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# The Challenges to Implementing Decentralized Water Reuse: a Greywater Recirculation Case Study in Boulder, Colorado

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THE CHALLENGES TO IMPLEMENTING DECENTRALIZED WATER REUSE:  
A GREYWATER RECIRCULATION CASE STUDY IN BOULDER, COLORADO

by

Katie Marie Spahr

B.S., California Polytechnic State University at San Luis Obispo, 2010

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The Challenges to Implementing Decentralized Water Reuse:  
A Greywater Recirculation Case Study in Boulder, Colorado  
written by Katie Marie Spahr  
has been approved by the Department of Civil, Environmental, and Architectural Engineering

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JoAnn Silverstein

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R. Scott Summers

Date \_\_\_\_\_

The final copy of this thesis has been examined by the signatories, and we find that both the content and the form meet acceptable presentation standards of scholarly work in the above mentioned discipline.

Spahr, Katie Marie (M.S., Department of Civil, Environmental, and Architectural Engineering)

The Challenges to Implementing Decentralized Water Reuse: A Graywater Recirculation Case Study in Boulder, Colorado

Thesis directed by Professor JoAnn Silverstein

Replacing potable water with graywater to flush toilets increases water efficiency in buildings. This study is an evaluation of water savings, environmental, economic, and policy impacts of graywater reuse systems as exemplified in a campus residence hall, Williams Village North, housing 500 students at the University of Colorado Boulder. Treatment of shower and sink drainage and recirculation for toilet flushing is estimated to reduce water use in the building by 20%, amounting to 3,300 m<sup>3</sup>/year (2.7 acre-feet/year). At municipal water and wastewater utility rates, the annual savings are around \$6,000 and will not provide a reasonable return on investment for the capital cost of the dual plumbing and treatment systems. However, the graywater system was found to meet goals for other aspects of water sustainability, including physical, institutional, social, and environmental efficiency. Economic and technological efficiency were found to be net negative and net neutral, respectively, based on the unit price of water. Incorporation of the value of benefits such as greater drought resilience and deferred capital expenditures for expansion of municipal water supply and refined treatment system design produce greater economic and process efficiency. Constraints imposed by water rights held by the City of Boulder limit the application of indoor (non-consumptive) graywater reuse and add environmental impacts. Statutory recognition of residential graywater recirculation as a conservation practice, not a second use, is consistent with current agricultural and industrial recirculation practices, and would enable reduction of as much as 10% of city-wide residential water demand.

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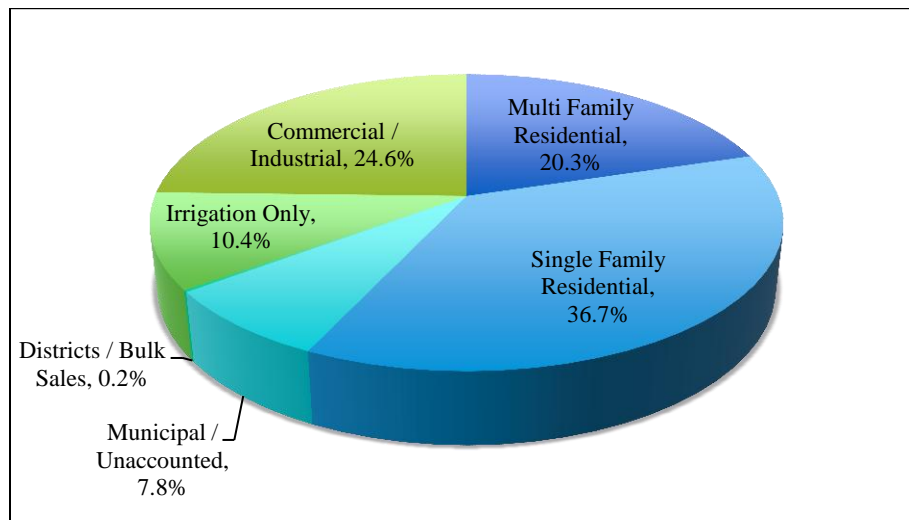
## Chapter 1: Research Motivation, Context, and Goals

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### 1.1 Water Conservation

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One of the most practical ways to address water shortages is conservation. By improving the efficiency of water use, communities become more resilient to water stresses such as drought and population growth. According to the USEPA, 8.5% of total freshwater withdrawals in the United States in 2005 were for domestic uses.<sup>1</sup> For urban areas this fraction is much higher. As seen in Figure 1.1, domestic use in Boulder, Colorado accounted for approximately 57% of total water supply. In years with normal precipitation, the City estimated that two-thirds of the potable water supply is for indoor use.<sup>2</sup>



**Figure 1.1 - Distribution of the City of Boulder 2007 Water Use.**  
(City of Boulder Source Water Master Plan)

Implementing residential-level water conservation programs in cities like Boulder where the majority of water is used indoors is one of the most effective means for demand management and thus can provide for a more diverse and sustainable water portfolio. The City of Boulder's plan is to meet 100% of municipal water demand in a Stage I, moderate, drought, with a return period of

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<sup>1</sup> "Water Sense: Water Use Today." EPA. Environmental Protection Agency. Web. 12 Mar. 2012.  
<[http://www.epa.gov/watersense/our\\_water/water\\_use\\_today.html](http://www.epa.gov/watersense/our_water/water_use_today.html)>.

<sup>2</sup> City of Boulder, MWH, and Amec. *City of Boulder Source Water Master Plan*. Rep. Vol. 2. 2009. Print. Detailed Plan.

20 – 50 years by an 8% reduction in annual water use; 14% reduction will allow survival of landscaping in a Stage II, serious, drought with a return of 50 – 100 years; 22% reduction will result in landscape loss in a Stage III, severe, drought with a return of 100 to 1,000 years

In order to implement a successful water conservation program, the use patterns of consumers must be evaluated. In a 1999 study funded by the American Water Works Association Research Foundation, the residential end uses of water in 12 cities was monitored to estimate how people use water once it enters their residence. Included in the 12-city study was Boulder, Colorado. As part of the study, 100 homes in Boulder were monitored for two 14-day periods, one period during warmer weather and one during colder weather. The results of indoor use distribution in Boulder are displayed in Table 1.1. Indoor water use was found to be fairly consistent throughout the year, regardless of outdoor temperature. Additionally, the indoor consumption values were close to the average indoor use measured for all 12 cities, and are consistent with the national average use.<sup>3</sup>

**Table 1.1 - Distribution of Water Use in Boulder, Colorado.**

Use	Gallons/capita/day	% of Total
Baths	1.4	2.16%
Clothes Washers	14	21.57%
Dish Washers	1.4	2.16%
Faucets	11.6	17.87%
Leaks	3.4	5.24%
Showers	13.1	20.18%
<b>Toilets</b>	<b>19.8</b>	<b>30.51%</b>
Other Domestic	0.2	0.31%
<b>Total Indoor</b>	<b>64.9</b>	

Each of the uses shown in Table 1.1 can be reduced through the installation of water efficient devices and fixtures. By installing fixtures like low-flow showerheads, faucet aerators, and/or water smart dishwashers, individual residences can experience a reduction of indoor water use up

<sup>3</sup> Heaney, James P., et al. "Nature of Residential Water Use & Effectiveness of Conservation Programs." *Boulder Community Network*. Web. 12 Mar. 2012. <<http://bcn.boulder.co.us/basin/local/heaney.html>>.



to 35%.<sup>4</sup> Even with these fixture changes, the distribution of water uses typically remains the same.<sup>5</sup> As Table 1.1 shows, the highest indoor use is for toilets, which account for approximately 30% of all indoor uses. Furthermore, toilet flushing was one of the most consistent water uses, averaging 5 flushes per capita per day.<sup>6</sup>

In order to reduce the amount of water used to flush toilets, a couple options exist. First, a lower tank capacity toilet can be installed. National Energy Policy Act of 1995 requires toilets to have tank capacities of 1.6 gallon/flush or less.<sup>7</sup> Toilets installed before 1993 use 4 to 5 gallons/flush, thus a switch to low flow toilets significantly reduces the water footprint of a toilet by as much as 68%. Further reduction can be achieved by changing user behavior, for example, through installation of dual flush toilets. However, installation of water-saving fixtures also is subject to economic factors. Home ownership was the strongest determinant of expressed willingness to purchase of water saving showers, washers and toilets in OECD countries.<sup>8</sup>

## **1.2 Graywater Recirculation**

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While reducing the amount of potable water used to flush toilets can result in significant water savings, the conundrum of using potable water to carry human waste remains. LEED water efficiency criteria for green buildings include use of non-potable water for waste conveyance.<sup>9</sup>

“Graywater” is recognized as a non-potable source for toilet flushing. California’s Title 22 defines graywater as the “wastewater from bathtubs, showers, bathroom washbasins, clothes washing machines, and laundry tubs but does not include wastewater from kitchen sinks or

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<sup>4</sup>“Water Use Statistics.” *Drinktap.org*. American Water Works Association. Web. 12 Mar. 2012. <<http://www.drinktap.org/consumerdnn/Home/WaterInformation/Conservation/WaterUseStatistics/tabid/85/Default.aspx>>.

<sup>5</sup> Heaney, James P., et al.

<sup>6</sup> Mayer, Peter W., et al. *Residential End Uses of Water*. Tech. Denver: AWWA Research Foundation, 1999. Print.

<sup>7</sup> “1.6 Gallon, Low-consumption Toilets.” *Toiletology 101*. Web. 12 Mar. 2012. <<http://www.toiletology.com/low-flow.shtml>>.

<sup>8</sup> Millock, K. & C. Nauges (2010) Household Adoption of Water-Efficient Equipment: The Role of Socio-Economic Factors, *Environmental Attitudes and Policy, Environment Resource Economics*, 46:539-565.)

<sup>9</sup> US Green Building Council (USGBC) (2011) Water Efficiency, in LEED 2009 New Construction and Major Renovation, updated 2011, 25-30.)

dishwashers.”<sup>10</sup> This water can be treated to an appropriate quality and reused inside a residence. For a typical residence in Boulder, recirculating graywater to flush toilets could result in savings in indoor potable water consumption by as much as 30%. While graywater has other uses outside of toilet flushing, notably outdoor use, the focus of this thesis is to evaluate the impacts of the non-consumptive use of graywater for toilet flushing. There are significant costs associated with indoor graywater reuse, which requires a separate graywater collection system and toilet supply plumbing, as well as storage and treatment equipment.

Graywater recycling systems span a range of sizes, treated water quality, and operating and maintenance requirements. For single family residences, simple graywater systems can be installed in bathrooms to collect shower and sink water to be treated for immediate use in adjacent toilets. A small unit process like this requires minimal plumbing alterations and can be a retrofit to most homes. However, the cost and operation requirements of these small graywater systems are barriers to wide application. Installation of larger systems in multi-residence buildings provides economy of scale for equipment and operations requirements, and installation of dual plumbing in new construction costs less than retrofitting. Currently indoor graywater recirculation systems of any size are rare in the US, and as a result their impacts on water demand have not been widely studied. However, growing interest in green building design, which incorporates water efficiency, will benefit from more information on the impact of water reuse on building water efficiency, water conservation, and water supply. Also, related environmental, economic, and institutional impacts have not been incorporated into the limited number of existing studies, although they may be important factors in marketing and permitting. Installation of a dual plumbing (“purple pipe”) treatment and storage system for graywater reuse in toilets at a new LEED Platinum residence hall on the University of Colorado Boulder campus provided an opportunity for a study of these factors at a scale that would produce information for designers,

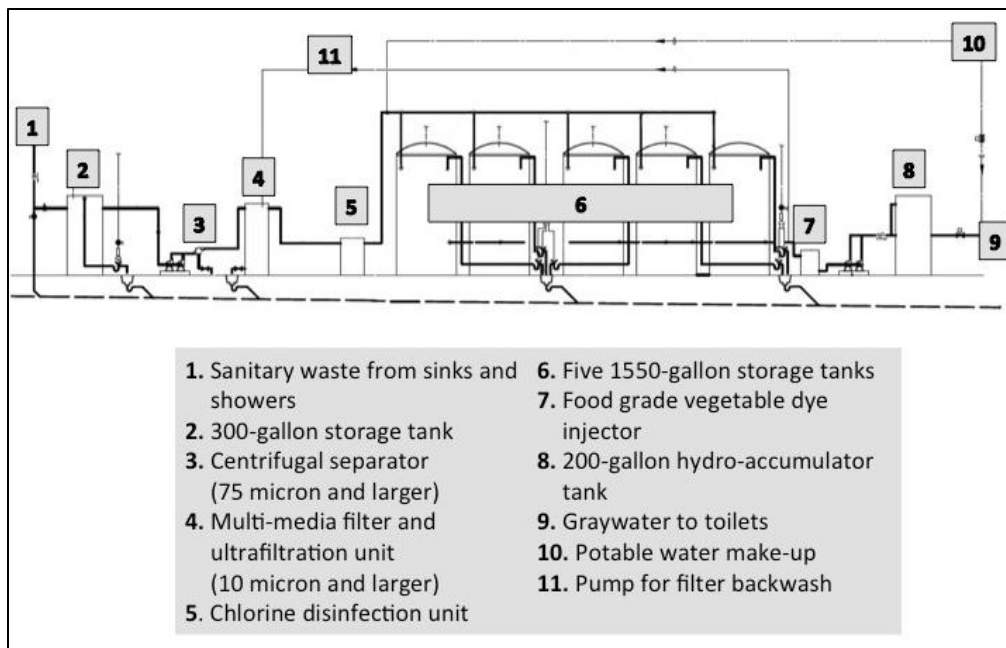
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<sup>10</sup> Department of Health Services Division of Drinking Water and Environmental Management. *California Health Laws Related to Recycled Water : Titles 22 and 17*. Rep. June 2001. Print.

building owners, utility managers, and regulators considering graywater systems as part of a strategy for reduction in potable water demand.

### 1.3 Case Study: Graywater Recycling System at Williams Village North

Williams Village North (WVN) is a 500-bed residence hall opened in 2011. LEED points were obtained for innovative wastewater technology from the graywater collection, treatment, and recycling system, and graywater recirculation also counted for water conservation points. Graywater is collected from the 65 sinks and 45 showers in the northwest wing of the building with 180 residents and piped to a water treatment system shown in Figure 1.2. Treated water is stored in pressurized tanks and distributed through purple pipes to flush the 105 toilets in the building.



**Figure 1.2 - Schematic of Graywater Treatment System.**

The influent storage tank provides flow equalization. Larger particles like hair and grit (> 75  $\mu\text{m}$ ) are removed in a centrifugal separator. Centrate flows by gravity through a multimedia filter and is pressurized before passing through the ultrafiltration membrane unit that filters out

particles larger than 0.1 microns. The ultrafiltration unit has a design capacity of 190 liters per minute (50 gallons per minute). No coagulant is added before the media filter, which serves more as a pretreatment unit for the ultrafiltration membranes, which are expected to remove virtually all bacteria and some viruses.<sup>11</sup> Contact with these biological constituents through splashes and aerosolization is a public health concern when using recycled water and ultrafiltration followed by disinfection was to further reduce the risk of exposure to toilet water. The filtrate is disinfected with chlorine and stored in tanks for a maximum of 48 hours. Before distribution, the treated water is injected with food grade purple dye. The system also has a potable water make-up line to account for any disparity between graywater supply and toilet flushing demand, as required by the International Plumbing Code.<sup>12</sup>

#### **1.4 Research Goals**

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This thesis uses a case study to evaluate the water demand, economic, environmental and institutional factors that influence decisions to install residential graywater. First, an estimate of water demand changes was made from a water balance on the Williams Village North residence hall. The water budget was calibrated using historic water use data from four neighboring residence halls in the campus housing area known as Williams Village. Estimates of water savings as well as physical system costs were the basis of an economic analysis. The interests of local institutions studied include the University and the local water and wastewater utility. Finally, wider issues of water rights, environmental impacts, and regulations are considered in the context of the State of Colorado.

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<sup>11</sup> Li, F., K. Wichmann, and R. Otterpohl, 2009 Review of the technological approaches for graywater treatment and reuses, *Science of the Total Environment*, 407:3439-3449.)

<sup>12</sup> International Code Council, *International Plumbing Code 2012*, ICC, Inc., 2011.

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## Chapter 2: Water Demand Impacts

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### 2.1 Background

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A water balance on the building was performed at a level of resolution to separate demand from toilets, showers and lavatory sinks. Comparison of potable water use and wastewater generation with and without graywater reuse is shown in Figures 2.1 and 2.2, respectively.

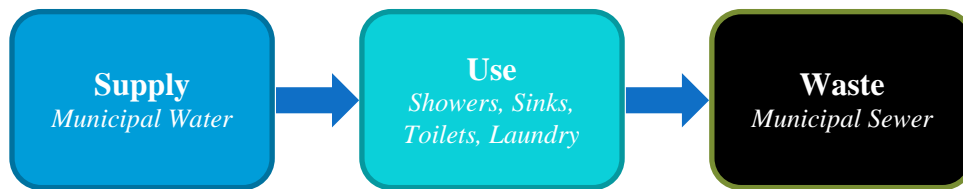


Figure 2.1 - Fate of Water in Residences with Centralized Systems without Water Recycling.

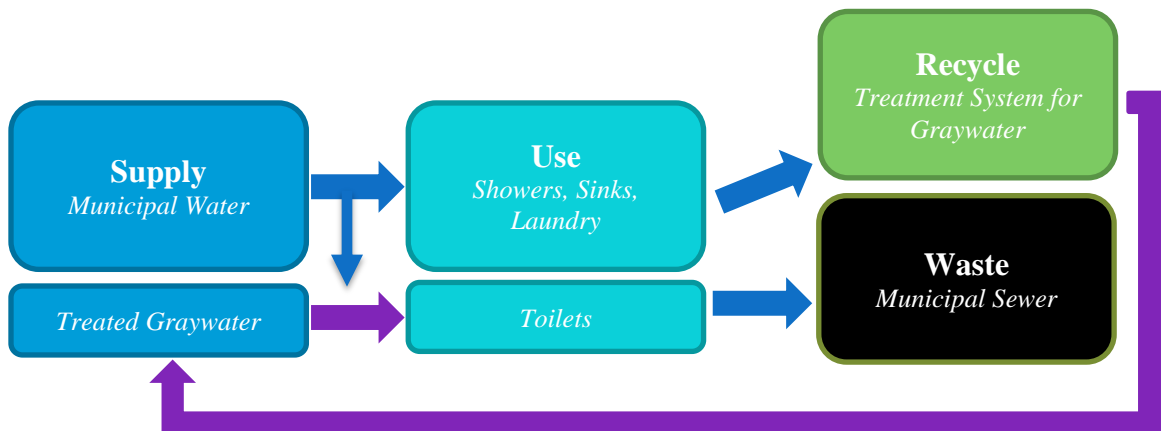


Figure 2.2 - Schematic of Centralized Fate of Water with Recycle.

#### 2.1.1 Methods

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In order to predict water demand in the residence halls, fixture counts and water use estimates from the mechanical/plumbing contractor, are used initially to estimate per capita demand without graywater reuse. This estimate was adjusted after comparison to 5 years of water use data from the older residences of comparable size and resident populations located in Williams Village.

Uncertainties in the estimates are characterized by examining the variability of water use data in adjacent residence halls.

## **2.2 WVN Occupancy and Predicted Water Use**

The water balance required compilation of WVN resident occupancy and estimating resident, staff, and visitor water use. Table 2.1 shows a summary of population and per capita daily demand data. The graywater input to the water balance consists of estimates of shower and lavatory sink water use by 180 of the 500 residents in the northwest wing.

Demand assumptions were based on a 1999 study of residential water use, which has been the used as a source in other fixture-based residential water demand estimates by USGS and the EPA.<sup>13</sup> The mechanical contractor for WVN supplied water use ratings for low-flow showers, sinks with aerators, and low flush toilets.<sup>14</sup> The Department of Housing and Dining Services at the University of Colorado, Boulder, supplied population information.

**Table 2.1 - Summary Table of Water Balance Assumptions**

<b>Water Balance Facts and Assumptions</b>		
<b>Occupancy</b>		
WVN Residents	500	people
Visitors	400	people/day
Residents in NW Wing	180	people
Staff	33	people
<b>Shower</b>		
Shower Flow Rate	1.5	gal/min
Average Length of Shower	7	min
Shower Use	1	use /resident/day
<b>Sink</b>		
Sink Flow Rate	1.5	gal/min
Resident Sink	7	gal/cap/day
Staff Sink	2	gal/cap/day
Visitor Sink	0.02	gal/cap/day
<b>Toilet</b>		
Toilet Flushing	1.3	gal/flush
Resident	5	flush/day
Staff	4	flush/day

<sup>13</sup> Mayer, P.W., W.B. deOreo, E.M. Opitz, J.C. Kiefer, W.Y. Davis, B. Dziegielewski, J.O. Nelson (1999) Residential End Uses of Water, TD223.R445, AWWA Research Foundation, Denver, CO.

<sup>14</sup> BCER Engineering, Non-Potable Water Plan, Sheet P-401, 04-01-2010

Visitor	0.1	flush/day
<b>Laundry</b>		
Laundry	40	gal/load
Resident	0.02	load/day
<b>Misc.</b>		
Unaccounted by fixtures	5%	of total water use

Water use for the WVN Residence hall was estimated from values in Table 2.1. Table 2.2 has a summary of the estimated total water use from each fixture category, all of which occurs during the academic year (275 days) when the building is fully occupied. Unaccounted use, estimated to be 5% of the total, included water used for drinking and in-room food preparation. During the summer, WVN has staff and visitors who are attending workshops or conferences. Due the fluctuating nature of summer building occupancy, water usage during that period of time was not calculated. Total water use for the academic year was estimated at 11.3 acre feet (AF), which translates into residents using 25 gallons/capita/day (gal/cap/day).

**Table 2.2 - Predicted WVN Total Water Use without Water Recycling.**

<b>Academic Year Use</b>		
Showers	5250	gal/day
Lavatory Sinks	3570	gal/day
Toilets	3470	gal/day
Laundry	400	gal/day
Unaccounted by fixtures	640	gal/day
Total Daily Use (academic year)	13,300	gal/day
Academic Year	275	days
<b>Academic Year Water Use</b>	<b>11.3</b>	<b>acre feet (AF)</b>
<b>Resident Daily Use (academic year)</b>	<b>25</b>	<b>gal/cap/day</b>

Graywater available for toilet flushing is comprised of water from showers and lavatory sinks, used by the 180 residents in the northwest wing during the academic year at the fixture use rates given in Table 2.1, equivalent to 17.5 gal/cap/day for residents. Collected graywater is assumed to be 95% of the water use, allowing for minor losses by evaporation, spillage and leaks during use so the net graywater produced for toilet flushing is  $0.95(17.5 \text{ gal/cap/day} \times 180 \text{ residents}) = 2,993 \text{ gal/day}$ . This is 14% less than the projected demand for toilet flushing, 3,474 gal/day, and potable

water will be used to augment the graywater. Water saved by graywater recirculated for toilet flushing throughout WVN during the academic year is 2,993 gals/day x 275 days/Academic Year (AY) =  $8.23 \times 10^5$  gal/AY = 2.5 AF/AY. Calculated water saved is 22% during the academic year, as shown in Table 2.3.

**Table 2.3 - Predicted Academic Year Water Savings.**

Total Annual Water Use (no recycle)	<b>11.3</b>	<b>AF/Academic Year (AY)</b>
Total Recycled Water Generated	2.5	AF/AY
<b>Potential Water Savings</b>	<b>22%</b>	

## 2.3 Water Use Variability Analysis

### 2.3.1 Validation of WVN Water Estimates

At the time of this study, WVN has been occupied for less than one year and there is no flow monitoring at the resolution necessary to verify the water budget estimates in Tables 2.1 and 2.2. However, historical water use information from three adjacent residence halls with approximately 2,500 residents is used to check the accuracy of the water budget for WVN. It is expected that WVN would fall into the lower range of water consumption in comparison to the other residence halls as WVN is outfitted with water conserving fixtures and does not have in-suite kitchens like some of the residence halls in the comparison. As with WVN, the annual per capita water use is based on the academic year of 275 days.

Population and water use information for four residences is summarized in Table 2.. The predicted water demand for residents in WVN, without graywater reuse, is 25 gal/cap/day, neglecting staff and non-resident student use for accurate comparison to the other residence halls. WVN total water demand estimates in Table 2.2 include additional use by students in an academic program and conference service staff that does not occur at the other residences. The projected demand for residents at WVN is not significantly different from the other residence halls. However this raises questions about the accuracy of the WVN water budget, since of all



the buildings only WVN has extensive water-saving fixtures, which should result in about 30% less consumption than those dorms outfitted with conventional fixtures and faucet aerators.<sup>15</sup>

**Table 2.4 - Water Use in Williams Village Residence Halls. Values for Stearns and Darley Towers and Bear Creek Apartments are based on 2009 water meter data. WVN estimate is from Table 2.2**

	Resident Population	Average Annual Water Consumption (kgal/year)	Water Use per Capita (gal/cap/day)
Stearns Towers	950	6534	25
Darley Towers	530	3784	26
Bear Creek A & B	979	7003	26
WVN Estimate (no recycle)	500	3438	25

In validating the predicted per capita usage for WVN against other residence halls, the estimated use was too high for a building outfitted with water-saving fixtures. A different approach was taken to get more accurate estimates water use to better estimate graywater generation. Residential water use data reported in “The Residential End Uses of Water,” (Mayer et al., 1999) is used to adjust the original water use distribution assuming less laundry use, and eliminating baths and dishwashing.

The known annual water use for the three older residence halls is now allocated among the use categories to produce new fixture use estimates for student residents shown in Table 2.5. It should be noted that the usage distribution was adjusted further for the Bear Creek consumption calculations as the residents have access to more in-suite kitchens than the other residence halls. The estimates for student resident use suggest that students take fewer showers and do less laundry than people living in single-family homes, so toilet flushing becomes a much larger fraction of indoor use.

<sup>15</sup>“Water Use Statistics.” *Drinktap.org*. American Water Works Association. Web. 12 Mar. 2012. <<http://www.drinktap.org/consumerdnn/Home/WaterInformation/Conservation/WaterUseStatistics/tabid/85/Default.aspx>>.

**Table 2.5 - New Use Statistics for Older Residence Halls applied to adjust water use estimates in WVN incorporating flows for water saving fixtures**

Use category	Older Residence Halls		WVN
Clothes Washers	1.22	loads / capita / month	1.6 gal/cap/day
Sinks	4.25	min / capita / day	6.4 gal/cap/day
Showers	3.33	min / capita / day	5.0 gal/cap/day
Toilets	2.64	flushes / capita /day	3.4 gal/cap/day
Other Domestic	0.1	gal/cap/day	0.1 gal/cap/day

Using these use statistics and the known flow rates and water fixture capacities at WVN, a new water budget was calculated. From the budget, new predicted water usage numbers were calculated for WVN incorporating the water saving fixtures alone and adding 22% reduction for the graywater system: 16.4 gal/cap/day and 13 gal/cap/day, respectively. Water usage without recycle can be found by adding all the gal/cap/day values in the last column of Table 2.5, and predicted savings from graywater is calculated when toilet flushing is subtracted from the total water usage. The new estimate produces a 35% reduction in water demand from the water efficient showers, sinks and toilets in WVN, based on the current average use of 25.5 gal/cap/day in the older residence halls, from Table 2.4.

Using the WVN estimates from Table 2.5, the 180 residents in the northwest wing will produce 2,052 gal/day graywater. Residents account for 94% of the toilet flushing demand, equal to 1,715 gal/day. Therefore, based on the new water use estimates, graywater can meet all the toilet flushing requirements for WVN, and installing the graywater system will result in a 22% reduction in water use or 1.45 AF/year though the use of graywater recirculation. Water monitoring at WVN will produce data to check estimates made by both the old and new methods.

### 2.3.2 Variability of Water Usage

Since the calculations from the previous section are based on annual average water usage, an additional analysis was performed to quantify the variability of indoor water usage from year to year. A simple statistical analysis was performed on 5 years' worth of data from two older residences, Stearns and Darley Towers. The monthly water use at each residence hall for 5 years

of meter data is shown in Figure 2.3. From the line graph, it is apparent that water consumption follows a consistent trend during the year with low water demand during the summer months when few students were in residence halls. The 95% confidence intervals on the 5-year average for the monthly usage data are shown in the bar graph. These confidence intervals show the small operating range for water demand and further illustrate the consistency of water usage each month, especially during the academic year.

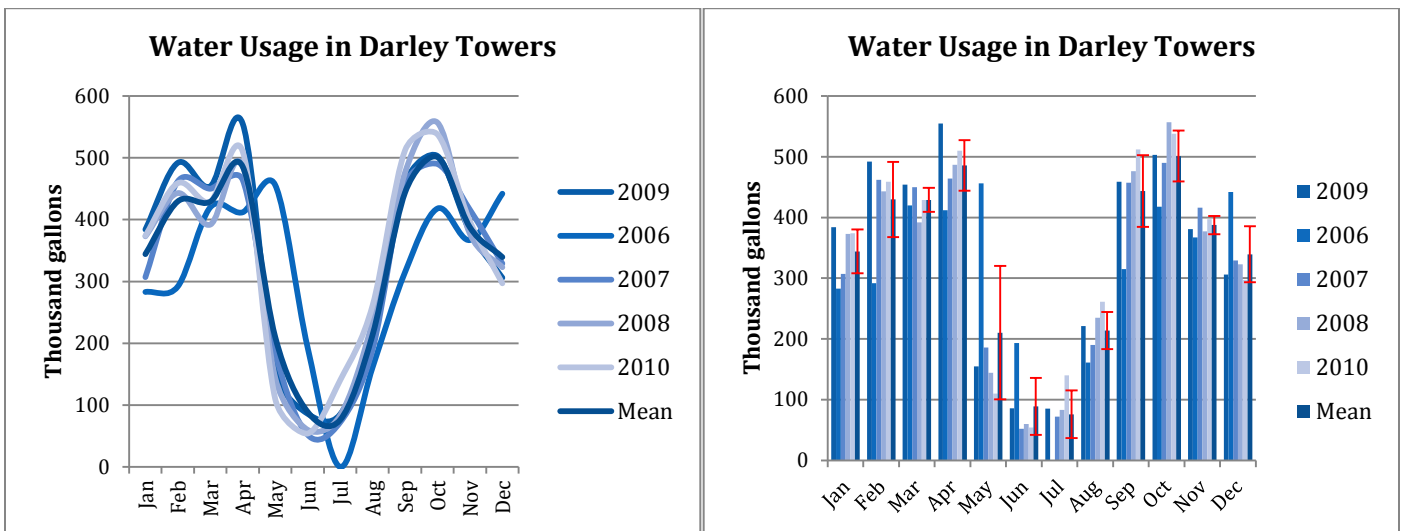


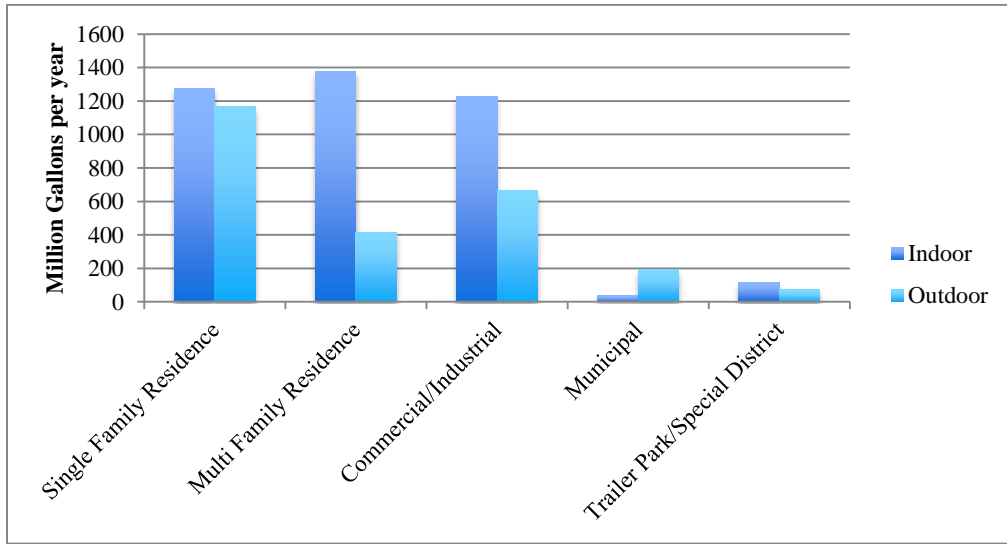
Figure 2.3 - Annual variability of water usage at Darley Towers.

Even though residents change from year to year, their overall water use habits are comparable to the previous year's residents. Because of the relatively stable nature of water use in residence halls, the impacts of indoor water reuse should be predictable. Once the graywater recycling system is installed in WVN, the baseline water use data as billed by the City of Boulder should experience the estimated 22% reduction each year that the system operates. For future planning of similar graywater systems, system sizing and predicted savings can be iterated from academic year water use data as data is found to be predictable and consistent.

## 2.4 Scale Up Implications

Utilities and planners are interested in the impact of residential graywater reuse on potable water demand, and for this study, population and water demand trends predicted for the City of

Boulder over a 25-year build out scenario are used as an example. The City Water meter data for average indoor and outdoor water use in single family and multi family residences, including group residences at the University of Colorado, commercial/industrial and municipal use between 1994 and 1997 are shown in Figure 2.4.<sup>16</sup>



**Figure 2.4 Average annual indoor and outdoor water use by customer categories in Boulder, Colorado between 1994 and 1997.**<sup>17</sup>

A distinct difference in water demand between categories of users, shown in Figure 2.6 is the fraction of total demand used indoors: 76.7% for multi family versus 52.2% for single-family residences. Furthermore, the general trend in residential population in Boulder over 25 years has been predicted to be increased infilling and densification of residences, with a 19.9% increase in multi family residences versus a 16.6% increase in single-family residences. In the same period, the service area population in Boulder is projected to increase from approximately 95,000 in 1993 to a maximum of 126,000 at build out. In addition to projections of increased growth, multi family and group residences are a more promising target for indoor graywater reuse due to economies of scale in capital and operations costs. Indoor water demand in multi family

<sup>16</sup> Hydrosphere Resource Consultants, Inc. (2000) City of Boulder Water Conservation Futures Study, Boulder, CO. [http://www.hydrosphere.com/publications/documents/WCFS\\_Final.pdf](http://www.hydrosphere.com/publications/documents/WCFS_Final.pdf)

<sup>17</sup> Ibid.

residences in Boulder also was projected to increase by 19.9% - proportional to the growth in the number of multi family residences, equivalent to 272 million gallons per year.<sup>18</sup>

For this study, a scenario for widespread adoption of graywater reuse at the municipal scale assumes that 100% of campus residence halls, which house 8,000 students, 100% of new multi family residences (4,798 units), and 25% of older multi family residences (4,595 units) will use graywater for toilet flushing when the City of Boulder has reached its build out residential capacity. The projected 22% reduction in indoor water use for the graywater system at the LEED platinum residence hall (WVN) was applied to all categories of users to predict the municipal water system impact. Water savings accounted for by the proposed level of implementation of indoor graywater reuse at build out are: 11.6 MG/yr for University of Colorado residence halls; for new multifamily residences, 57.1 MG/yr; and for retrofitting 25% of older multifamily residences, 72.3 MG/yr, for a total estimate of future water savings of 141 MG/yr. Total municipal water demand at build out was projected to be 8,048 MG/yr<sup>19</sup>; so the estimated water conservation impact of significant indoor graywater reuse under the proposed scenario is almost 1.8% of total projected demand for the City of Boulder at maximum build out. This estimate is conservative since an end-use study of water demand in Boulder residences concluded that 28.7% of indoor water demand was for toilet flushing.<sup>20</sup> Using the latter estimate for multi family residences with indoor graywater reuse, the municipal impact is estimate to be 2.3% of projected demand.

## 2.5 Conclusions

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Two methods have been applied to estimating water demand in a new 500-bed LEED platinum residence hall at the University of Colorado, Boulder. One, based on builder estimates of fixture use, does not capture the impact of water saving fixtures in the new building, when use is compared with historic water demand in comparable older residence halls. The second method

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<sup>18</sup> Ibid.

<sup>19</sup> Ibid.

<sup>20</sup> Ibid.

relies on disaggregated water use data collected from single-family homes in Boulder, Colorado calibrated to actual potable water use in existing campus residence halls. This method reflected a 35% reduction in water use from water saving showers, sink faucets and toilets – from 25 to 16.5 gallons/resident/day. Both methods predicted 22% reduction in indoor use through graywater recirculation for toilet flushing.

Scale greatly impacts the perceived benefits of indoor graywater recirculation. For residential buildings, graywater recycling for toilet flushing can reduce indoor water use by over 22 to 28.7%, which is a significant savings at the household scale. Coupled with water saving fixtures as at WVN, savings may be as much as 50% of indoor use.

The impact is reduced when the same fractional water savings are applied on a city-wide basis, where non-residential indoor use, irrigation, and single-family residences significantly influence demand. Assuming adoption of indoor graywater reuse for toilet flushing in all campus residences halls, and a fraction of multi family residences, the reduction in total municipal water demand in Boulder is approximately 2%. Moreover, based on the WVN residence hall water budget estimate, water saving fixtures may achieve reduction in indoor use of up to 35% and be installed easily in both single- and multi-unit residences. In cities with higher density housing and prevalence of multi-resident buildings, however, more centralized graywater systems can achieve water savings at a significant economy of scale and convenience to residents.

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### *Chapter 3: The Economics of Water Efficiency: A Graywater Case Study*

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This chapter provides a more in-depth economic analysis of the impact of installing graywater recirculation systems for the treatment of graywater to flush toilets. First, a framework for analyzing water conservation will be discussed through the definition of overall water use efficiency and its corresponding components. Each of these components will be defined and discussed in the context of graywater recycling. Next, a holistic economic analysis will be performed, incorporating the components of overall water use efficiency. This analysis will include the economic impact the system poses to the campus, water utility, and environment.

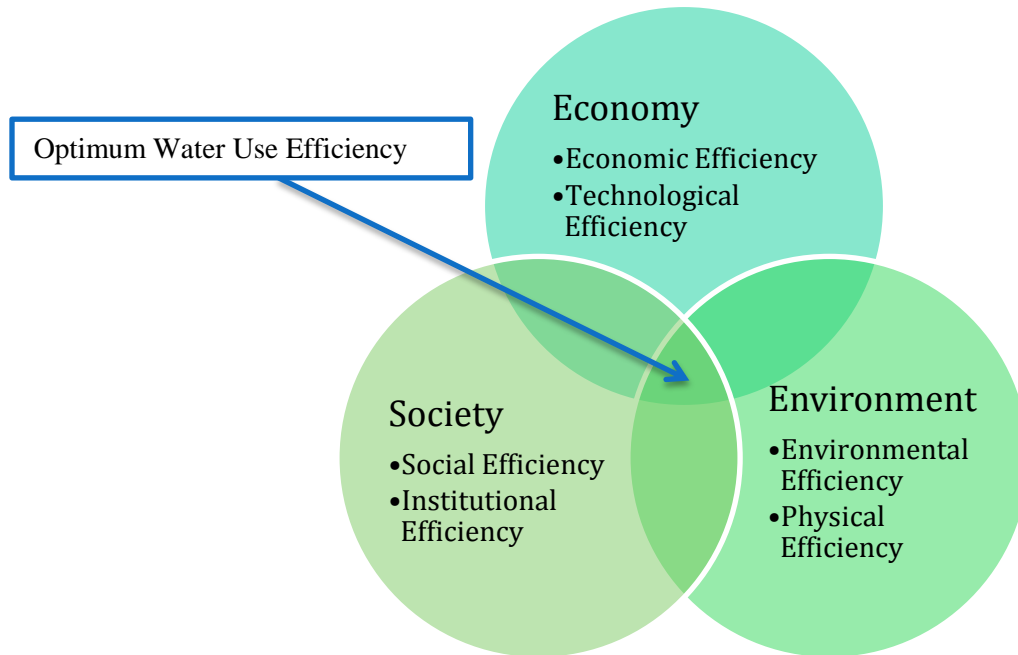
#### **3.1 Components of Overall Water Use Efficiency**

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The economics of water efficiency can be characterized to include the following 6 components: physical efficiency, economic efficiency, institutional efficiency, social efficiency, environmental efficiency, and technological efficiency.<sup>21</sup> As the components can be broadly defined, some overlap occurs between and among categories. Each of component is complex, yet, for the sake of brevity, the scope of this section is to summarize some main considerations for each in regards to graywater recycling in Boulder, Colorado. The components listed above will be evaluated for a more holistic economic analysis beyond potential savings incurred to water and wastewater customers.

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<sup>21</sup> Billi, A., G. Canitano, and A. Quarto. "The Economics of Water Efficiency: A Review of Theories, Measurement Issues and Integrated Models." *OPTIONS Mediterraneenes* B 57 (2004): 228. Print.



**Figure 3.1 - Triple Bottom Line Approach and the components of Water Use Efficiency.**

Although efficiency for each component can be defined and optimized within the parameters of that specific component, *overall water use efficiency should reduce the amount of water needed for any goal while still accomplishing that goal.*<sup>22</sup> Thus, water use efficiency is achieved when all needs are met without compromising efficiency. For the purpose of this thesis, the desired outcome is achieved when overall water use efficiency is met at the convergence of the economy, environment, and society. This is known as the Triple Bottom Line approach, and Figure 3.1 shows how the components of water use efficiency can be divided into a Triple Bottom Line analysis. The classification of some of the efficiency components to economy, society, and environment are arbitrary yet still make important contributions to Triple Bottom Line analysis.

<sup>22</sup> Gleick, Peter H., and Nicholas L. Cain. *The World's Water, 2004-2005: The Biennial Report on Freshwater Resources*. Washington, D.C.: Island, 2004. Print. page 104



### 3.1.1 Physical Efficiency

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Physical efficiency is achieved when the least amount of water is used for any activity.<sup>23</sup> In real world applications, achieving strict physical efficiency can be infeasible due to factors like public acceptance and / or complexity of design. For a graywater recycling system, physical water efficiency is obtained through use of recycled shower and sink water to flush toilets, therefore offsetting the potable water demand for flushing toilets. By using the treated water supply more than once, the physical efficiency of the system increases. While this physical efficiency can be easily measured, the overall impact on water use efficiency needs to be evaluated further as the installation of a graywater system has intrinsic economic and environmental costs that need to be addressed.

### 3.1.2 Economic Efficiency

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Economic efficiency is achieved when the incremental cost of reducing demand is the same as the incremental costs of augmenting supply.<sup>24</sup> Economic efficiency operates on the principles of equimarginal value and marginal cost pricing.<sup>25</sup> In other words, the principle of equimarginal value assumes that water is a homogeneous good that is allocated in a way that all users derive equal value from the last (marginal) unit used or consumed. Additionally, marginal cost pricing assumes that the marginal benefit of use of the resource should be equal to the marginal cost of its supply, assuming equimarginal value exists.<sup>26</sup> Incorporating these two principles, a water resource is economically efficient when the cost of an additional unit of water is the same for the user and supplier, regardless of the source. This statement assumes three efficiency conditions: water is distributed efficiently from each source to the treatment process, overall production of water, in the scope of quantity and quality, is efficient, and water is distributed efficiently to users once treated.

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<sup>23</sup> Ibid.

<sup>24</sup> Gleick 104.

<sup>25</sup> Billi 231.

<sup>26</sup> Billi 231.

A graywater system would be economically efficient when the amount invested in graywater per unit water conserved would be equivalent to the costs per unit of developing new supplies. This situation assumes that external costs like treatment and conveyance are included in the economic analysis. This assumption is often the biggest challenge in evaluating economically efficient water conservation measures as it is widely noted that water has traditionally been thought of as a free resource of unlimited supply with zero costs at the supply point.<sup>27</sup> Water users have been charged only a portion of the cost of extraction, transfer, treatment, and disposal and justification of installing expensive decentralized graywater systems cannot often be justified by water savings alone.

### 3.1.3 Institutional Efficiency

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Institutional efficiency refers to the ability of outstanding policies and institutions to support or deter the adaptation of conservation. Common nuisances to institutional water efficiency policies include property and water rights, building codes, and supply side management of water resources.<sup>28</sup> While water rights and other legalities that interfere with water recirculation will be addressed in the next chapter, supply side management can be addressed now. Supply management refers to the common practice of water utilities expanding their water portfolios through acquiring new freshwater sources. Utilities, especially in Boulder, tend to overdevelop their water portfolios to increase the level of system reliability.<sup>29</sup> For example, in 2000, Boulder's raw water supply, neglecting drought reservation and some exchanges, was firmed at 33,000 Acre-feet (AF) to address the demand of 22,400 AF.<sup>30</sup> This overinvestment in raw water sources is a financial burden that the general public generally does not understand, as it is not reflected in their water rates.<sup>31</sup>

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<sup>27</sup> Billi 231.

<sup>28</sup> Billi 231.

<sup>29</sup> Howe, Charles W., Mark G. Smith. "Incorporating Public Preference in Planning Urban Water Supply Reliability." *Water Resources Research* 29.10 (1993): 3363. Print.

<sup>30</sup> Hydrosphere Resource Consultants, Inc., and Aquacraft, Inc. *City of Boulder Water Conservation Futures Study*. Tech. Boulder, 2000. Print. 1.

<sup>31</sup> Howe 3363.

For much of the Arid West, new sources are scarcer and existing water resources are being depleted faster than their recharge rates. A new approach needs to be taken to balance water resources for a sustainable water future. Shifting water supply management to include demand-based policies in which uses of water are evaluated for efficiency can provide for a more secure water future. In areas like Boulder with overdeveloped water portfolios, demand management can provide a means to control the increased water usage associated with population growth without the expenditure of capital required to develop new sources. Graywater recirculation can be considered one of the many tools in the toolbox of water conservation, and conversely, demand management.

As the owner and operator of the system, the University of Colorado is an additional institution that should be considered in the economic evaluation. The economic costs to the university include the costs discussed in economic efficiency section. Externalities to these costs include the promotion of the university campus as a “green” institution and benefits associated with being branded in that manner. The City of Boulder can also benefit from the externalities associated with being branded “green”.

#### 3.1.3.1 Impact on Water and Wastewater Utilities

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The overall institutional impact of addressing water use through conservation technologies like graywater recycling can have positive effects as institutions benefit from reduced water waste and more efficient operation. The institutions most effected by the installation of graywater systems are water utilities that depend on fixed revenue to operate their plants. For conservation to be economically efficient, both the finances and the economics of the utilities need to be evaluated.

Finances of a utility include plant investment fees and user fees. To cover capital costs of water treatment and save for future plant expansions, utilities charge a plant investment fee (PIF)

when an increase in demand is placed in the city's existing water and wastewater system.<sup>32</sup> PIFs are calculated in conjunction with a user's water budget. User rates are charged based on a water budget that is calculated to cover the cost of source water extraction, treatment plant operation, and treated water delivery. Boulder operates on an increasing block rate structure in which each block is allocated a different portion of the water budget and is charged a different percentage of the operational costs; in the City of Boulder Block 2 is the rate that charges in full for the variable costs of extraction, treatment and delivery. Roughly 60% of the users in Boulder are charged at Block 2, which currently operates under the rate of \$3 per thousand gallon (kgal).<sup>33</sup>

The economics of a water utility expand beyond the finances to include the opportunity cost of water. In Boulder, this opportunity cost is associated with the cost of water rights. Although paid off long ago, the City of Boulder has approximately \$400 million dollars invested in water rights.<sup>34</sup> If users were to be charged for the full economic costs of their water, rates would include the opportunity costs of these water rights. This opportunity cost arises from the value of denying other users access to the water in which rights are held. Roughly calculated, this would add \$1.55 per kgal. Adding that to the Block 2 level would result in a fee of \$4.55 per kgal, or a 1.5 fold increase in rate at the Block 2 level. In order to better evaluate the cost of water and thus the compare water savings incurred with a graywater system, the rate of \$4.55 per kgal will be used to represent the actual cost of City of Boulder water.

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<sup>32</sup> Planning and Development Services Center. *Estimating Water, Wastewater & Irrigation Plant Investment Fees and Determining Water Meter Sizing*. Publication. City of Boulder, 2009. Print.

<sup>33</sup> Howe, Charles. Personal interview. 30 Jan. 2012.

<sup>34</sup> Howe.

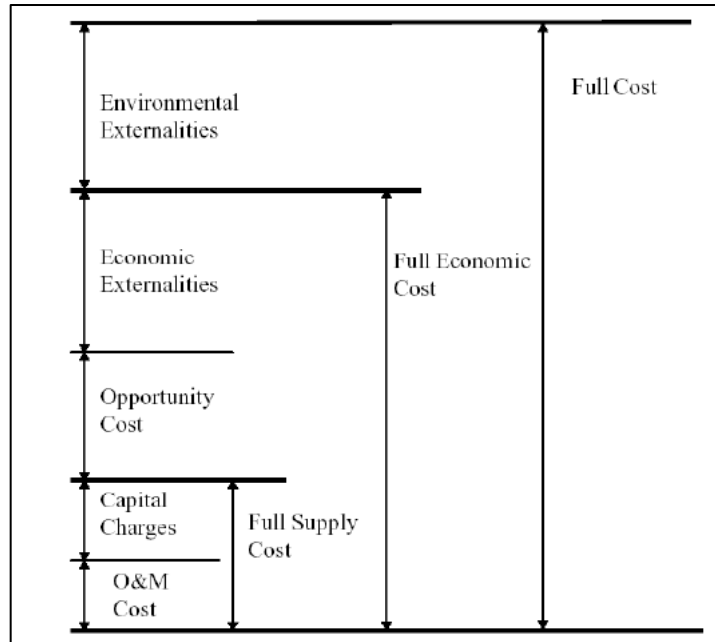


Figure 3. 2– Water Utility Costs<sup>35</sup>

Figure 3.2 shows the distribution of water utility finances and economics. In the figure, full supply costs represent utility finances and full economic costs represent water utility economics. As illustrated in the figure, the additional component of environmental externalities is included in the full costs. These externalities are difficult to economically quantify and will be discussed later.

When looking at WVN and its consequent scale up to the City of Boulder, impacts to the utility are felt at the 30% city scale up level as calculated in the Water Balance portion of this report. City scale up would result in a predicted total reduction of treated water demand by 2%. The main economic motivations for utilities to enact conservation efforts are to reduce treatment costs and avoid the capital of developing new sources for water utilities.<sup>36</sup> A 2% demand reduction would offer a factor of safety for water utility operations and could delay the need for treatment plant capacity expansion and / or source development. Wastewater utilities would experience greater savings as the cost per unit treated wastewater is more than per unit treated

<sup>35</sup> Billi 237.

<sup>36</sup> Beecher, Janice A., Patrick C. Mann, Youssef Hegazy, and John D. Stanford. *Revenue Effects of Water Conservation and Conservation Pricing: Issues and Practices*. Tech. no. NRRI 94-18. National Regulatory Research Institute, 1994. Print.

drinking water.<sup>37</sup> The greatest financial impact on utilities with municipal installation of graywater recycling systems is the impact on revenues from reduced potable water demand.<sup>38</sup> Calculations for this loss of revenue to both the water and wastewater utilities are presented in a later section. As mentioned in Chapter 1, water use from toilets is the single most predictable and consistent water use in a residence. Due to the reliable nature of toilet flushing, water savings from implementing graywater systems to augment flushing water are expected to be significant and consistent and should be considered a permanent revenue loss to utilities once a system is installed. Careful rate planning can absorb and mitigate the lost revenue, as conservation planning should already be included in the determination of future fees. As the fluctuation of these rates directly impacts the public, the effect of water conservation on users is discussed in the next section.

#### 3.1.4 Social Efficiency

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Social efficiency is achieved when all users' needs are met.<sup>39</sup> It is in the best interest of utilities in the developed world to have 100% coverage within municipal boundaries as users are customers that pay into the system and cover the costs of treatment. Additionally, developing land legally obligates users to have a potable water source and a means to dispose of wastewater generated. Thus, the coverage component of social efficiency is already being met and will continue to be met assuming the current legal climate and customer/supplier relationship continues.

As mentioned in the economic efficiency section, there is a historical discrepancy in the value that users place on water and the actual costs that incurred in development, treatment, and delivery of treated water. When discussing the economics of utilities, a proposed additional fee of \$1.55 per kgal should be added on to each incremental block rate fee, except Block 1, to better

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<sup>37</sup> Allen, Bob. Personal interview. 24 Jan. 2012.

<sup>38</sup> Beecher et al. iii

<sup>39</sup> Billi 228.

represent the opportunity cost of access to water rights. Imposing this fee would have a larger impact on lower income homes not billed at the Block 1 rates.

The largest hurdle to overcome to reach social efficiency is the cultural belief that water is infinitely available and accessible and thus water conservation is not necessary. Historically this belief has been reinforced through the low costs of treated water charged by utilities. In the arid West, residents may feel some of the pressure associated with limited water resources and the eminent threat of droughts, yet still choose to cover their backyards with Kentucky bluegrass. This attitude, termed “green lawn syndrome,”<sup>40</sup> can be addressed with educational campaigns, but it could take generations of severe droughts to alter the current norm.

Even if some of the issues discussed above are resolved, the installation of a graywater recycling system may only be attractive to a small subset of the population. Historically it has been shown that metering and price have an effect on water use,<sup>41</sup> but these factors may not be influential at the dormitory level as the residents do not currently receive feedback on their water usage. When considering the scale-up implications of recirculation systems to a residential level, the price elasticity of water rates becomes more important. Financially, when considering non-university housing, the systems will be the most attractive to multifamily residences that have an economy of scale to offset the high capital costs associated with the installation of a graywater recirculation system. Until more units are bought and systems are produced on a larger scale, which would drive the system capital costs down, the biggest market for graywater recirculation will remain with multiple family housing units.

### 3.1.5 Environmental Efficiency

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For environmental efficiency to be reached, natural resource conservation is included in the economic analysis of a policy or system. Water conservation is ripe with environmental efficiency: by reducing demand, less freshwater supplies have to be developed, more water is left

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<sup>40</sup> Billi 233.

<sup>41</sup> Howe, Charles W., and F.P. Linaweaver. "The Impact of Price on Residential Water Demand and Its Relation to System Design and Price Structure." *Water Resources Research* 3.1 (1967): 27. Print.

in stream, and thus natural hydrology can be better preserved. Reduced treated water demand also results in a corresponding reduced energy demand from reduced pumping costs and reduced treatment costs, thus conserving fossil fuels and reducing greenhouse gas generation. For the City of Boulder, water conservation, like the installation of graywater systems, could mean reduced operating costs in developing sources like Windy Gap that provides an inconsistent and environmentally degrading source of water. Achieving water conservation through graywater recirculation provides for an intermediate decentralized step though the treatment of graywater onsite and thus treated water pumping costs are reduced with the reduced demand. Additionally, graywater treatment systems can be designed to remotely remove personal care products (PCPs) from the wastewater stream and thus improving wastewater influent quality and reducing the energy and resources required to remove the nuisance compounds at the wastewater utility. By removing PCPs at the source, less persists through the wastewater treatment plant and effluent and receiving body water quality improves.

### 3.1.6 Technological Efficiency

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Technical efficiency is used to refer to the ratio of outputs to inputs, like dollars per unit of water used.<sup>42</sup> This can be achieved by either increasing outputs or reducing water inputs. The end goal is to extract more valuable products from the same resources.<sup>43</sup> As extremely efficient technologies are created all the time, two distinctions in technology should be made to account for user interaction: best available technology and best practical technology.

Best available technology is the best commercial technology available for reducing water use.<sup>44</sup> For the case study of WVN, this technology would be dry composting toilets in which no water is used. As this is not a logistically or socially feasible technology for WVN, the solution of best practical technology through the installation of a graywater recirculation was implemented to satiate the current political and social norms. The best practical technology solution incorporates

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<sup>42</sup> Gleick 103.

<sup>43</sup> Billi 228.

<sup>44</sup> Gleick 104.



social judgments of social acceptability to define a more realistic estimate of the maximum practical technical potential. The installed system could be further iterated to be more economically and financially feasible if a lower, but still socially acceptable, level of treatment was reached with a more basic and less costly treatment system.

### 3.1.7 Overall Water Use Efficiency

Table 3.1 summarizes the previous sections by listing the challenges that need to be addressed for graywater recirculation to meet Triple Bottom Line Criteria.

**Table 3.1 - Components of Overall Water Use Efficiency and the Challenges Posed by Each Component.**

Component	Challenges Posed
Physical Efficiency	Social Acceptability
Economic Efficiency	Value of Water
Institutional Efficiency	Economics and Finances of Water Utilities
Social Efficiency	Social Equity, Cultural Beliefs
Environmental Efficiency	Enhancing Natural Water Quality
Technological Efficiency	Best Available Technology vs. Best Practical Technology

To address the social acceptability challenge posed in physical and technological efficiency, public acceptance surveys should be administered to gauge how residents view the water recirculation system. These surveys can also address the challenges of social and economic efficiency by getting a better understanding of how users value water. Environmental efficiency is already assumed to be achieved by maintaining flow in source water bodies, but this component can be reevaluated once system operation data is produced and operation and maintenance is better understood. Two components of interest that could alter the environmental efficiency of the recirculation system are the frequency of membrane replacement and power consumption.

### 3.2 Economic Analysis of the Graywater Recirculation System in Williams Village North

This section will address the economic costs to the user, of the University of Colorado, and the utility, or the Utilities Division of the City of Boulder. Referring back to Figure 3.2, this section attempts to quantify only the full supply cost of water to address institutional, social, and

economic efficiency. While the other components of overall water use efficiency are equally important, it is out of the scope of this thesis to attempt to quantify these externalities.

### 3.2.1 Cost of Water per Thousand Gallon

In order to understand the economics of the recirculation system, the annual cost of water produced by the system was calculated. Using the capital costs as taken from the designing engineer's estimates, an annualized cost was found. This cost was then normalized for the volume of water that the system is permitted to treat each year. The result, as highlighted in Table 3.2, is a cost of roughly \$66 per thousand gallons of water. The costs for annual operation and maintenance (O&M) were predicted to be 5% of the capital costs based off of values found in literature,<sup>45</sup> once the system is in operation, this amount will be better known. With the expected savings, the annual return on investment is roughly 13%, which does not account for changing rates or inflation. The return on investment number was calculated using water utility Block 2 savings with included opportunity costs added to wastewater savings.

<b>Capital Costs</b>	
<b>Graywater System</b>	\$ 197,000
<b>Purple Piping</b>	\$ 239,000
<b>Total Capital Costs</b>	\$ 436,000
<b>Discount Rate</b>	5%
<b>System Lifespan</b>	20 years
<b>Equivalent Annual Cost of System</b>	\$ 34,990
<b>O&amp;M (5% Capital)</b>	\$ 21,800 / year
<b>Equivalent Annual Cost of Operation</b>	\$ 56,790 / year
<b>Amount of Graywater to be Treated</b>	867 kgal / year
<b>Graywater Costs</b>	\$ 66 / kgal
<b>Money Saved (Block 2)</b>	\$ 7,430 / year
<b>Annual Rate of Return</b>	13% / year

<sup>45</sup> Friedler, E., and M. Hadari. "Economic Feasibility of On-site Greywater Reuse in Multi-storey Buildings." *Desalination* 190.1-3 (2006): 229. Print.

When comparing the cost of water produced by the system at \$66 to the rate that the utility charges (\$ 4.55 / kgal, adjusted for opportunity costs) the graywater system does not seem to be economically advantageous to the University of Colorado. The City of Boulder rates neglect to include the PIF that is required for all new water users as the figure is unknown at this point in time, but the annualized number is not expected to increase the rate by a large enough magnitude through the inclusion of the PIF to be comparable to the cost per thousand gallon of the system. Overall, when taking into consideration the low ROI and low expected annual water savings, the system is not considered to be economically efficient.

### 3.2.2 Lost Revenue to the City of Boulder

As the demand for potable water will be reduced by the installation of a recirculation system, the University of Colorado will experience a reduction in utility bill from the City of Boulder. This savings for the university translates to a revenue loss to the City of Boulder, as shown in Table 3.3.

**Table 3.3 - Expected Revenue Losses to the City of Boulder**

	<b>\$ / kgal</b>	<b>Lost Revenue</b>
<b>Block 1</b>	\$ 2.25	\$ 1,950
<b>Block 2</b>	\$ 3.00	\$ 2,600
<b>Block 2 w/ Opportunity Costs</b>	\$ 4.55	\$ 3,900
<b>Wastewater</b>	\$ 4.02	\$ 3,500

As the table shows, even when the cost of water includes opportunity costs, the installation of a graywater system does not present a positive economic analysis. Regardless of the treated water delivery, reduced revenue due to less wastewater adds a consistent loss of \$3,500. This conclusion confirms the initial hypothesis that graywater systems do not prove to be an attractive option when only economic factors are considered.

### 3.3 Conclusions

The conclusions of this chapter are summarized in Table 3.4. As shown, the majority of the components discussed have a net positive efficiency except for economic and technological efficiency. The system, as expected, was not found to be economically efficient after a simple

economic analysis was performed. Additionally, the system was found to be neutral in regards to technology as a less energy intensive system could have been selected to create an appropriate water quality for toilet flushing.

**Table 3.4 - Overall Water Use Efficiency for WVN Graywater Recirculation System.**

Component	Net Efficiency	Explanation
Physical Efficiency	Positive	Increased physical water use efficiency
Economic Efficiency	Negative	High capital and O&M costs are not offset by water savings
Institutional Efficiency	Positive	Water Utility benefits from water conservation, CU Boulder benefits from green technology
Social Efficiency	Positive	All residents benefit from system
Environmental Efficiency	Positive	Natural hydrology maintained, removal of PCPs
Technological Efficiency	Neutral	While technology is water efficient, system requires frequent parts replacement and creates additional building energy demand

Overall, the installation of a graywater recycling system has the potential for high overall water use efficiency and satisfies the convergence of the triple bottom line components.

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## ***Chapter 4: Water Rights, Permitting, and the Implications of the Current Legal Climate in Boulder Colorado***

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The largest roadblock to implementing the system at Williams Village North was creating operating conditions that were in adherence to Colorado water rights. This chapter provides an overview of water rights and explains them in the context of reuse in Colorado. Next, a few examples of current reuse projects are discussed. Following that, the permitting process for the system at Williams Village North will be discussed. Finally, recommendations will be made for future successfully graywater and reuse projects in Boulder. The environmental implications of water rights and importing water will also be discussed.

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### **4.1 Overview of Water Rights**

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One of the biggest challenges to the implementation of water reuse applications and water conservation policies anywhere is a state's water law policies. This complicated network of laws and rights can make or break a water conservation project. There are 3 types of water rights that can be held: riparian, prior appropriation, and hybrid. Riparian rights are typically found in states with abundant access to surface waters and are based off of property ownership boundaries. Conversely, prior appropriation water rights govern most arid states and are based on the "first in time, first in right" mentality that can be traced back to when miners settled the west.<sup>46</sup> Hybrid systems operate in states that started with a riparian rights system and then switched to a system of appropriation while still retaining some of the riparian rights.<sup>47</sup>

Colorado's water rights system is based of the doctrine of prior appropriation. In this doctrine, each water right user is given a right that dictates the quantity of water allowed and its specified beneficial use. Unlike riparian rights, prior appropriation rights do not require the water to which rights are held to be on or bordering the property of the right holder. In fact, many water rights

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<sup>46</sup> Getches, David H. *Water Law in a Nutshell*. St. Paul, MN: West Publ., 1990. Print.

<sup>47</sup> Ibid.

do not even require the water to be used in the same basin.<sup>48</sup> Additionally, priority of rights is granted to the user who obtains the right first. Thus senior right holders have first priority to meet the quantity stated on their right and then junior users can withdraw from whatever remains. In times of drought or low flow, junior users can be denied water, especially in waterbodies where rights are over-appropriated.<sup>49</sup> Each right has a defined beneficial use, with no beneficial use is seen as superior to another, regardless of social or economic benefits.<sup>50</sup> Irrespective of senior or junior standing, all water rights are granted under reasonable use and reasonable diligence. This means that although the water is allocated to a specific use and waste of it is not allowed for, long-term failure to use a right can result in abandonment of the right.<sup>51</sup>

## **4.2 Water Conservation and Reuse Under Prior Appropriation Water Rights**

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The construction of prior appropriation water rights presents fundamental challenges to the implementation of water conservation and water reuse policies. If users do not withdraw close to their allocated amount because of conservation measures, they can lose their water right.

Achieving water efficiency is not a priority unless there is equivalent growth, and thus expansion of users, to make up for the water being conserved. In the context of downstream users, senior water rights holders require certain flows downstream and return flows from municipal uses need to be retained. Water reuse technologies that have a consumptive use are incorrectly thought to lead to reduced flows. For example, using graywater to replace a use in which potable water is typically used does not change the return flows as the equivalent amount of potable water would have been used consumptively. If anything, allowing for multiple uses of water improves overall water quality by allowing more water to remain in stream. Colorado, and other parts of the arid west, has a large amount of natural waterbodies that are effluent dominated and could benefit from the increased dilution factor that occurs when more water remains in the stream and less treated wastewater is discharged to the receiving body.

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<sup>48</sup> Ibid.

<sup>49</sup> Ibid.

<sup>50</sup> Ibid.

<sup>51</sup> Ibid.

An additional impediment posed by the structure of prior appropriation water rights is defining the constraints of a municipal use. Some water rights decrees allocate water for “one municipal use” which can be interpreted in a spectrum of different ways. Further restraining multiple uses is the philosophy predominant in Colorado in which once a use has been completed, the right of the user terminates.<sup>52</sup> To add another layer of complexity, legal oversight can be difficult to enforce at the municipal scale due to the personal, household level of use.

Other water rights, or water from the western slopes of the Rocky Mountains in the case of the City of Boulder, have a defined “use to extinction” clause written into the water rights decree. Use to extinction means that the user does not have a required return flow after the initial appropriated use. Most of the water that falls in to this category is “foreign” water, or water from another unconnected watershed. In Colorado, only foreign water is eligible for reuse.<sup>53</sup> While reusing the imported water provides for a more efficient use of the particular source, there are environmental costs to water importation including increased greenhouse gas emissions and the alteration of natural hydrology.

#### **4.3 Environmental Impacts of Importing Water in Colorado**

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Population settlement patterns in Colorado result in guaranteed water disparity: 75% of the population lives on the Eastern Slope, or Front Range, while 75% of the freshwater resources flow on the Western Slope.<sup>54</sup> The majority of projected population growth in the state is predicted to occur on the arid Front Range, thus the challenges to provide abundant water resources is further escalated. Since the 1890 construction of Grand Ditch project, water has been diverted from the Western Slope for use on the Front Range.<sup>55</sup> In the following decades, trans-basin projects grew in size to meet the water needs of agriculture and growing populations. Figure 4.1

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<sup>52</sup> Maynard, Alison. "The Reuse Right in Colorado Water Law: A Theory of Dominion." *Denver University Law Review* 68 (1991): 413. Print.

<sup>53</sup> Maynard, 413.

<sup>54</sup> "Water Rights Planning." *Supply and Planning*. Denver Water. Web. 02 Apr. 2012. <<http://www.denverwater.org/SupplyPlanning/WaterRights/>>.

<sup>55</sup> "Let's Just Say 'no' to More Transbasin Diversions." *Editorials*. Sky-Hi News, 1 Dec. 2009. Web. 02 Apr. 2012. <<http://www.skyhidailynews.com/article/20091201/NEWS/912019992>>.

shows in blue arrows the major trans-basin transfers in Colorado. These projects provided attractive water futures because to the sources were abundant, opposition to changing rights from agricultural to municipal on the Front Range existed, and water quality and endangered species issues emerged in the natural waters on the Front Range.<sup>56</sup> In addition, the use of foreign water provides municipalities with a use to extinction that benefits users in lax return flow accounting.<sup>57</sup>

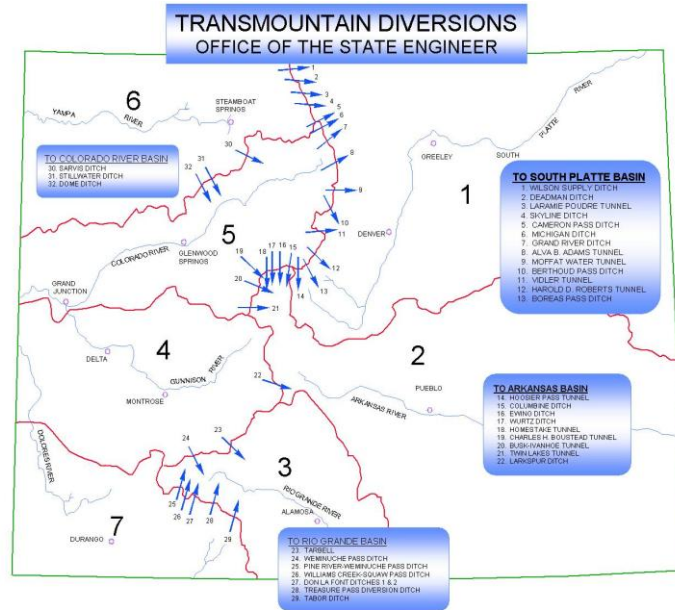


Figure 4.1 - Major Trans-Basin Diversions in Colorado.<sup>58</sup>

While trans-basin diversions presented an attractive option for the expansion of a municipality’s water resource portfolio, the net aggregate environmental impact of Front Range communities drawing from Western Slope water resources is negative. In a culture where water rights to most water bodies are over-appropriated, access to Western Slope water is quickly grabbed up by Front Range users, often causing a social inequity between the more affluent Front Range users and the existing Western Slope users.<sup>59</sup> As more water was diverted from the Upper Colorado and Fraiser Rivers, the main water resources flowing through the Western Slope, the

<sup>56</sup> Nichols, Peter D., Megan K. Murphy, and Douglas S. Kenney. *Water and Growth in Colorado: A Review of Legal and Policy Issues*. Rep. University of Colorado School of Law: Natural Resources Law Center. Print.

<sup>57</sup> Ibid

<sup>58</sup> "Transbasin Diversions." *Water Diagrams*. Colorado Division of Water Resources. Web. 02 Apr. 2012. <<http://water.state.co.us/SurfaceWater/SWRights/WaterDiagrams/Pages/TransbasinDiversions.aspx>>.

<sup>59</sup> Nichols, x.



natural hydrology of the rivers has been destroyed though reduced flows. Reduced flows have resulted in the increase of endangered species and warmer water temperatures. Also suffering from reduced flows are communities downstream on the Western Slope that depend upon flows for recreation and tourism.<sup>60</sup>

While some of these issues are being mitigated, future plans to redirect water to the Front Range need to be more sensitive to the environmental costs of trans-basin transfers. Developed projects are extremely expensive and should only be implemented once all other potential demand management programs are exhausted. Incorporating water reuse into municipalities' water portfolios can ensure a more resilient water supply. For reuse to have the biggest impact, definitions of decreed uses need to be expanded while still maintaining return flows. All imported water should carry a use to extinction mandate such that once the water gets to the Western Slope it is used in the most efficient way possible.

#### **4.4 Water Reuse Projects in of Colorado**

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Despite the challenging climate for implementing water reuse projects, communities on the Front Range of Colorado have been able to implement successful, legally sound, reuse projects. The largest of these is the operations of Denver Water who will provide 5 billion gallons of recycled water a year to customers in the metropolitan Denver area once build-out is complete.<sup>61</sup> The water reuse facility was developed as part of the Blue River Decree of 1955 that requires Denver to maximize its use of Western Slope water as to minimize or defer the future need to import more water from the Western Slope.<sup>62</sup>

Not all graywater recycling projects in Colorado have faced as much adversity as the system in Williams Village North. As part of the South Lincoln Redevelopment Project, the Denver

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<sup>60</sup> Ibid.

<sup>61</sup> "Recycled Water." *Water Quality*. Denver Water. Web. 02 Apr. 2012. <<http://www.denverwater.org/WaterQuality/RecycledWater/>>.

<sup>62</sup> Carder, Carol. "Water, Water Not Everywhere." *Denver Water Recycling Plant Treats Wastewater for Reuse*. Progressive Engineer. Web. 02 Apr. 2012. <<http://www.progressiveengineer.com/features/denverwater.htm>>.

Housing Authority built an 8-story, 100-unit senior living facility at 1099 Osage in Denver.<sup>63</sup> The building is certified LEED platinum and has a pilot graywater recirculation system for 25% of the residents that reuses water from showers and sinks to flush toilets.<sup>64</sup> The pilot system does not operate under a special city permit nor is there any concern about water rights as the water use is covered under “municipal use”.<sup>65</sup> At the time this paper was written, the system was just about to be started up as the building reached occupancy.<sup>66</sup>

Nearby Boulder, the City of Broomfield reclaims some of its wastewater to irrigate public spaces. In order for this operation to legally operate, Broomfield went to water court and agreed to use other water sources to augment the reclaimed water being used.<sup>67</sup> The overall impact to downstream users is negligible with this settlement; if anything water quality is improved as more natural water is retained in the water bodies.

In the scope of the Williams Village North project, many similar applications exist legally in the City of Boulder. Since the use is non-consumptive, the graywater recirculation system can be likened to car washes that capture and reuse rise water or cooling systems that recirculate water. While these systems are simpler than the system at Williams Village North, their operations are essentially the same and thus water use definitions and water rights decrees are not applicable for the proposed application.

#### **4.5 Permitting Process for William Village North**

Since Colorado is currently working on the regulations for graywater reuse, the permitting of systems has not been standardized. Currently, on-site graywater systems are grouped with decentralized sanitation devices like septic tanks. Since graywater quality is more benign than

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<sup>63</sup> Schroepfel, Ken. "South Lincoln Redevelopment and 1099 Osage." *Denver Infill and Denver Urbanism: Planning and Development in The Mile High City*. Denver Infill, 15 Nov. 2011. Web. 02 Apr. 2012. <<http://denverinfill.com/blog/2010/11/south-lincoln-redevelopment-and-1099-osage.html>>.

<sup>64</sup> "Colorado Sustainable Design Awards: Residential Multifamily." *Colorado Sustainable Design Awards: Residential Multifamily Colorado Business Magazine*. ColoradoBiz, 1 Nov. 2011. Web. 02 Apr. 2012. <<http://www.cobizmag.com/articles/colorado-sustainable-design-awards-residential-multifamily>>.

<sup>65</sup> "1099 Osage Graywater System." Telephone interview. 29 Mar. 2012.

<sup>66</sup> Ibid.

<sup>67</sup> "No. 09SA213. - CENTENNIAL WATER AND SANITATION DISTRICT v. CITY AND COUNTY OF BROOMFIELD - CO Supreme Court." *FindLaw*. 20 June 2011. Web. 02 Apr. 2012. <<http://caselaw.findlaw.com/co-supreme-court/1571630.html>>.

blackwater, especially in regards to pathogen content, grouping the two water types provides a challenging environment for the ease of graywater regulating. Once the wastewater streams are legally defined as separate, graywater regulation becomes more feasible.

As there are no official state guidelines for the reuse of graywater at this point in time, the operational oversight of graywater systems falls on the local city government. Permitting for this project required the University of Colorado to present the proposed project to the City's Water Resource Advisory Board (WRAB) for approval before heading on to City Council. The University went before the WRAB twice, once in July 2011 and once in February 2012. While the WRAB members were generally supportive at the July meeting, the largest problem identified in moving forward with the project was compliance with the water rights decrees held by the City of Boulder. Additionally, the WRAB members wanted an environmental and economic impact report before approving the project. This report was prepared and presented before the WRAB in February 2012. The report, which can be found in Appendix A, found that the economic costs to the City of Boulder upon operation of the system were small. The environmental impacts of the system operation were a net positive, but the City's stipulation that foreign water be imported (to ensure water decree compliance) has negative environmental impacts. The next section will discuss the environmental impacts of using foreign water for reuse.

In addition to the University's environmental and economic impact report, an opinion document and a draft permit were submitted by members of the City of Boulder Utilities division to the WRAB during the February meeting. As alluded to, in order to protect Boulder's water rights and maintain a very conservative water rights stance, the legal staff of the City required augmentation of the City's water supply with water from Windy Gap, a source that is decreed for use until extinction. As mentioned in the economics portion, the City of Boulder has overdeveloped its water supply so as to provide an extremely high level of reliability; the Windy Gap project is one of Boulder's most expensive water supplies and contributes to the high

reliability ranking.<sup>68</sup> In terms of conventional municipal use, municipal users tend to be more comfortable with lower reliability if it results in lower water bills; keeping rights to sources like Windy Gap is not financially smart, especially due to the variable nature of the water supply.<sup>69</sup> As a conventional municipal source, Windy Gap water is unattractive because it requires a trans-basin transfer and is not consistently available. Requiring this water for augmentation of the recirculation system at Williams Village North is not a practical long-term solution.

As Windy Gap water does not provide the optimal operational solution to water rights compliance, other water sources were evaluated for their potential for recirculation. The most attractive option was the possibility of recirculating water from the Colorado-Big Thompson (C-BT) project. Water from the C-BT project is conveyed from the Northern Colorado Water Conservancy District (NCWCD) to the Boulder Reservoir.<sup>70</sup> On average, the Boulder Reservoir supplies 20% of the City of Boulder's municipal supply; the majority of this water being sourced from the C-BT project.<sup>71</sup> When required, Windy Gap water is also pumped to the Boulder Reservoir.<sup>72</sup>

NCWCD determines the acceptable uses of C-BT water for its downstream users. In order to get approval for the Williams Village North system to operate on C-BT water, City and University staff met with the director of NCWCD on February 14, 2012. At the meeting, the director expressed support for the recirculation system due to its non-consumptive nature and likened the operation to agricultural applications in which irrigation water was allowed to be captured and reapplied. Before the City will allow C-BT water to fulfill the uses at WVN, an official option letter from the Board of NCWCD needs to be received, a task that is currently being completed.

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<sup>68</sup> Howe, Charles W., and Mark Griffin Smith. "Incorporating Public Preferences in Planning Urban Water Supply Reliability." *Water Resources Research* 29.10 (1993): 3363-369. Print.

<sup>69</sup> Ibid.

<sup>70</sup> City of Boulder, MWH, and Amec. *City of Boulder Source Water Master Plan*. Rep. Vol. 2. 2009. Print. Detailed Plan.

<sup>71</sup> "Boulder's Source Water Information." *Public Works Department - Utilities Division*. City of Boulder, 7 Apr. 2009. Web. 02 Apr. 2012. <[http://www.bouldercolorado.gov/index.php?option=com\\_content](http://www.bouldercolorado.gov/index.php?option=com_content)>.

<sup>72</sup> City of Boulder, 4-41.

While C-BT water provides a more environmentally friendly source of water for the recirculation project, it is still trans-basin water and does not address the inherent problem of increasing water efficiency, regardless of source location. This is where the redefinition of uses becomes extremely important. In the case of the WVN system there is non-consumptive reuse and the net effect on water utilities is reduced water demand and reduced wastewater flows. Both of these attributes classify the system as a water conservation measure and no water right decree is violated. In moving forward with graywater policy, especially in the context of indoor recirculation, water rights should not be an issue as return flows are not being affected. The same argument can be made for replacing potable water with graywater for irrigation, as mentioned previously, but it is not in the scope of this thesis to expand upon this argument.

Regardless of source water, for the permitting process the City of Boulder required a maximum monthly volume of water to be recirculated in the WVN system. Table 4.1 shows these values that were calculated using the conservative estimate found in the Water Balance portion. As shown, due to the unknown occupancy of the residence hall over summer, the system is not permitted to run in June and July and must be taken off line.

**Table 4.1 - Maximum Volumes Permitted to be recirculated at Williams Village North.**

	Permitted Graywater (kgal)
Aug	53.55
Sep	100.40
Oct	103.74
Nov	100.40
Dec	76.97
Jan	76.97
Feb	97.05
Mar	103.74
Apr	100.40
May	53.55

## 4.6 Conclusions

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This chapter attempted to explain the nuances of implementing a recirculation system in Boulder, Colorado. While some of the water rights issues outlined could result in expensive water court settlements, the scope of this project is not violating basic municipal water rights and thus some of the requirements of the permitting process are unnecessary.

For a future municipal graywater project to be successful in a climate of conservative interpretation of prior appropriation water rights and for future source water resiliency, the following things need to happen.

1. Expand the definition of “one municipal use” to allow graywater to be substituted potable water for uses in which drinking water quality water is not required.
2. Enact measures to reduce the dependence on foreign waters. While this may be unrealistic, especially in places where water has never abundantly flowed, communities should be encouraged to maintain and responsibly augment their local water basins.
3. Promote water conservation and other demand management efforts to address water shortages locally. Future water sustainability and resiliency will depend on local solutions.

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## *Chapter 5: Conclusions and Future Work*

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As populations continue to grow and become more aware of the challenges associated with future water resource acquisition, non-traditional water sources need to be included for water portfolio resiliency. One of these non-traditional sources, water conservation, is not a physical source but creates more useable water by increasing water use efficiency. For urban settings like Boulder, implementing water conservation measures on a municipal scale can have large and resonating impacts for future water security. One of the easiest targets for water conservation is addressing the water used to flush toilets that accounts for roughly 30% of indoor residential uses. Installing a smaller tank to reduce flush volume results in significant potable water savings, but augmentation of the flushing water with graywater from showers and sinks replaces the potable water demand for toilets all together.

The current economic and political climate in Boulder lends to graywater recirculation at a larger, multifamily building scale. The LEED platinum residence hall at Williams Village North presents a fitting pilot project for the study of the efficacy of installing graywater recirculation systems. Upon analysis, using graywater from showers and sinks could result in the augmentation of all the flushing demand in the residence hall which can be likened to a 22% overall potable water demand reduction. Since water usage in residence halls was found to be fairly consistent over the last 5 years and toilet flushing is one of the most predictable and consistent water use behaviors, these savings are expected to remain on a permanent basis once the system is operational. Two methods were used to project the water usage at Williams Village North; one method used typical ranges from previous literature and the other method back-calculated water usage from historical residence hall data. The efficacy of these methods can be further evaluated once more building water use data is generated at Williams Village North.

Using the projected water savings at Williams Village North, a city-wide scale up was performed on projected growth within the City of Boulder. This scale up resulted in an overall

reduction of city demand of roughly 2%. This small reduction of water demand would have minimal impact in changes in the water and wastewater treatment plant future operations but would reduce current chemical demands and provide a factor of safety for future growth. On the scale of Williams Village North, the expected savings to the University of Colorado, and conversely loss of revenue to the City of Boulder, is projected to be around \$6,000 per year. Since the system to be installed has capital cost only upward of \$400,000, the strict economics of graywater recirculation cannot justify system installation. In order to better understand the holistic impact of installing a recirculation system, an analysis of overall water efficiency was performed that found the system was physically, institutionally, socially, and environmentally efficient. As mentioned, economic efficiency was not achieved at this point. The system was also found to be neutral in technological efficiency as the treatment system design is elaborate and appropriate water quality could be achieved with a simpler system.

In addition to the economic challenges presented by the recirculation system, Colorado water rights posed an additional challenge to system implementation. With the constructs of prior appropriation water rights and defined water uses, graywater recirculation can pose threats to the operation of the traditional system. As the graywater system outlined in the proposal is merely a water conservation method, water rights should not be affected at any level. Additionally, by creating multiple hoops for users to jump through, governments create a hostile environment for innovative water technologies and do not empower users to use water more efficiently. Increasing water efficiency is one of the most powerful tools regulators, especially on the Front Range of Colorado have, in securing future water resource abundance. Effort should be taken by governing bodies to encourage demand management behaviors and reduce the dependence on developing trans-basin water transfers.



## 5.1 Future Work

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This thesis presents a background analysis of the efficacy of graywater recirculation systems in Boulder, Colorado. While performing the analysis, the following areas were identified as potential areas of future study:

1. **Characterizing water use patterns.** Understanding how people use water on a fixture and frequency basis can help designing engineers and utilities in their planning.
2. **Analyzing how people value water and correlating the valuation to water use behavior.** This relationship governs water use trends and better understanding the interface between valuation and action can shape future demand management policies.
3. **Operational efficiency of a graywater recirculation system on a residence hall scale.** Operational data from the Williams Village North system will be informative in better understanding the implications on water savings with an additional component of increased building energy use.
4. **Institution motivations in implementing water conservation projects.** This study could compare the motivations of institutions to change existing policies to create a friendlier environment for conservation taking into account drought conditions and global climate change preparedness.

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*Appendix A: Study of Water Supply, Economic and Environmental Impacts of Indoor Recirculation at Williams Village North*

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# **Study of Water Supply, Economic and Environmental Impacts of Indoor Recirculation at Williams Village North**

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## **Background**

This report is a review of the water supply, economic and environmental impacts of a proposed project to recirculate treated graywater from showers and lavatory sinks to be used for toilet flushing in a new LEED Platinum residence hall at CU Boulder, Williams Village North. The study was prepared at the request of the staff of the City of Boulder Utilities Department and the Water Resources Advisory Board. Earlier this year, Utilities Staff and Counsel expressed concern that indoor (non-consumptive) recirculation of treated graywater might constitute a “second use” that was not allowed under the City’s senior water rights that specify “one use.” Under that interpretation, it was further suggested that only Windy Gap project water managed by the Northern Colorado Water Conservancy District (NCWCD) would be eligible to offset the water being recirculated. (Williams, 2011; WRAB, July 2011). Because water from the Windy Gap project is not a consistent component of the City’s normal water supply, a study was requested to provide the City of Boulder with the anticipated costs and benefits of using Windy Gap water for indoor recirculation of treated graywater at the Williams Village North residence hall. Also, after communication with the office of the General Manager of NCWCD, an alternative being considered in consultation with NCWCD and the City is allocation of Colorado-Big Thompson (C-BT) project water, which is a consistently larger component of the City’s water supply.

The Colorado Department of Natural Resources (CDNR) Division of Water Resources recently released an Administrative Position Statement relevant to this study that specifically separates indoor recirculation of municipal water from reuse outside the site: *“For water users that rely on municipal water supplies, the Colorado Division of Water Resources does not regulate the reuse of gray water within the municipal system. If water is reused or re-circulated as a part of residential, commercial, or industrial operations, and that reuse or recirculation takes place within the confines of that operation, that is, there is no reuse of water after it leaves the site, there is no water rights conflict. This is based on an assumption that the water right allows Municipal uses, or Residential, Commercial, and Industrial uses, and due to the fact that, if certain reuse or recirculation systems are used in a residential, commercial, or industrial operation, they are by definition Residential, Commercial, or Industrial uses.”* (CDNR, 2011)

In keeping with the CDNR characterization, the term recirculation will be used in this report to refer to operation of the graywater system at Williams Village North.

Overall, the water supply, economic, and environmental impacts of graywater recirculation at Williams Village North are small, as presented in the following sections. The benefits of the project are educational – for the student residents and visitors to Williams Village North (WVN) and to the CU Boulder community as a component of the Campus sustainability initiatives. Other graywater projects going forward in the State of Colorado include a student residence reuse project at Colorado State University where treated graywater is used for landscape watering, and Denver Housing Partners, which has indoor recirculation of graywater for toilet flushing. Collection of extensive water quality data from the graywater system at WVN will provide information on the performance and reliability of commercial graywater treatment systems of value to regulatory agencies and the public. In addition, water budget and water quality data can benefit the City of Boulder government in getting reliable information on the performance and impacts of graywater recirculation. The scale of the demonstration project at Williams Village North is large enough to provide reliable data, but small enough that the anticipated economic and environmental impacts will be low, provided the City’s water rights concerns are satisfied.

### **Water Supply Impact**

Water savings are estimated from recirculating treated shower and lavatory sink drain water from one wing of Williams Village North (WVN) residence, housing 180 residents, for toilet flushing in the entire residence, with 500 residents, as well as public restrooms used by students taking classes at WVN and the offices for Conference Services.

#### Method

Due to the short time frame for the report requested by the City of Boulder Utilities Department, flow data for showers, lavatory sink and toilet flushing have not yet been collected at WVN. Estimates of these flows are based on WVN plumbing system design estimates (Keith Jones and Greg Thompson, BCER Engineering) and calibrated WVN to historic indoor water use in academic year 2009-2010 at other Williams Village residences: Stearns East and West, Darley, and Bear Creek Apartments.

Population, Fixtures and Water Use at Williams Village North (BCER Engineering, 2011)

Total Number of WVN Residents	500
Residents in Northwest Wing*	180
Total Number of Showers:	98
Number of Showers in Northwest Wing*	31
Shower flow	1.5 gpm
Total Number of toilets	105
Number of residence area toilets	94
Toilet flush volume	1.3 gal/flush
Total Number of Lavatory Sinks	141
Numbers of Lavatory Sinks in Northwest Wing*	44
Estimate Lavatory Sink Water Use	7 gpcd

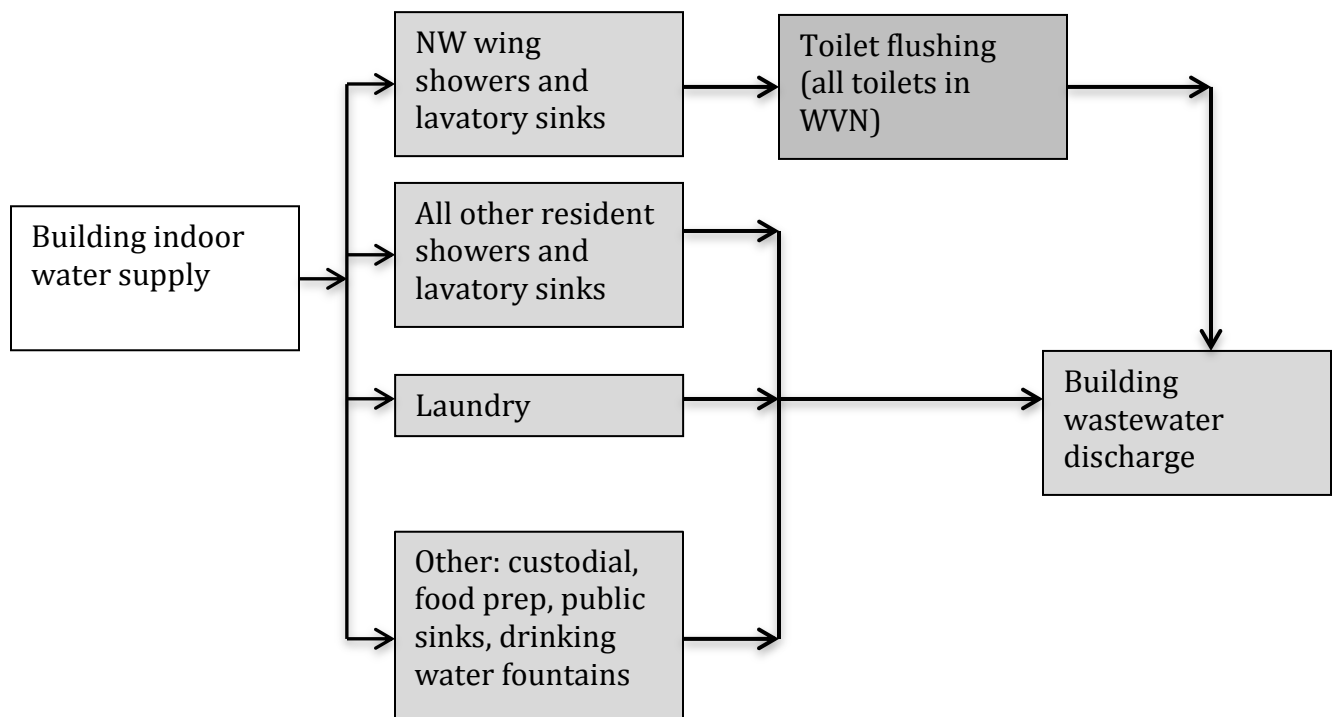
\*Graywater collection from Northwest Wing Shower and Lavatory Sinks

### Assumptions

Period of graywater recirculation to toilets	Academic year: 275 days/yr
Resident toilet use	5 flushes/day
1st floor toilet use	4 flushes/day for staff and 0.1 flush/day for students
Resident lavatory sink use	7 gpcd
Resident shower use	one 10.5-gal. shower/person/day
1st floor lavatory sink use	2 gpcd
Visitors (students, etc.) toilet	0.1 flush/student/day
Visitors lavatory sink	0.1 use/student/d @ 0.2 gal/use
Wastewater generated	95% of indoor water use

### Water budget at WVN, with and without Toilet Flushing with Graywater

Figure 1. Graywater recirculation scenario - proposed toilet flushing with graywater:



Results of the water budget estimates with and without use of graywater for toilet flushing are shown in Tables 1 – 4 below.

Table 1. Water budget at Williams Village North without graywater recirculation.



No Recirculation	AY gpcd	AY kgal/d	Summer gpcd	Summer kgal/d	fixture % of total AY use	Indoor Use kgal/y	Indoor Use af/y	Wastewater kgal/y
Resident Toilet Flushing	6.5	3.25			22.9%	894		
Showers	10.5	5.25			36.9%	1444		
Resident Lavatory Sinks	7	3.5			24.6%	963		
1st floor toilet (gpcd based on staff only. Visitors added to kgal/d)	5.2	0.21	5.2	0.16	1.5%	73		
1st floor lavatory sink (gpcd based on staff only. Visitors added to kgal/d)	2	0.07	2	0.06	0.5%	25		
Laundry	2.5	1.25			8.8%	344		
Misc. kitchen, custodial, drinking including bottle filling station, add 5%	0.001	0.68		0.01	4.8%	187		
<b>Total, No Recirculation</b>	<b>26.5</b>	<b>14.21</b>		<b>0.23</b>	<b>100%</b>	<b>3,929</b>	<b>12.07</b>	<b>3,732</b>

Table 2. Estimates of graywater available for toilet flushing at WVN

GRAYWATER Generation - current configuration	AY (gpcd)	AY (kgal/d)	ANNUAL INDOOR WATER SAVINGS (kgal)	ANNUAL INDOOR WATER SAVINGS (af)
Assume no graywater in summer				
Resident Showers	10.5	1.89	520	
<u>Resident Lavatory Sinks</u>	7	1.26	347	
Total graywater available for toilet flushing		3.15	866	2.66

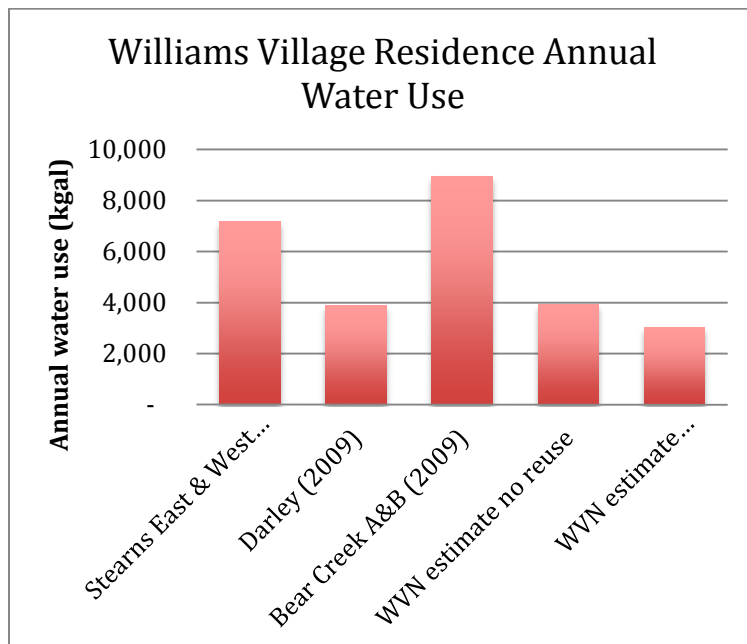
Table 3. Water budget for Williams Village North with graywater recirculated for toilet flushing.

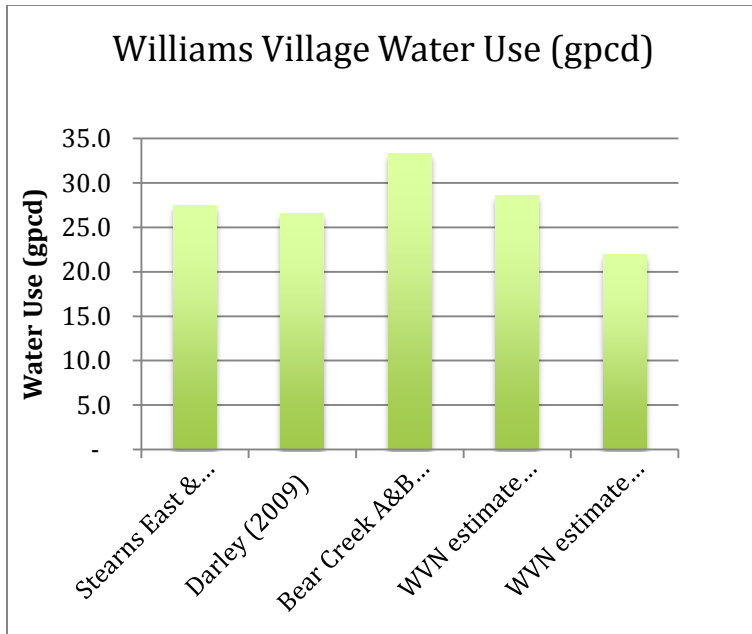
GRAYWATER RECIRCULATION FOR TOILET FLUSHING	AY gpcd	AY kgal/d	Summer gpcd	Summer kgal/d	fixture %	Indoor use kgal/yr	Indoor use af/yr	Wast e-water (kgal/yr)
Resident Toilet Flushing Use	6.5	3.25			1%	28		
SUBTRACT GRAYWATER FRACTION	-6.3	-3.15						
Showers	10.5	5.25			48%	1444		
Resident Lavatory sinks	7	3.5			32%	963		
1st floor toilet (gpcd based on staff only. Visitors added to kgal/d)	5.2	0.21	5.2	0.16	2%	73		
1st floor lavatory sink (gpcd based on staff only. Visitors added to kgal/d)	2	0.07	2	0.06	1%	25		
Laundry	2.5	1.25			11%	344		

Misc. kitchen, custodial, drinking including bottle filling station, add 5%	0.001	0.52		0.01	5%	144		
<b>Total use with GRAYWATER RECIRCULATED FOR TOILET FLUSHING</b>	<b>20.2</b>	<b>10.90</b>		<b>0.23</b>	<b>1.00</b>	<b>3,019</b>	<b>9.28</b>	<b>2,868</b>

Table 4. Comparison of WVN indoor water use estimates with 2009 data at Williams Village

	Resident population	water use (kgal/yr)	Water use (gpcd)
Stearns East & West (2009)	950	7,170	27.4
Darley (2009)	530	3,871	26.6
Bear Creek A&B (2009)	979	8,955	33.3
WVN estimate no recirculation	500	3,929	28.6
WVN estimate graywater recirculation	500	3,019	22.0





### **Summary of Estimated Water Supply Impacts**

**Recirculation of treated graywater from approximately one-third of WVN residents for toilet flushing is estimated to save 866,700 gallons per year (2.66 acre-feet/yr), a 23% reduction of estimated indoor water use and wastewater generation in WVN. Total indoor water use in the Williams Village residence area in 2009 was approximately 20,000,000 gallons. Adding the supply for the new WVN residence is estimated to increase indoor use (without recirculation) by 3,929,000 gallons. Recirculation for toilet flushing would produce savings of approximately 3.6% of indoor water use in Williams Village residences.**

### **Economic and Environmental Impacts**

For evaluation of economic and environmental impacts, information on graywater quality, wastewater quality, and source water environmental effects were considered. At the suggestion of the City of Boulder Water Utility staff and the Water Resources Advisory Board (WRAB), we communicated with Eric Wilkinson, General Manager of the Northern Colorado Water Conservancy District, regarding their policies on indoor recirculation of both Colorado-Big Thompson (C-BT) and Windy Gap (WG) project water. We received a reply from a member of his staff, Dana Strongin, stating that NCWCD had no policy regulating use of either C-BT or WG project water for indoor recirculation of graywater for toilet flushing. She suggested that any such policies originated with municipalities (correspondence appended). **This is not an affirmative policy statement from NCWCD, and the City and the University are currently in discussion with NCWCD to determine the possibility for an official policy of how indoor recirculation would affect the C-BT contracts between Northern and the City of Boulder that is acceptable to both parties.**

### **Economic Impact**

Using data from CU's Facilities Management and the City of Boulder an economic analysis was performed to analyze the costs and benefits to the City of Boulder and CU Boulder.

#### Cost and Benefits to CU Boulder

When performing the cost analysis for CU Boulder, it was decided that the campus is significantly invested in the pilot project through the capital required to install the system in the Williams Village North facility. As the purpose of this pilot project is focused on education and water conservation, the perceived economic benefits from reduced water consumption are not expected to be great because the relatively low price of water does not provide a return on the capital investment. Due to the nature of the campus being early adopters of this technology, it is hoped that increased operational knowledge and enumerated water savings benefits from the pilot project will increase public interest in similar units thus increasing demand and decreasing water recirculation systems unit costs. Because of these factors, only the annual savings to the campus from a reduced water bill will be included in the economic analysis for CU Boulder. From the water balance performed, the total amount of water being recirculated is estimated to be 2.66 af/year. Data on water use at Williams Village in 2010 show that almost all water use is billed at the Block 1 rate. Using this rate, the reduction in CU's water bill represented by 866,700 gal/year would be \$1,900.

#### Costs and Benefits to the City of Boulder

The staff of the City's Utilities Department has calculated the cost to the City for placing sufficient Windy Gap water in the City distribution system on a daily basis to offset the recirculation portion of the Campus total use. (Ellinghouse, 2012) The estimate of costs is based on the assumption that the City would not have any need to import Windy Gap water. In months when Windy Gap water was part of the City's normal supply, and was placed in the distribution system at a rate exceeding the daily reusable amount (range of 0.07 to 0.17 af/day from August to May) there would be no additional costs. Using the conservative assumption that Windy Gap water was only imported to satisfy the reuse requirement, the estimated total cost, including O& M, lost hydropower revenue, increased pumping and treatment costs for the Boulder Reservoir Water Treatment Facility, when that plant is used to provide Windy Gap water to the City system, and staff time accounting for reusable water delivery will be \$10,087 per year. In addition, lost revenue from the University's reduced water bill will be approximately \$1,900/year.

#### Summary of Economic Impacts

**Overall, the installation of the system has estimated maximum cost to the City of Boulder of approximately \$12,000/year. Probably the financial impact on the City of the water saved by indoor recirculation is significantly less than other water conservation practices that the campus has implemented in recent years which have produced much larger water savings - some of which have been partially funded through the City.**

## **Environmental Impacts**

### Boulder Creek

Typically, non-consumptive indoor recirculation at WVN has similar impacts on stream flow as typical building water conservation projects. In general, less potable water supply is used, resulting in a reduction in withdrawals, and an increase in stream flow below a water intake. At the same time, wastewater flow is reduced by the same amount of the decreased withdrawal. When treated wastewater is mixed with in-stream flows at the discharge point, the flow rate water delivered downstream does not change from that prior to the recirculation. In theory, there could be an environmental benefit from increased in-stream flows above the wastewater discharge point, and increased dilution of the wastewater constituents discharged after treatment. On the scale of the WVN graywater recirculation project, these benefits would be negligible. However, if Windy Gap water is the only reusable supply, then the environmental impacts of extra pumping in years when the City would not normally use Windy Gap water should be considered. The major impact is the release of more CO<sub>2</sub> from the increased energy required for pumping, estimated to be 238,344 pounds per year. As with the cost impacts, this is a maximum estimate, assuming that Windy Gap water is not placed in the City distribution system as part of the normal water supply in a sufficient amount to meet the reusable requirement.

### Wastewater

No new constituents will be added to wastewater from indoor recirculation. The treatment system at WVN consists of direct filtration through granular media, membrane filtration and chlorine disinfection to meet State guidelines for treated graywater used to flush toilets. No chemical coagulants or anti-scalants are added before filtration. A food-grade purple dye will be added to the finished graywater. Filter backwash water will consist only of solids trapped from the shower and lavatory sink water, which are normal domestic wastewater constituents.

The concentration of constituents such as BOD, ammonia, and suspended solids in WVN wastewater would increase. However, overall mass loading of these constituents would remain the same, so there should be no impact on wastewater treatment costs determined by mass loading, such as power for aeration and solids handling processes.

### Other Impacts

There will be reduced demand for water from the Betasso pipeline. If thermoelectric power were used in place of the lost hydropower, there would be a slight increase in CO<sub>2</sub> emissions. The City staff did not quantify this impact. The only CO<sub>2</sub> release information provided was for pumping WG project water, a significantly larger CO<sub>2</sub> release.

Given the water rights issues in Boulder and the cost of residential graywater treatment systems, it seems unlikely that even indoor recirculation will be practiced widely.

However, indoor recirculation could become a component of adaptive strategies to mitigate the effects of extreme drought. If the indoor recirculation demonstration project at WVN goes forward, data on water quantity and quality will be acquired at a scale and duration that will aid in evaluation of on-site graywater recirculation by the State and local communities, including the City of Boulder.

### **Summary of Environmental Impacts**

**Direct environmental benefits from water savings from recirculation of 2.66 af per year of graywater at Williams Village North residence hall will be small. The major negative impact is increased CO<sub>2</sub> release when Windy Gap water is not a normal part of the City's water supply.**

### **Educational Benefits**

Over the past 10 years, CU Boulder has committed significant financial and educational resources to achieving a more environmentally sustainable campus. Efforts include conservation of water and energy in campus buildings, addition of photovoltaic electricity generation, solar water heating, recycling solid waste, composting, biodiesel fuel generation, and subsidized mass transit use by faculty, staff and students. Recent buildings constructed on campus meet at a minimum LEED silver standards, with more recent projects meeting gold and even platinum standards. "Water efficiency" is receiving greater attention from the US Green Building Council as a component of sustainable building design. Incorporating green building features, including water conservation and innovative wastewater management, into a campus residence hall has made campus sustainability efforts more transparent to students, turning efficiency efforts into educational opportunities. For example, the Residential Academic Program housed in WVN has a class this semester on Residential Water Reuse, and students contributed to the water budget information in this report.

### **Deliverables and Benefits to the City of Boulder**

The increasing interest in green buildings will mean greater consideration of novel methods of reducing water use and wastewater generation, including indoor graywater recirculation for non-potable uses. In anticipation of future interest in graywater reuse as part of a water conservation portfolio, the CU demonstration project at Williams Village North will provide the City with water quantity and water quality data from a population size and over a duration to enable the City to better assess the conservation, environmental, economic and water quality impacts at very low cost and without risk to the City system. All original data and summary reports on the WVN demonstration will be made available to the City for their use in future planning.

### **References**

BCER Engineering, Design of Water Supply System for Williams Village North, 2010.

Colorado Department of Natural Resources, Division of Water Resources Administrative Position for Gray Water Reuse, September 7, 2011, p. 2

<http://bcn.boulder.co.us/basin/waterworks/bldrres.html>

Black and Veatch Engineers, "City of Boulder, CO Source Water Quality Planning Study, Phase I, April 2003.

Ned Williams and Carol Ellinghouse, City of Boulder Utilities Department, personal communications, 2011.

Strongin, Dana, Northern Colorado Water Conservancy District, personal communication, 2011.

City of Boulder Water Resources Advisory Board, \*Recommendation on the MOU with CU about Recirculation of Residence Hall Wastewater (8:15

p.m.)  [Agenda item 6.pdf](#)  [Agenda 6 MOU with CU.mp3](#)



## **Addendum 1. Correspondence from NCWCD.**

**From:** Dana Strongin <dstrongin@ncwcd.org>  
**Date:** September 20, 2011 8:27:39 AM MDT  
**To:** Joann Silverstein <Joann.Silverstein@colorado.edu>  
**Subject:** **RE: question about NCWCD policy on reuse**

JoAnn,

Good luck in your research. I'm always impressed with CU's efforts in relation to sustainability.

Dana

Dana Strongin | Communications Specialist  
220 Water Ave | Berthoud, Colorado 80513  
Direct 970-622-2239 | Cell 970-817-3440  
Main 800-369-RAIN (7246) | Fax 877-851-0018  
dstrongin@ncwcd.org | www.northernwater.org  
Conserve water - it starts with you.

-----Original Message-----

**From:** Joann Silverstein [mailto:Joann.Silverstein@Colorado.EDU]  
**Sent:** Friday, September 16, 2011 2:21 PM  
**To:** Dana Strongin  
**Subject:** Re: question about NCWCD policy on reuse

Dear Dana,

Thank you so much for your reply. I was indeed asking about graywater toilet flushing, and you answered my question.

You are right that the cost of these systems can be high for a single family, and are probably not returned as saving on water bills. The University of Colorado is interested in indoor graywater reuse for their new residence halls as part of the sustainability initiatives.

Regards,  
JoAnn

On Sep 14, 2011, at 2:01 PM, Dana Strongin wrote:

[JoAnn,](#)

[I apologize for our delay in addressing your question.](#)

[I'd like to make sure I understand your question correctly. Are you](#)

asking about our policies in relation to reusing indoor water for flushing your toilet (for example, taking used water from your dishwasher and finding a way to use it for toilet flushing)?

If that is indeed your question, I can answer it pretty simply. We do not have policies on graywater for C-BT or Windy Gap.

It's possible the municipalities who own C-BT and Windy Gap water do, but not so much in terms of reuse - I'd imagine they would be considering health or other standards in their municipal, plumbing-related codes. You could possibly contact Northeastern Colorado water providers to see if they have policies like that.

As for my own curiosity, I wonder what the cost of such a system would be and how long it would take the average homeowner to see a cash return.

Thanks,  
Dana  
970-622-2239

-----Original Message-----

From: Eric Wilkinson  
Sent: Friday, September 02, 2011 5:31 PM  
To: Brian Werner; Dana Strongin  
Subject: FW: question about NCWCD policy on reuse

Brian and Dana:

Could one or both of you respond to this. If you have any questions, please do not hesitate to contact me.

Thanks,

Eric

Eric Wilkinson, P.E. | General Manager  
220 Water Ave. | Berthoud, CO 80513  
Direct 970-622-2201 | Cell 303-877-4188  
Main 800-369-RAIN (7246) | Fax 877-851-0018  
ewilkinson@ncwcd.org | www.northernwater.org  
Conserve water - it starts with you.

-----Original Message-----

From: Joann Silverstein [mailto:Joann.Silverstein@Colorado.EDU]

Sent: Friday, September 02, 2011 11:43 AM

To: Eric Wilkinson

Subject: question about NCWCD policy on reuse

Dear Mr. Wilkinson,

I am teaching a class at CU Boulder on water reuse in Colorado and would

like information on the Conservancy District's policies on reuse of

C-BT

and Windy Gap water for indoor (non-consumptive) use of graywater for toilet flushing. Can you direct me to the best source describing your policies on indoor graywater use?

Thank you very much,

JoAnn

JoAnn Silverstein

Professor

Dept. Civil, Environmental and Architectural Engineering

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