 lbs CO_2/kWh (Poole and Younos 2009). This energy coefficient (1.985867 lbs CO_2/kWh) was used to calculate Tom's Creek Village carbon footprint for water consumption and wastewater discharge from electricity use (1.67 kWh/1,000 gallons; 2.7 kWh/1,000 gallons).

RESULTS AND DISCUSSION

Energy consumption and CO_2 output are presented for the following systems at Tom's Creek: 1) The current conventional potable water system; 2) A potential rainwater harvesting system; 3) The current hybrid wastewater system; and 4) A potential onsite decentralized wastewater management system.

Carbon Footprint of Water Consumption at Tom's Creek Village Using a Potable System

Table 3 reflects Tom's Creek Village carbon footprint of water consumption while using a potable system.

Table 3. Carbon Footprint due to Water Consumption for Tom's Creek Village I & II Using Conventional Water Supplies

Location	Annual water consumption (gallons/yr)	Estimated electricity use attributed to water use (kWh/yr) (x 1.67 kWh/1,000 gal)	Estimated CO_2 output (lb/Year) (x $\frac{1.985867 \text{ lb } CO_2}{\text{kWh}}$)
Tom's Creek Village I	1,554,500	2,596	5,155
Tom's Creek Village II	3,230,200	5,394	10,713
Total	4,784,700	7,990	15,868 (7.9 Tons CO_2)

Impact of Rainwater Harvesting and Use on Tom's Creek Village's Carbon Footprint

Table 4 shows how much water and energy is saved if a rainwater harvesting system were implemented in Tom's Creek Village.

Table 4. The Impact of Rainwater Harvesting and Use on Tom's Creek Village Carbon Footprint due to Water Consumption

Location	Rainwater harvesting/use potential (Eq. 1) (gallons/yr)	Difference between harvested rainwater and water consumption (gallons/year)	Estimated electricity use (kWh/yr) for delivery (x. 1.67 kWh/ 1,000 gal)	Estimated CO_2 output lb/year (x $\frac{1.985867 \text{ lb } CO_2}{\text{kWh}}$)
Tom's Creek Village I & II	11,376,759	4,784,700 < 11,376,759 (0)	0	0

Table 4 shows that if rainwater harvesting is implemented in Tom's Creek Village and uses rainwater for both indoor and outdoor uses, the neighborhood's carbon footprint of water consumption can be reduced to zero. Table 4 does not reflect the impact of electricity that is potentially needed for running a pump for rainwater distribution inside and outside residential units. Energy is assumed to be minimal if rainwater is gravity-fed from a storage tank located on top of the residential unit (Younos and Grady 2009). If the storage tank is located on the ground level or in the basement, a pressure pump is required for distribution purposes; the energy use and carbon footprint of a residential unit with this rainwater harvesting system design should be determined.

Table 4 assumes rainwater will be used for both indoor and outdoor uses. Additional treatment is required for harvested rainwater used indoors. If rainwater is used for landscape irrigation only, the potable water consumption can be reduced 10-30%. Table 5 reflects an average residential unit's carbon footprint without rainwater harvesting and one with rainwater harvesting (it is assumed 20% of each residential unit's potable water is used for landscape irrigation). The residential unit's carbon footprint is decreased 20% with the implementation of a rainwater harvesting system for landscape irrigation.

Table 5. Average Residential Unit's Carbon Footprint of Water Consumption with and without a Rainwater Harvesting System

Tom's Creek Village	Average annual water consumption (gal/yr)	Estimated electricity use attributed to water use (kWh/yr) (x 1.67 kWh/1,000 gal)	Estimated CO_2 output (lb/Year) (x 1.985867 lb CO_2 / kWh)
Residential Unit	38,817	65	129
Residential Unit with Rainwater Harvesting System	31,054	52	103

Carbon Footprint of Wastewater Discharge at Tom's Creek Village

Table 6 reflects Tom's Creek Village carbon footprint of wastewater discharge while using a conventional system.

Table 6. Carbon Footprint due to Wastewater Discharge for Tom's Creek Village I & II Using Conventional Water Supplies

Location	Annual wastewater discharge (gallons/y)	Estimated electricity use attributed to wastewater discharge (kWh/yr) (x 2.7 kWh/ 1,000 gal)	Estimated CO_2 output (lb/Year) (x 1.985867 lb CO_2 / kWh)
Tom's Creek Village I	1,627,500	4,394	8,726
Tom's Creek Village II	2,771,400	7,483	14,860
Total	4,398,900	11,877	23,586 (11.8 Tons CO_2)

Impact of Onsite Wastewater Management System on Tom's Creek Village's Carbon Footprint

Table 7. The Impact of Onsite Wastewater Management System on Tom's Creek Village's Carbon Footprint due to Wastewater Discharge

Annual Energy Use by Recirculating Sand Filter (kWh) (Espinosa 2010)	Estimated CO_2 output (lb/Year) (x 1.985867 lb CO_2 / kWh)
25,404	50,449 (25 Tons CO_2)

Table 6 and 7 compare the carbon footprint between the current STEP/STEG hybrid system and a complete onsite wastewater management system, the recirculating sand filter. The recirculating sand filter emits 53% more carbon dioxide than the STEP/STEG because of all amount of energy the pumps require to recirculate the water. The current hybrid produces a lower carbon footprint than a completely decentralized system.

CONCLUSIONS

Our results suggest that rainwater harvesting at Tom’s Creek Village has potential to significantly reduce energy consumption, and therefore carbon output, versus conventional residential water supply systems. Decentralized wastewater systems also have potential to reduce energy consumption. At our study site, the hybrid system was less energy intensive than the completely decentralized system that required recirculation of water via 12 pumps. However, environmental benefits may outweigh energy and carbon costs in decentralized filtration systems. For example, completely decentralized wastewater systems require less transport of waste and potential for leakage from pipes to surface waters.

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