Integrated Water Planning Through Building Level Cascade of Water Use

ESTCP Project #EW-201155
Energy and Water Projects

September 2019

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
9/13/2019	ESTCP Final Report	

4. TITLE AND SUBTITLE
Integrated Water Planning Through Building Level Cascade of Water Use

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT

6. AUTHOR(S)
Elisabeth M. Jenicek, Martin Page, Andy Hur, Drew Ahern, and Noah Garfinkle

5d. PROJECT NUMBER
EW-201155

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Research and Development Center (ERDC)
Construction Engineering Research Laboratory (CERL)
PO Box 9005
Champaign, IL 61826-9005

8. PERFORMING ORGANIZATION REPORT NUMBER
EW-201155

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Environmental Security Technology Certification Program
4800 Mark Center Drive, Suite 17D08
Alexandria, VA 22350-3605

10. SPONSOR/MONITOR'S ACRONYM(S)
ESTCP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
EW-201155

12. DISTRIBUTION / AVAILABILITY STATEMENT
Distribution A. Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This demonstration project investigated the integration of state-of-the-art water saving technologies for reducing water demand at the building level. A cascade approach was used, whereby technologies were considered for treating and reusing water to meet demands more efficiently by matching the appropriate water quality with the appropriate use. The study investigated the integration of the cascade approach with the more conventional, but not yet fully implemented, approach of water conservation, which allowed for measurement of the relative benefits and costs of emerging versus more proven technologies. Based on demonstration site factors, the project focused primarily on efficient water fixtures and graywater reuse technologies. Most of the technologies studied were at the bathroom scale, though one building scale system was evaluated as well. The study found that: (1) water conservation fixtures achieved a savings rate of 14 % as compared to the target rate of 30%; (2) graywater reuse systems studied in this project require further improvement before their widespread adoption can be recommended; (3) the bathroom scale under-sink graywater reuse system required further technical improvements to meet some of the water quality requirements for toilet flushing.

15. SUBJECT TERMS
Integrated Water Planning, Building Level Cascade, Water Use, Building Automation System

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Elisabeth Jenicek
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (include area code)
Unclassified	Unclassified	Unclassified	SAR	168	217-373-7238

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EXECUTIVE SUMMARY

This demonstration project investigated the integration of state-of-the-art water saving technologies for reducing water demand at the building level. A cascade approach was used, whereby technologies were considered for treating and reusing water to meet demands more efficiently by matching the appropriate water quality with the appropriate use. The study investigated the integration of the cascade approach with the more conventional but not yet fully implemented approach of water conservation, which allowed for measurement of the relative benefits and costs of emerging versus more proven technologies.

The project considered a range of water saving technologies that building managers could consider. Based on demonstration site factors, the project focused primarily on efficient water fixtures and graywater reuse technologies. Most of the technologies studied were at the bathroom scale, though one building scale system was evaluated as well. For bathroom retrofits, the technologies investigated included 0.5 gpm sink faucets with infrared (IR) auto-off sensors, an under-sink graywater reuse system, low flush toilets and/or alternate toilet sensor settings, and 2 gpm showerheads in building locker rooms. The building scale system that was investigated was a graywater reuse system that treated graywater from sinks and showers such that it could be reused for toilet flushing. The primary metric for the project was to reduce water demand at the building level by 30%. Impacts on operations and maintenance, as well as energy consumption, were also measured.

In the case of a building comprised primarily of office space, conservation fixtures achieved a reduction in overall facility water use of 7% as compared to the target rate of 30%*. An additional 7% reduction was realized by adjusting toilet automatic flush mechanisms, for a total building potable water reduction of 14%. Several factors contributed to this lower than projected reduction. First, faucets and showers represented a small fraction of the building water demand, which included specialized research facilities with high water needs, so associated improvements had limited overall impact. Second, recommendations for toilet retrofits were limited to flush valve sensor adjustments, with toilet and flush valve replacements planned by the facility for an upcoming remodel. Despite this low figure, the faucet and shower retrofits paid for themselves in less than a year with the cost of water alone. Lastly, the under-sink graywater system did not recover enough water from the sinks to support the toilet flushing.

The graywater reuse systems studied in this project require further improvement before their widespread adoption can be recommended. For the building scale graywater reuse systems, the product water quality in the storage tank was acceptable for reuse activities, but this may be dependent on the amount of makeup (dilution) water that was injected into the product tank at the particular test site. Additionally, the building scale system was susceptible to down times due to controls or sensor malfunction, which were difficult to troubleshoot by support staff. Once these issues are ad-

* CERL would achieve a 47.2% reduction with both plumbing fixture and toilet retrofits. Implementation of waterless urinals and under-sink scale graywater reuse system would save water by 51.3%

dressed, such systems could eliminate toilet water flushing demand in building types such as barracks and gymnasiums. From a cost perspective, this practice faced challenges and would be most effective for new structures or structures in which shower drain plumbing is easily accessible to perform the necessary plumbing retrofits for segregating gray and black water. For improving future deployments of similar systems, pre-validation of the systems using protocols based on the ANSI/NSF 350 standard should be required, with modifications made to reflect the expected graywater generation schedule for the building and design. A more extensive level of treatment should be targeted in the validation phase in order to avoid water quality concerns. On-site performance and automation validation over a three month startup period, as well as the first year's maintenance, should be included in contracts for installing these systems in buildings in order to ensure that systems do not fail after installation. Systems that can reuse a larger fraction of the building water demand should be explored to improve life cycle costs. Life cycle cost analysis tools should be used up front to project return on investment to ensure the payback period will be acceptable. Non-market valuation factors, such as emergency operation of critical facilities, need to be considered, and associated models to support this analysis need to be developed.

For the bathroom scale under-sink graywater reuse system, further technical improvements are required to meet some of the water quality requirements for toilet flushing. While the system generally worked well to clarify and disinfect the water, the level of organics removal of 83% fell short of the 90% removal level that would be needed to bring the biochemical oxygen demand (BOD) below 10 mg/L. In addition, physical system modifications are necessary to improve the energy efficiency, self-cleaning capability, chlorine dosing levels, and controls. These improvements are key for making the system cost-effective. The approval process and retrofit times for installing the under-sink system were also longer than expected, and the associated costs may be a limiting factor for achieving a target payback period. To improve future deployments of similar technologies, the pre-validation phase should target a more extensive level of treatment than the standards in order to provide a margin of safety, and the validation testing should be performed under flow conditions representative of bathroom usage (i.e., weekend downtimes). Overall, the challenges faced with autonomous performance and cost require improvements before such a bathroom scale water reuse approach can be considered.

This study confirmed that conservation technologies such as efficient fixtures can improve sustainability and resiliency in a cost effective manner. On the other hand, water reuse at the building scale is still a maturing technology space, and challenges with automation, retrofit cost, and a relatively low ratio of water cost to capital costs still present barriers to the adoption. Higher levels of water reuse through advanced treatment could be one option for improving payback, though regulatory challenges may limit that approach in the near term. Alternatively, non-market-cost valuations based on the need for DoD facilities to meet water demand reduction targets within Executive Order 13693, Net Zero policy, and water security capabilities described in Army Directive 2017-07, could still drive technology adoption. During the study, it was also noted that some facilities at installations, such as off-grid training areas, incur very high water and wastewater costs that are on the order of 100-fold the cost for on-grid buildings. Targeting these areas may provide an alternative cost-effective approach for maturing water reuse technology for future building scale applications. Overall, there is considerable work remaining to provide building scale solutions to support integrated capabilities that can fully address current DoD guidance and policies for water resilience and security.

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ACKNOWLEDGMENTS

Funding for this demonstration was provided by the Strategic Environmental Research and Development Program (SERDP) under Environmental Restoration (ER) Project 201155, "Integrated Water Planning Through Building Level Cascade of Water Use."

One Army and one Marine Corps installation provided demonstration sites and technical support to this project. At Marine Corps Recruit Depot San Diego, Mr. Richard Hatcher provided much needed support. Mr. Les Gioja provided guidance and support at Engineer Research and Development Center, Construction Engineering Research Lab in Champaign, IL. Early review and guidance was provided by Mr. Scott Clark, technical adviser, and Mr. Glen DeWillie, of HydroGeoLogic, Inc.. Finally, the team and authors gratefully acknowledge the financial support and technical guidance provided by the Environmental Security Technology Certification Program (ESTCP) Office under the leadership of Mr. Timothy Tetreault and Dr. James Galvin, as well as the support provided by Ms. Sarah Medapalli, Mr. Jeffrey W. Houff, Mr. Peter Knowles, and Mr. Jonathan Thigpen, of Noblis and HydroGeoLogic, Inc. (HGL) throughout the project period of performance.

Thanks are also extended to Illinois Department of Health, the U.S. Environmental Protection Agency, and the Army Public Health Center.

LIST OF ACRONYMS

Term	Definition
AFCEE	Air Force Center for Engineering and the Environment
ANSI	American National Standards Institute
APHA	American Public Health Association
AS/NZS	Australian/New Zealand Standards
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASME	American Society of Mechanical Engineers
AWE	Alliance for Water Efficiency
AWWA	American Water Works Association
BAS	Building Automation System
BLCC	Building Life Cycle Cost
BMP	Best Management Practice
BOD	Biological Oxygen Demand
BTU	British Thermal Unit
CAC	Common Access Card
CAPEX	Capital Expenditure
CERL	Construction Engineering Research Laboratory
CMU	Concrete Masonry Unit
COD	chemical oxygen demand
CRADA	Cooperative Research and Development Agreement
DI	Drill Instructor
DLA	Defense Logistics Agency
DoD	U.S. Department of Defense
DPW	Directorate of Public Works
EISA	U.S. Energy Independence and Security Act of 2007
EO	Executive Order
EPAct	Energy Policy Act
ER	Environmental Restoration
ERDC	U.S. Army Engineer Research and Development Center
ESTCP	Environmental Security Technology Certification Program
EW	Energy and Water
FEMP	Federal Energy Management Program
FY	Fiscal Year
GBCI	Green Building Certification Institute
GHG	Greenhouse Gas
GPD	Gallons per Day
GPF	Gallons Per Flush
GPH	Gallons per Hour

Term	Definition
GPM	Gallons per Minute
GW	Graywater
HET	High Efficiency Toilet
HGL	HydroGeoLogic, Inc.
HQ	Headquarters
HVAC	Heating, Ventilating, and Air-Conditioning
ICC	International Code Council
IDPH	Illinois Department of Public Health
IES	Illuminating Engineering Society
ILA	Industrial, Landscape, or Agricultural
IPC	International Plumbing Code
IR	Infrared
LEED	Leadership in Energy and Environmental Design
LID	Low Impact Development
LPG	Liquefied Petroleum Gas
MaP	Maximum Performance
MCA	Military Construction, Army
MCRD	Marine Corps Recruit Depot, San Diego
NAVFAC	Naval Facilities Engineering Command
NIST	National Institute of Standards and Technology
NSF	National Science Foundation
NSN	National Supply Number
NTU	Nephelometric Turbidity Units
NZI	Net Zero Installation
O&M	Operations and Maintenance
OMB	Office of Management and Budget
ORP	Oxidizing-Reduction Potential Probe
PCP	Physical Conditioning Platoon
PERC	Plumbing Efficiency Research Coalition
SAR	Same as Report
SEM	Scanning Electron Microscope
SERDP	Strategic Environmental Research and Development Program
SF	Standard Form
SIR	Savings to Investment Ratio
SMART	Sports Medicine and Reconditioning Therapy
SSPP	Strategic Sustainability Performance Plan
TC	Total Coliform
TSS	Topographic Support System
UFC	Unified Facilities Criteria

Term	Definition
UIUC	University of Illinois at Urbana-Champaign
ULFT	Ultra-Low-Flush Toilet
USACE	U.S. Army Corps of Engineers
USAF	U.S. Air Force
USEPA	U.S. Environmental Protection Agency
USGBC	U.S. Green Building Council
UST	Underground Storage Tank
VoIP	Voice-Over Internet Protocol

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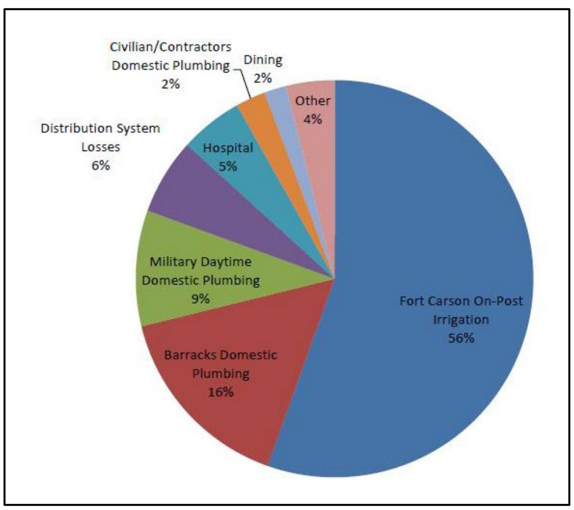
1.0 INTRODUCTION

Department of Defense installations used 85.5 billion gallons of potable water in fiscal year 2016 (FY16). At the same time, installations generated nearly an equivalent amount of sewage and paid for its treatment. Nearly all of the water used by installations is potable though that level of purity is not required for all applications. Across the U.S. it is estimated that 30% of potable water is used for toilet flushing alone. Using the appropriate level of purity for each application, in some cases using water for several applications, preserves fresh water resources for required uses, supports sustainable water supplies for the future, reduces energy and chemicals required to process and pump potable water and sewage, reduces hydraulic load on existing sewer systems, and reduces cost for both purchased water and sewage treatment services. In addition, water reuse strategies support achievement of mandated water conservation targets (2%/year from 2007 through 2025) and increase water resilience and security. This report includes information on the water, energy, and operations and maintenance savings that may be gained through the use of efficient plumbing fixtures and graywater reuse systems.

1.1 Background

The current building water system in typical DoD facilities uses highly processed potable water for all uses, including landscape irrigation. A cascading water use system reserves potable water for necessary uses, using processed graywater and rainwater for other purposes, and reducing DoD potable water costs and demand. A cascading system matches supply with demand, targeting rainwater collection toward landscape irrigation, graywater reuse to toilet flushing, and condensate collection to cooling towers and industrial usage. This demonstration project addresses retrofits that are applicable to the enormous stock of existing buildings with minimal alterations.

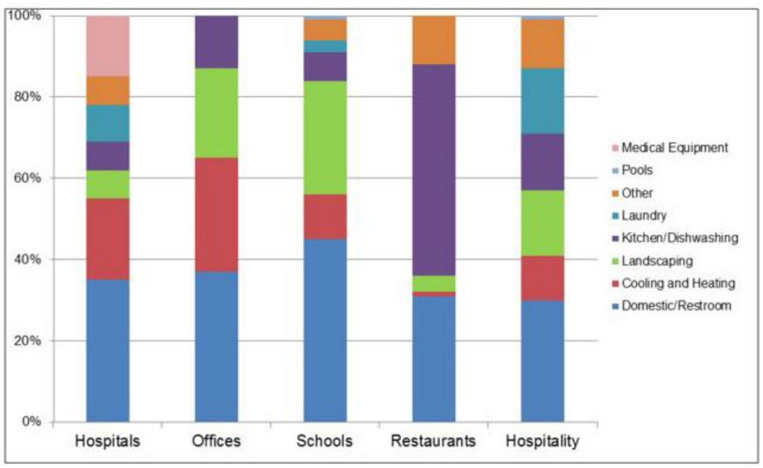


Source: McMordie Stoughton et al. (2012)

Figure 1-1. Example of DoD installation breakout of water by end use.

Water reuse refers to the reclamation, treatment, and recycling of wastewater, rainwater, and air conditioning condensate. Reused water is not used for drinking, which accounts for only 1% of overall consumption.* While irrigation and toilet flushing are two of the most common reuses of water, a variety of other possibilities exist, including groundwater/ aquifer recharge, heating/cooling (cooling towers, water-cooled equipment, and boilers), vehicle washing, and some industrial processes. Figure 1-1 shows the water consumption by end use for an Army site located in the western United States, indicating that irrigated landscape consumes over 50 % of water. This degree of irrigation is typical in arid regions, however, even installations in mesic regions consume up to 20% in irrigation of public areas, sports fields, and parade grounds, especially with the prevalence of short-term droughts in many regions (PNNL 2013).

Water reuse technologies are widely applicable across Department of Defense installations. Military installations continue to tap potable water for all building uses, though industry estimates that about 65% of interior water use can be recycled as graywater. Water reuse potential for administrative/office buildings is approximately 41% as shown in Figure 1-2. While using water efficiently should remain the top priority, alternative sources of water—including those available at the building level—should be considered a part of the water supply mix.



Source: USEPA (2012)

Figure 1-2. Water distribution by end use in typical commercial facilities.

The DoD does not currently practice graywater reuse at the building scale. Existing reuse systems are primarily using tertiary treated wastewater for landscape irrigation. In the Army, these systems irrigate golf courses at Fort Carson and Fort Huachuca. Specific systems that recycle water include Army vehicle wash racks.

This demonstration includes two graywater reuse applications. The first system is a building-scale application reusing shower drain water to flush toilets at a building scale shower/latrine facility. The system collects drain water to a holding tank, cleans using filtration and chemicals, and pumps to toilets in the same facility. The second system is a bathroom-scale packaged unit that reuses sink drain water to flush toilets in the same office building bathroom.

* Maureen Duffy. Water Reuse White Paper. American Water.

DoD currently lacks detailed cost and performance data and specific implementation guidance to fully implement a building level water reuse system. Retrofitting existing buildings with an integrated water use cascade will help maintain critical operation centers in regions that are currently facing water shortages, will promote goodwill in surrounding communities, and will serve as a model of sustainable development for other governmental and non-governmental organizations. A significant benefit is establishing good practice for best use of a critical resource in a future of increasing scarcity and water pricing.

Approximately 35% of the Army's barracks alone include centralized shower rooms that may benefit from a cost effective retrofit to graywater reuse systems. Most shared public building bathrooms, such as offices and training buildings, would benefit from distributed graywater reuse systems. Efficient plumbing fixtures in most facilities, particularly faucets and showerheads that utilize hot water, should be considered for cost-effective retrofits. Toilet and urinal retrofits are applicable primarily in facilities where larger groups of individuals share bathrooms, that is, most non-residential buildings.

The original facilities selected for the demonstration included several locations that met the study criteria for retrofit of a centralized graywater system—a forward training area with gang showers and sinks—and the criteria for retrofit of a distributed graywater system—a gymnasium with a high use of shower facilities and adjacent toilets. A variety of circumstances led to changes to the initially planned demonstration site to two separate locations: U.S. Army CERL campus in Champaign, IL for the distributed graywater system retrofit, and Marine Corps Recruit Depot San Diego, CA for the centralized graywater system retrofit. In the case of the MCRD, this project documented an existing centralized graywater system for its performance and cost-effectiveness. CERL in particular offered ready access to monitor performance data as it is the location of the investigators work site. The results at these demonstration sites were used to estimate DoD-wide water, energy and operations and maintenance cost savings potential.

1.2 Objective of the Demonstration

The objective of this project was to demonstrate and validate the retrofit of existing buildings with an integrated suite of water efficiency and reuse technologies that support building level cascade of water use thereby reducing potable water consumption. An existing administrative building was retrofit with a cascading water use system that combined the proven technologies of water efficiency with newer, less applied concepts of graywater reuse to provide an optimized, highly efficient system for minimizing potable water use in DoD buildings. A new training barracks that was constructed with a building scale graywater reuse system in place was monitored for its ability to meet the project's performance objectives.

Water and energy savings were validated through audits and metering. Water quality was evaluated with continuous monitoring as well as grab samples of treated graywater. Additional data was collected on usage factors such as building population and bathroom use. Qualitative data was collected from user surveys and interviews with operations and maintenance personnel. Insights from the demonstration were used to provide guidance for future alteration of criteria and guidelines: Department of Defense Unified Facilities Criteria (UFC) 2-420-01, 25 October 2004 (Including change 10, October 26, 2015) Plumbing Systems and UFC 1-200-02, 1 December 2016 High Performance and Sustainable Building Requirements.

The project findings will be provided to the appropriate service organizations (Army: Headquarters, U.S. Army Corps of Engineers [HQUSACE]; Navy: HQ Naval Facilities Engineering Command [NAVFAC]; U.S. Air Force [USAF]: Air Force Civil Engineer Center [AFCEC]). Appropriate professional organizations for tech transfer, journal articles and conference presentations, include the American Water Works Association, the American Water Research Association, and the Water Reuse Foundation.

This project has also generated interest among the code organizations. National Sanitation Foundation (NSF) 350, the consensus criteria for graywater reuse, was released in July 2011. At this time only one system has been certified (a residential system). Although the demonstration does not require NSF 350 certification, the demonstrated technologies are required to meet the water quality criteria of the standard. The findings from this demonstration project will provide information for non-Defense organizations who are also seeking solutions to water scarcity.

In summary, the objectives of this demonstration and validation project are to:

- Demonstrate effectiveness of water conservation, harvesting, and reuse technologies.
- Demonstrate an integrated, controlled, cascading system, including:
  - Building-scale reuse systems.
  - Bathroom-scale reuse systems.
- Compare performance of demonstration building(s) pre- and post-retrofit.
  - Potable and graywater volume.
  - Water quality.
  - Energy and cost savings.
  - Reliability, maintainability and user satisfaction.
- Provide engineering guidance to support DoD-wide adoption.

1.3 Regulatory Drivers

Reducing potable water consumption by retrofitting plumbing fixtures and using alternate sources wherever possible will help DoD installations meet several water efficiency mandates. While the main sustainability driver containing key water targets is Executive Order 13693, Planning for Federal Sustainability in the Next Decade, a summary of water mandates are listed in Table 1-1.

Table 1-1. Current water mandates.

Federal Mandate	Water Topic	Water Performance Target
EO 13123, 6/99	Potable Consumption	Cost-effective efficiency: FEMP BMPs
EO 13423, 1/07	Potable Consumption	Reduce by 2%/year from 2007 to 2015
	Water audits	10%/year every 10 years
	Products/Services	Procure water efficient; WaterSense®
EISA 2007	Covered Facilities	Evaluation, projects and follow-up
	Post-Const Stormwater	Restore to pre-development hydrology
EO 13514, 10/09	Potable Consumption	Reduce by 2%/year from 2007 to 2020
	Industrial, Landscape, Ag	Reduce by 2%/year from 2010 to 2020

	Water Reuse	Identify, promote and implement
	Stormwater mgmt.	Implement & achieve EPA objectives
EO 13693, 3/15	Potable Consumption	Reduce by 2%/year through 2025
	Industrial, Landscape, Ag	Reduce by 2%/year through 2025
	Metering	Install meters to improve management
	Stormwater Mgmt	Install LID to improve SW management
2016 DoD SSPP	Potable Consumption	Reduce by 2%/year from 2007 to 2020
	Industrial, Landscape, Ag	Reduce by 2%/year from 2016 to 2020
DoD UFC 1-200-021/13	Indoor Water	ASHRAE 189.1-2011 & WaterSense®
	Outdoor Water	Reduce by 50%; ASHRAE if cost effect
	Heating & Cooling Water	ASHRAE when cost effective
	Measurement of Water	Meter IAW DODI 4170.11

- Executive Order 13123 (EO 13123), signed June 1999: *EO 13123* provides guidance for reducing water through cost-effective efficiency. This led to development by the Federal Energy Management Program (FEMP of the Department of Energy of the water efficiency best management practices (BMPs).
- Energy Policy Act of 2005 (EPAct 2005), effective as of 8 August 2005: *EPAct 2005* mandated efficiency standards for water fixtures. Toilet efficiency standards were set at 1.6 gallons per flush, commercial urinals at 1.0 gpf, residential showerheads at 2.5 gpm, residential and commercial faucets at 2.2 gpm, and public restroom faucets at 0.5 gpm and 0.25 gallons per cycle. Additionally, water efficiency standards were set for clothes washers, dishwashers, automatic commercial ice makers, and commercial pre-rinse spray valves. Agencies were also required to reduce water consumption intensity when cost effective.
- Executive Order 13423 (EO 13423), signed on 24 January 2007: *EO 13423* provides guidance in the development of water management plans and implementation of Best Management Practices (BMPs) for water efficiency as identified by the Federal Energy Management Program (FEMP). EO 13423 establishes new water efficiency rules for Federal facilities, requiring a 2% annual reduction in water consumption intensity (gallons per square foot) from a 2007 baseline through the end of FY15, or 16% by the end of FY 2015. It further requires water audits at Federal facilities of at least 10% of facility square footage at least once every 10 years. Finally, it encourages the procurement and use of water-efficient products and services, specifically identifying the U.S. Environmental Protection Agency's (USEPA's) WaterSense© program as a source of guidance.
- Energy Independence & Security Act (EISA 2007), effective 19 December 2007: *EISA 2007* amends Section 543 of the *National Energy Conservation Policy Act*, the foundation of most current energy requirements. It adds further water conservation requirements and provides guidance for facility energy management and benchmarking. Under EISA 2007, agencies are required to categorize groups of facilities that are managed as an integrated operation and to identify "covered facilities" that constitute at least 75% of the agency's facility energy and

water use. Each of these covered facilities will be assigned an energy manager responsible for completing comprehensive energy and water evaluations, implementing efficiency measures, and following up on implementation.

- Executive Order 13514, Federal Leadership in Environmental, Energy, and Economic Performance (EO 13514); signed 5 October 2009: *EO 13514* expands the water efficiency and conservation requirements of EO 13423 and EISA 2007. The new mandate extends EO 13423's 2% annual water consumption intensity reduction requirement into FY20, resulting in a total water reduction requirement of 26% from the baseline year of 2007. Additionally, the new rules require similar 2% annual reduction for agency industrial, landscaping, and agricultural water consumption through 2020, for a total of 20% water consumption reduction relative to the 2010 base year. EO 13514 also encourages agencies to identify, promote, and implement water reuse strategies that reduce potable water consumption and support objectives identified in the storm water management guidance issued by the USEPA.
- Executive Order 13693, Planning for Federal Sustainability in the Next Decade, signed 25 March 2015 (EO 13693): *EO 13693* extended existing efficiency goals for potable and Industrial, Landscape, or Agricultural (ILA) water reduction to 2025, requiring an additional 2% reduction per year. The current goal for potable water is 2% reduction per year from 2007 to 2025, for an overall reduction of 36%. The current goal for ILA water is a 2% reduction per year from 2010 to 2025, for an overall reduction of 30%. Additionally, the EO required installation of water meters to improve management and to install low impact development (LID) to improve storm water management.
- 2016 DoD Strategic Sustainability Performance Plan (SSPP): The *2016 Department of Defense Strategic Sustainability Performance Plan (7Sep2016)* reviews DoD policy and strategy and reviews performance in a number of issue areas including water resources management. The water resources goals include reduction of water intensity of 2%/year in facilities using a baseline of FY 2007, and in industrial, landscaping, and agriculture using a baseline of FY 2016.
- DoD's UFC 1-200-02, *High Performance and Sustainable Building Requirements: Encourages the Use of Reclaimed Water*, WaterSense® and ASHRAE for indoor fixtures and appliances, ASHRAE for outdoor water and heating/cooling when cost effective, and installation of water meters IAW DODI 4170.11.
- Army: The Army adopted federal requirements through policy and regulations—The Army Energy Security and Sustainability Strategy and the Army Installations 2025 capture these—and have advanced the concept even further by establishing challenging targets for fixed installations to achieve net zero water. The Installation Energy and Water Security Policy establishes requirements to sustain critical mission capabilities and mitigate risks posed by energy and water disruptions affecting installations (Feb2017).
- Navy: The Navy's OPNAV M5090.1 manual encourages water re-use in a general way, also leaving open feasibility in the context of economic payback and other factors: 20-3.12. Water Reuse. To support water conservation efforts, Navy commands shall ensure all activities implement water reuse practices to reclaim, recycle, and reuse wastewater to the maximum extent feasible, taking into account economic payback, process requirements, and the scarcity of water resources available to the primary water supplier for the installation. Reuse of water shall be accomplished per all applicable federal, state, and local laws, E.O.s, regulations and requirements.
- Industry standards and codes:
    - Plumbing and building codes influence the adoption of water efficient products and processes. DoD adopts the International Code Council (ICC) International Plumbing Code

(IPC) as the primary standard for DoD facility plumbing systems. The code has a 3-year development cycle for updates. The process of amending codes is long and labor-intensive and requires the support of water stakeholders. Any additions, deletions, and revisions to the IPC are listed in Appendix A "Supplemental Technical Criteria" of Unified Facilities Criteria (UFC) 3-420-01, 25 October 2004.

- WaterSense® is a U.S. Environmental Protection Agency (USEPA) partnership program that certifies water fixtures that meet rigorous criteria in both performance and efficiency. Specifications and criteria are available for bathroom sink faucets, shower heads, tank-type and flushometer-valve toilets, urinals, weather-based irrigation controls, and spray sprinkler bodies. Specifications that are in the public review stage include soil moisture controlled landscape irrigation controls and bath and shower diverters. WaterSense® also certifies landscape professionals and provides certification for water-efficient homes.
- The U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED®) Green Building Rating System is a voluntary standard for high performance sustainable buildings. LEED® certification validates that a building is a high performing, sustainable structure. Certification also benchmarks a building's performance to support ongoing analysis over time to quantify the return on investment of green design, construction, systems, and materials. All Army Military Construction, Army (MCA) projects meeting the Minimum Program Requirements for LEED® certification are to be planned, designed, and built to be Green Building Certification Institute (GBCI) certified at the Silver level or higher.
- ASHRAE developed Standard 189.1-2009 in conjunction with the USGBC and the Illuminating Engineering Society (IES). This standard is intended to provide minimum requirements for sustainable or green buildings through the general goals of reducing energy consumption, addressing site sustainability, water efficiency, occupant comfort, environmental impact, materials, and resources. The Army adopted the energy and water standards of ASHRAE 189.1-2009 for all new construction and major renovations through the *Sustainable Design and Development Policy.* This adoption has been extended to version ASHRAE 189.1-2011.

Many of these policies, directives, and executive orders overlap in their requirements. Collectively the pertinent requirements are:

- Reduce potable water usage by 36% by FY2025 (relative to 2007).
- Reduce industrial, landscape, and irrigation water usage by 18% by 2025 relative to 2016 for the DoD (30%, relative to 2010, for the Army).
- Increase usage of alternate sources of water thereby improving water security.
- Construct or renovate buildings in accordance with sustainability strategies, including potable water conservation and water reuse strategies.

1.4 Cost of Water

Installation potable water supply is often undervalued when compared to higher cost energy. Low water pricing leads to long payback periods for water investments and can lead to waste and inefficiencies. The price of water at an installation is determined either by the source utility or, where installations supply their own water, by governing policy for calculating utility resale rates. These rates are then used in billing reimbursable customers and vary by customer class.

In contrast to price, the value of water is influenced by the degree of availability. Water is typically undervalued when considering water stress, both seasonal and chronic, in many regions of the United States.

When taken as an average, the cost of potable water to Department of Defense installations was $3.15 for every thousand gallons (Kgal) for fiscal year (FY) 2015. (Water reuse and industrial, landscape and agricultural water categories are reported separately.) Using the Army as an example, while total potable water use has declined since FY 2007, the unit cost of water rose by more than 80 percent through FY 2017 (see Figure 1-3). Water rates in the United States increased by 5.34 percent annually between 2004 and 2016 (AWWA 2017).

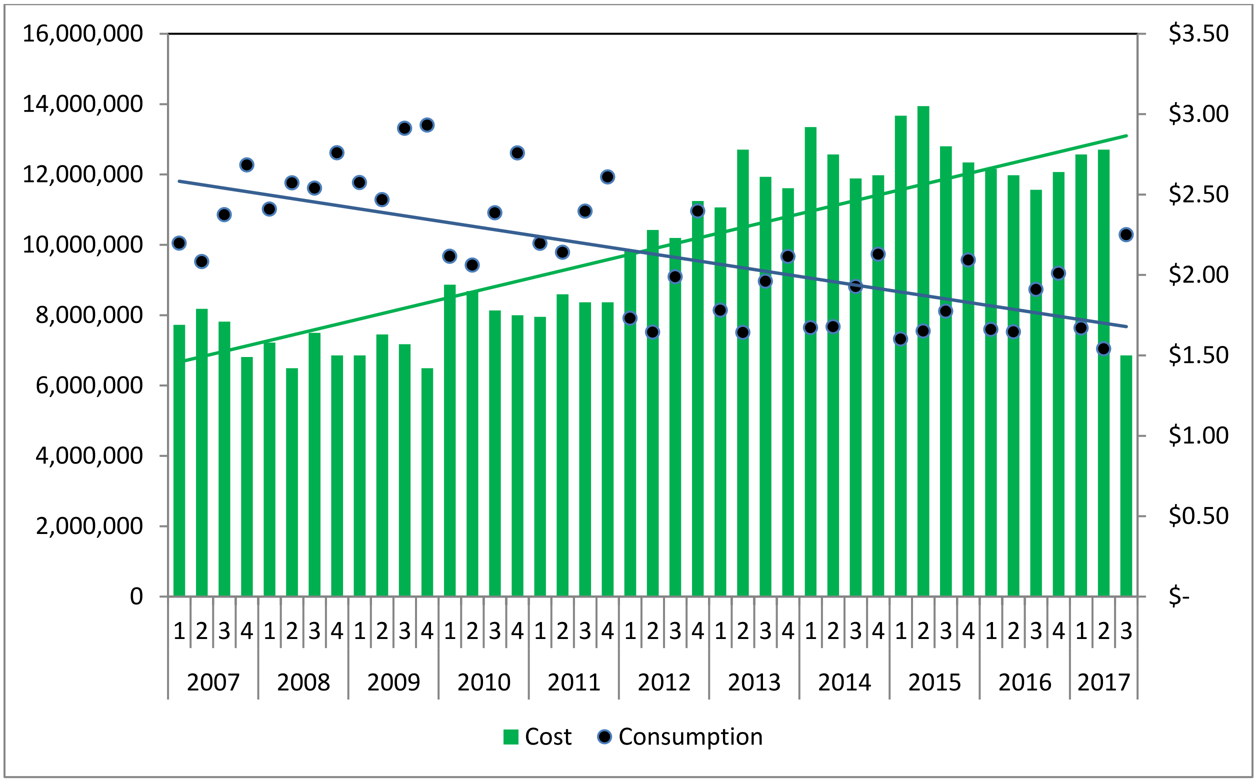


Figure 1-3. Historic quarterly demand and average cost for Army potable water.

Water cost varies between installations for a number of reasons. For installations that purchase water from a local utility, unit price trends are regionally based on factors ranging from the water source (surface, ground, reuse), the cost to operate water and wastewater treatment facilities, and the degree of infrastructure reinvestment by the utility supplier.

For installations that withdraw, treat and distribute their own water, the true cost of water will be closely linked to the age and condition of water infrastructure. Treatment plants and distribution systems that require large inputs of energy, material and repairs cost more to operate. The unit price passed on to reimbursable customers is higher.

It is imperative that installations account for all of the operations and maintenance costs incurred by the water system when setting water rates for reimbursable customers. Categories of cost include operations, system losses, energy cost, capital charges and overhead costs in support of the treatment and supply of drinking water. There may be additional costs to the treatment and distribution system that don't show up as operations and maintenance, for example, disposal of treatment by-products such as sludge. It is important that the energy burden of the water system is fully accounted for. This requires careful attention to any changes in pump efficiencies or operating hours from year to year.

For this demonstration project, the actual billed water rates were used for the life cycle cost analysis. For the ERDC-CERL demonstration site this rate was $10/kgal. For the MCRD San Diego demonstration site this rate was $10.53/kgal. Both of these rates include sewage treatment.

2.0 TECHNOLOGY DESCRIPTION

2.1 Technology Overview

This section includes descriptions of the following technologies that were a part of this demonstration project. The development of each technology shall be described first, followed by a discussion about advantages and limitations of each technology:

- Efficient plumbing fixtures.
    - Low flush toilets (1.6 gpf) with auto flushing sensors.
    - Low flow faucets (0.5 gpm) and sensors.
    - Low flow showerheads (2.0 gpm).
    - New generation waterless urinals—approved project mod, April 2015.
    - Water efficient shave stands—approved project mod, April 2015.
- Graywater reuse technologies.
    - Centralized gang sink/shower graywater collection, treatment and reuse for toilet flushing (1,500 gpd; 500 gal graywater (GW) & clean water underground storage tank [UST]).
    - Distributed sink graywater collection, treatment and reuse for toilet flushing (50 gpd).
    - Integrated controls for monitoring quality and managing use.

2.2 Technology Development

Water-efficient plumbing fixtures are vastly improved since the first push for water efficiency. These improvements parallel the increasingly stringent Federal policies to reduce water use and increase fixture efficiency. Where once saving water was enough, today's efficient fixtures also meet strict performance criteria.

2.2.1 Efficient Plumbing Fixtures

This discussion covers toilets and automatic flushing technologies, lavatory faucets, kitchen faucets, and showerheads. Water efficient fixtures are some of the easiest conservation retrofits to accomplish. EPAct 2005, EISA 2007, EO 13423, EO 13514, and EO 13693 require Federal agencies to achieve water reduction targets and improve water efficiency by incorporating best management practices and through the use of water efficient products and services.

In addition, the Army now mandates that indoor water consumption in new construction and major renovation shall use technologies that result in at least 30% reduced consumption of potable water as compared to the base case facility. Standards have been established for specific technologies by USEPA *WaterSense*®, ENERGY STAR, and *ASHRAE 189.1-2011*, which are referenced in the DoD's sustainable design and development criteria.

While criteria specify maximum flow rates, a range of flows are available for some fixtures. It is important to ensure that user needs are met while achieving the greatest savings possible. *WaterSense*® labeled devices have been tested for performance as well as efficiency. Some super-saver fixtures may be well worth the investment to decrease water use even more.

2.2.1.1 Toilets

The largest water users in the residential sector are toilets, accounting for nearly 30% of indoor water consumption. Savings are achieved by reducing the number of gallons per flush (gpf) volumes. *ASHRAE 189.1-2011* mandates that tank-type toilets shall be 1.28 gpf (4.8 L) and shall be certified to the performance criteria of the USEPA *WaterSense*® Tank-Type High-Efficiency Toilet Specification. ASHRAE mandates that flushometer valve type toilets shall also be 1.28 gpf though the requirement for *WaterSense*® compliance was not yet in place at the time of ASHRAE's release. The *WaterSense*® flushometer-valve water closet spec, released in 2015, also specifies 1.28 gpf (4.8L) as a maximum.

2.2.1.1.1 Technology

Replacement of high water consumption toilet fixtures has been the chief initiative of water industry's reduction of potable water use campaign since the 1980s. Installation of 1.6 gpf toilets is now standard; it is increasingly rare to encounter older 3.5 and 5.0 gpf fixtures. As market saturation of efficient toilet fixtures occurred, development of different technologies to achieve lower flush volumes emerged. Currently, two distinct types of toilet fixtures are prevalent in the marketplace today: Ultra-Low-Flush Toilets (ULFTs, aka "low-flow" or "ultra-low-flow") and High-Efficiency Toilets (HETs). The distinction between these fixtures rests in the quantity of water used per flush; ULFTs are defined by an effective flush volume in the range between 1.28-gpf and 1.6-gpf (4.8 L and 6.1L), while HETs are defined as 1.28-gpf or less (4.84 L).

ULFTs first began making their way into residential dwellings in the 1980s. The first mandated use occurred in Massachusetts in 1989. After 15 other states followed suit, the U.S. Congress extended the requirement to all toilets sold nationally in the 1992 Environmental Policy Act (AWE 2010).

In the late 1990s, HETs emerged as an improvement over ULFTs, saving 20% more water per flush. Just a few years later the first HET technology fixtures became available in the marketplace. Today HETs outlive and outperform their predecessor; as a result there are nearly three thousand tank-type and 350 flush-valve type HET fixture models available. Four types of HET technologies commonly found on the market are gravity fed single-flush, dual-flush, pressure-assist, and power-assist toilets.

Urinals meeting and exceeding federal standards have been available since 1994. Non-water urinals, composting urinals, and retrofit devices aren't included in the *WaterSense*® specification.

2.2.1.1.2 Policy

Virtually all toilet models sold in the United States meet both flush volume and performance standards required by the American National Standards Institute/American Society of Mechanical Engineers (ANSI/ASME), however concerns regarding customer expectations and approvals of toilet fixtures led to the development of the Maximum Performance (MaP) testing project in 2003. MaP promoted development of more water-efficient toilets by "rewarding" models that provide better flushing performance. MaP testing supplies performance information on toilet fixtures, providing a roadmap for water managers by distinguishing between good and marginal performers (Veritec and Koeller 2010). *WaterSense®* only certifies toilet fixtures that complete a third-party certification process (USEPA 2017). For HETs, the USEPA has adopted a 350 gram of MaP media (soy bean paste) as the minimum performance threshold for earning *WaterSense®* certification. MaP testing has found that toilet fixtures available in today's marketplace are significantly better performers than those tested when the MaP project began in 2003. Nearly 100 percent of new toilet models meet the *WaterSense®* 1.28-gpf requirement (Koeller and Gauley 2016). Much of this improvement is credited to the wide marketplace acceptance of MaP testing, and an ongoing dialogue and cooperation between the Steering Committee for Water Efficient Products, the USEPA, and toilet manufacturers.

2.2.1.2 Urinals

Along with toilets, urinals can use a significant amount of potable water in commercial and institutional buildings. Older urinals can consume as much as five times the current Federal standard of 1.0 gpf. EPA estimated that up to 65 percent of existing urinals exceed current maximum flush volume allowed by federal standards, some by as much as 3.0 gpf (USEPA 2017). *ASHRAE 189.1-2011* mandates that flushing urinals shall be 0.5 gpf (1.9 L) though the requirements for *WaterSense®* flushing urinals was not in place at the time of ASHRAE's release. The *WaterSense®* flushing urinal spec, released in 2009, also specifies 0.5 gpf (1.9 L) as a maximum. This value was selected based on being a widely accepted industry standard and already available on the market for several years.

2.2.1.2.1 Technology

Since the federal standards for urinal flush volume were enacted (EPAct 1992), manufacturers have developed urinals that both meet and exceed the initial 1.0 gpf (3.9 L) standard. The newer more efficient urinal standard can save at least 0.5 gallons of water per flush compared to the old standard. Replacing pre-1994 urinals with the new high-efficiency fixtures can save even more water. During the spec development process, *WaterSense®* product research identified at least eight manufacturers offering nearly 40 models of urinals rated at a maximum of 0.5 gpf. The *WaterSense®* specification applies only to urinals that use water to convey liquid waste through a trap seal into a gravity drainage system. This includes the ceramic (vitreous china), plastic, or stainless steel urinal fixture and the pressurized (i.e., flushometer valve) or gravity tank-type flushing device. Non-water urinals and composting urinals are not addressed by the specification. Likewise, retrofit devices are not included as the intent of the specification is to recognize and label complete, fully functioning fixtures or fittings (USEPA 2009).Recent urinal developments include the hybrid model that was partially assessed in this project.

2.2.1.2.2 Policy

In addition to the efficiency standards of ASHRAE and *WaterSense*®, all flushing urinals are subject to ANSI-approved national performance standards that include ASME and IAPMO. Ceramic flushing urinal fixtures are subject to the performance requirements of ASME A112.19.2/CSA B45.1, stainless steel urinal fixtures are subject to the performance requirements of ASME A112.19.3/CSA B45.4, and plastic urinal fixtures must comply with IAPMO Z124.9. Flushometer valves are subject to American Society of Sanitary Engineers (ASSE) #1037—Pressurized Flushing Devices (Flushometers) for Plumbing Fixtures, while gravity tank-type flushing devices are subject to the requirements of ASME A112.19.2/CSA B45.1. In addition to the above, the flushing device primary actuator must be of a non-hold-open design; the flushing device must not be adjustable as to its rated flush volume beyond ± 0.1 gpf (0.4 L); and, the flushing device must be designed such that any interchangeable parts would not cause the device to exceed its rated flush volume.

2.2.1.3 Faucets

Water faucets are a significant percentage of indoor water use in residences, accounting for one-fifth of consumption. Savings are achieved by reducing the volume of flow in gallons per minute (gpf). The reduction in hot water flow from faucets also saves the energy required to heat the water.

2.2.1.3.1 Technology

The best practice for faucet water usage varies by faucet type. Generally, kitchen faucets require a relatively high water flow to fill pots and perform other kitchen-related tasks. Maximum water flows from the earliest Federal legislation, the Energy Policy Act of 1992 (EPAct 1992), which specifies a maximum faucet water flow of 2.2 gpm at 60 psi, are still considered appropriate for kitchen faucets. A number of more water efficient kitchen faucets are available for those willing to forego quickly filled kitchen sinks. Some even have adjustable flow rates to allow for the higher flow when needed. These lower flow kitchen faucets should be considered and installed where appropriate to achieve further kitchen water savings.

WaterSense® has released a more stringent specification for non-public lavatory faucets. To warrant a *WaterSense*® label, private residential lavatory faucets must have a flow rate no greater than 1.5 gpm at 60 psi. Best practice for public lavatory faucets comes from an American Society of Mechanical Engineers (ASME) code, which requires a flow rate of no greater than 0.5 gpm at 60 psi except for metering faucets that should flow at 0.25 gal/cycle (gpc) according to the Code of Federal Regulations. Often, these levels of water flow are achieved as effectively with faucet aerator retrofit as with replacement fixtures. Faucet aerators restrict water flow while maintaining the feel of higher pressure by mixing air into the flowing water.

ASHRAE 189.1-2011 also sets forth maximum flow rates for faucet fixtures. Public lavatory faucets shall not exceed 0.5 gpm (1.9 L/min); public metering self-closing faucets, 0.25 gal (1.0 L) per metering cycle; residential bathroom lavatory sink-faucets, 1.5 gpm (5.7 L/min) or 60 psi; residential kitchen faucets, 2.2 gpm (8.3 L/min).

There are a variety of different mechanisms for activating faucets beyond the traditional manual method. These include sensors that turn faucets on when triggered by a person's presence and faucets that shut off after a certain amount of time has passed or amount of water has flowed. In theory, many of these mechanisms have the potential to help conserve water. In fact that was the intention behind the development of some. However, a number of empirical studies contest the idea that manual water faucets are less efficient than their competitors. Sensor-activated faucets in particular have been shown to use more water than their manual counterparts (Gauley and Koeller 2010). While more studies are certainly needed to clarify the most water efficient faucet activation method, caution should be used when considering non-manual faucets, and especially sensor-activated faucets, to ensure that these models are the most water efficient option.

2.2.1.3.2 Policy

Provisions of ASHRAE 189.1-2011 apply to new construction and renovation. Table 2-1 lists the requirements.

Table 2-1. New construction and renovation faucet requirements.

Faucet Type	Function	Maximum Flow Rate/Water Use
Public lavatory faucets	Lavatory faucets	Maximum flow rate of 0.5 gpm (1.9 L/min)
Public metering	Self-metering. self-closing faucet	Maximum water use of 0.25 gal/cycle (gpc) (1.0 L/cycle)
Residential bathroom		Maximum flow rate of 1.5 gpm (5.7 L/min)
Residential kitchen faucet	kitchen faucet	Maximum flow rate of 2.2 gpm (8.3 L/min)
Source: ASHRAE 189.1-2011		

2.2.1.4 Shower heads

Showering represents a significant water use and represents a great target for water savings. Showering consumes one-fifth of indoor residential water use. Low-flow showerheads are also cheaper to install than low-flow toilet fixtures, making them a good candidate for short-term cost-effective implementation in DoD facilities. Low-flow showerhead retrofits are one of the most cost-effective BMPs because of the energy savings resulting from reductions in hot water heating. This retrofit alone can pay for itself in less than a year.

2.2.1.4.1 Technology

It is easy to make mistakes when replacing shower heads; they are as easy to remove as they are to install. When replacing shower heads for water savings, it is critical to keep this in mind and to ensure that water efficient shower heads provide adequate water for washing and rinsing, and also an aesthetically pleasing shower.

Prior to development of the *WaterSense*® specification, there were no universally accepted criteria for measuring showerhead performance. The *WaterSense*® performance requirements address flow rates across a range of pressures, spray force, and spray coverage. These requirements are designed to ensure both a high level of performance and user satisfaction, thereby ensuring that high-efficiency showerheads remain installed.

WaterSense® estimates that 10 percent of showerheads are replaced each year to account for wear and tear and breakage. Replacing failed showerheads with efficient models will quickly reduce water use for showering to a minimum.

2.2.1.4.2 Policy

Federal guidelines mandate that all showerheads manufactured and sold in the United States after 1 January 1994 must use no more than 2.5 gpm. The USEPA's *WaterSense®* has a standard of 2.0 gpm at water pressure of 80 psi. ASHRAE 189.1-2011 also sets forth maximum flow rates for residential showerheads at 2.0 gpm (7.6 L/min) at 80 psi.

These units could save 3.5 gal/minute per shower resulting in a 35 gal water saving for a 10-minute shower. Substantial savings could accrue in water and sewer charges and energy used for heating water. For example, 100 people per day with a daily 10-minute shower and total water and sewer costs of $5.00* per 1000 gal, neglecting cost of energy for heating, would provide a savings of $6387.50/yr:

100 showers/day x 3.5 gal/min x 10 min/shower x $5.00/1000 gal x 365 days/yr

2.2.2 Graywater Treatment Systems

This discussion covers graywater treatment systems, building scale and under-sink scale. Gray-water represents consumed water for showers and bathroom sinks. Compare to black water that requires a high level of treatment, graywater treatment systems can treat wastewater from showers and bathroom sinks and reuse for non-contact purposes (non-potable) such as for toilet flushing. Graywater treatment systems can reduce potable water consumption and are cost effective and environmentally beneficial in regions where water is vulnerable. Water pricing is still too low in many regions which renders the use of graywater treatment systems not feasible due to lengthy payback periods.

2.2.2.1 Building Scale

Building scale graywater collection and treatment systems become more practical if situated close to areas of both large graywater supply and water demand, such as locker-room showers and sinks, laundry facilities, or mechanical rooms.

2.2.2.1.1 Technology

Building scale graywater reuse system will collect the drain water to a holding tank, clean using filtration and chemicals, and pump to adjacent toilets in the same facility to replace the potable water for toilet flushing. Excess graywater will be diverted to the sanitary sewer line. In large scale systems, more advanced treatment methods, such as membrane filtration, can be applied due to efficiencies of scale. The higher quality product water can then be stored for longer periods of time and be used for applications beyond toilet flushing, such as washing equipment.

* The rate of $5 is a typical cost used for example purposes. Median water cost of $4.62, with a 5.34 percent annual increase over the past 12 years (AWWA 2017) and $5.67, increasing 4.6 percent over the last year (Circle of Blue 2017).

2.2.2.1.2 Policy

The 2011 NSF/ANSI Standard 350 provides guidance on onsite residential and commercial water reuse system to assure water is treated to safe level for non-potable applications (e.g., surface or subsurface irrigation, toilet/urinal flushing, decorative fountains, etc.).

Table 2-2. Scope of standards for on-site residential and commercial water reuse treatment system.

Building Types	Residential, up to 1,500 gallons per day Commercial, more than 1,500 gallons per day and all capacities of commercial laundry water
Types of wastewater treated (influent)	Combined black and graywater Graywater Bathing water only Laundry water only
Uses of treated water (effluent)	Non-potable applications, such as surface and subsurface irrigation and toilet and urinal flushing
Ratings	Two classifications that vary slightly in treated water quality: Class R: single-family residential Class C: multifamily and commercial Systems are further described by the type of wastewater treated (combined, graywater, bathing only or laundry only).
Source: (NSF/ANSI 2011)	

2.2.2.2 Under-Sink Scale

Under-sink scale graywater reuse systems have the advantage of potentially requiring less modification of existing infrastructure. In a distributed application, the extent of water treatment can be tailored to the immediate intended reuse, and the water storage time can be reduced. The system collects effluent from bathroom sinks and uses it for flushing the toilets. In this under-sink scale system, sink effluent is collected and passed through a simple treatment system immediately next to the sinks.

2.2.2.2.1 Technology

The under-sink scale treatment system provides a self-cleaning, upflow filter for removal of pathogens, organic matters, and particulates, followed by chlorination in the storage tank. In a single-story building, this system would require a pump to deliver water to the toilets. In a multi-story building setting, this water could be delivered to toilets in the bathroom below for flushing, using gravity as the driving force and requiring fewer energy inputs.

2.2.2.2.2 Policy

An under-sink scale water reuse system follows the guidance for onsite residential and commercial water reuse systems from 2011 NSF/ANSI Standard 350. Table 2-2 summarizes standards for on-site residential and commercial water treatment and reuse systems.

2.3 Advantages and Limitations of the Technologies

2.3.1 Efficient plumbing fixtures

2.3.1.1 Advantages

The main advantage to retrofit or replacement of plumbing fixtures is the ability to reduced water use at low cost. It is easy to implement low GPM faucets/showerheads; and somewhat easy to retrofit some toilets/urinals, depending on types (note that flush valves must match fixtures to achieve rated efficiencies). Employing automated sensors may decrease human contact with germs and reduce damage to flush handles when user activates with foot instead of hand to avoid contact. Overall, efficient plumbing fixtures offer quick paybacks for low-cost items, namely, faucet aerators and showerheads.

2.3.1.2 Limitations/disadvantages

The main limitation of retrofit or replacement of toilets and urinals is cost, as the purchase price is prohibitively high to achieve an acceptable payback. With the retrofit to water-free urinals, any existing copper piping would need to be replaced, adding cost. In addition, some training of maintenance personnel is needed for cleaning/maintenance in order to ensure that these fixtures continue to operate as designed. End users must also be 'trained' to make sure no coffee/foreign liquids are disposed of in urinals. Auto flushing mechanisms can experience 'ghost flushing' if not properly configured, thereby increasing water use. A general limitation of reducing fixture flows through improved efficiency is that too low water flow can cause problems in drain line transport, that is, clogged drains due to insufficient water to carry solid waste through the system. Wastewater treatment processes can also be affected by extremely low flows in drain lines.

2.3.2 Graywater systems

2.3.2.1 Advantages

The advantages to graywater treatment systems are reduced potable water demand, reduced water treatment chemicals and energy, and reduced flows to wastewater treatment systems. All of these carry corresponding reductions in cost.

2.3.2.2 Limitations/disadvantages

The main limitation to graywater treatment systems is that their installation/operation is dependent on local codes. Many states still do not address this technology, making the systems difficult to set up by even an educated and motivated water manager. Graywater systems also require routine maintenance to remain operational, which may be a challenge either with training government personnel or ensuring that maintenance contracts include provisions to cover this.

2.3.2.3 Implications of low flows and dry drains

An issue that emerged along with lower water flush volumes in toilets is that of drain line transport or "dry drains". Much of the existing wastewater infrastructure was not designed with today's low flows in mind. Pipe diameters are larger than is necessary to accommodate decreased flows. The slope of drain lines is sometimes not steep enough and plumbing joints that form 90 degree elbows can trap waste that contains less water than what the system was designed for.

Many plumbing experts are concerned that we are at or approaching a "tipping point" where a significant number of sanitary waste systems will be adversely affected by drain line transport problems, especially in larger commercial systems that have long horizontal drain lines to the sewer. When a graywater reuse system collects discharged water from lavatory basins, clothes washers, bathtubs and shower fixtures for reuse – for flushing water closets or sub-surface irrigation purposes – it is taking water away from the sanitary drainage system. The wastewater flow needs to be maintained at a level to keep the hydraulic depth of flow sufficient for proper water velocities and drain line transport.

The Australasian Scientific Review of Reduction of Flows on Plumbing and Drainage Systems (ASFlow) Committee was formed to conduct research into the effects of reduced flows on drainage systems and utility infrastructure. Research results informed changes to the plumbing code. This research included testing for the impact of reduced flush volumes for toilets and for reduced flow due to non-water urinals. Changes to the code were made to address flow challenges of plumbing system components:

Non-flushing (water-free) wall-hung urinals (water-free wall-hung urinals with an integral cartridge seal or integral self-sealing mechanical non-water using urinals): A water-free urinal shall be installed only where at least two fixtures, excluding a cleaners sink, are connected upstream of the connection of the water-free urinal to the discharge pipe (AS/NZS 3500.2a).

Ninety-degree sweep junctions: Junctions installed in a vertical plane shall not be used for connection of stacks. Sweep and 45 degree junctions may be laid in the vertical plane for the connection of a single discharge pipe or drain provided a 45 degree junction shall only be used for the connection of a water closet pan (AS/NZS 3500.2b).

ASFlow and the Plumbing Efficiency Research Coalition (PERC) joined forces in 2010 to work on a research program investigating the effect of reduced water flows in sanitary drainage systems resulting from reductions in water use from plumbing fixtures and fittings, appliances, and commercial and institutional equipment. The coalition sought to determine the minimum amount of water necessary to safely flush drain lines.

PERC is comprised of five organizations: the Alliance for Water Efficiency, the Plumbing Manufacturers Institute, the International Association of Plumbing and Mechanical Officials, the International Code Council, and the Plumbing-Heating-Cooling Contractors Association.

The USEPA's *WaterSense®* incentive labeling program held off developing a specification for High Efficiency Commercial Toilets pending completion of this research in the area of drain line transport.

A study by the United Kingdom's Environment Agency recommends that, for new buildings, a revision of existing drainage design standards must be undertaken to accommodate planned reductions in water demand. These alterations could include the use of pipes with smaller diameters and steeper gradients. Minimum slope in Australia is 1.67%; in the United States, the minimum slope is 1.0104% (1/8 in. per foot) because they generally use smaller drain pipes.

2.3.3 Performance advantages

The performance advantages of the technologies demonstrated in this project include the ability to be integrated into existing infrastructure and the ability to meet current and expected future regulations pertaining to water conservation and reuse. For example, the commercial scale Sloan AQUS system was developed and demonstrated to show that it is possible to install graywater reuse systems with minimal infrastructure modification. By collecting and reusing water in the same bathroom, the system avoids tearing out walls and buried pipes. In addition, the system was validated using the most stringent graywater reuse standard available, the NSF 350 standard. This was to ensure that it would meet current and future building codes and regulations.

2.3.4 Cost advantages

Potable water use within buildings incurs several costs to an installation. First, the installation must obtain and treat the water to a potable level. The cost of delivered water depends on the source and its location. Costs include procurement, transport, treatment, and storage. Next, it must distribute the water under pressure across the installation to various users. Most of the used water must then be pumped back to a wastewater treatment plant, after which it is treated prior to discharge into the environment. Each of these processes uses large infrastructure that must be maintained, repaired, and periodically replaced. All of these factors contribute to the true cost of water, but many utilities and installations do not reflect this true cost in their water billing rates.

Even when the utility water rates are used as the basis for economic analysis, the technologies to be demonstrated are expected to pay back in less than 10 years, based on current water prices. Water cost at DoD installations is anticipated to increase as they compete with other water demands within their regions. Across the U.S., utilities report an average annual increase in price of 5.34% per year from 2004 to 2016. Water prices are beginning to rise to absorb the cost of infrastructure improvements, rising on average at double the consumer price index of 2.3%. (AWWA 2015).

On military installations water costs are also rising, even while water use declines in response to regulatory mandates. For example, for the Army, the average water rate has risen in six of the ten years between 2008 and 2017. As water prices continue to rise, the technology payback period will become even shorter.

2.3.5 Performance limitations

The greatest technical risk associated with this demonstration is the suite of regulatory requirements that must be navigated. Graywater reuse is generally regulated at the state level. This in turn is reflected in building plumbing codes. In addition, Counties often have specific health related requirements. The greatest potential regulatory risk to graywater reuse in general is use in states that do not allow graywater reuse. In reference to the MCRD demonstration site, the use of graywater in buildings is currently allowed at the site in California. The codes in California contain requirements that govern required treatment level, material, type and location of locking valves, marking, separation/barriers, and signage. Regulatory Framework Title 22 (California) requires inspection by an AWWA cross-connection control program specialist prior to initial operation and annually thereafter. In reference to the Champaign demonstration site, Illinois did not have a graywater regulation at the time of this project. Researchers worked with the Illinois Environmental Protection Agency to obtain approval for the bathroom scale system.

Another potential technical risk is system integration. System integration risks for water conservation technologies were observed at the CERL site. Reduced lavatory water flows due to retrofit with low-flow aerators provided an inadequate amount of input water to the graywater treatment system. The low flow aerators were removed for the duration of the demonstration.

Risks for integrating graywater reuse technologies are low, since they operate on a separate piping system from the existing potable water piping. Risks for graywater reuse will be lowered further by using systems that are plug-and-play and can be bypassed safely in the event of equipment failure or downtime. Risks associated with cross contamination can be mitigated by following standard practices for use of reclaimed water, including air gaps, check valves, warning signs, and standard color coding for pipes containing reused water.

Limitations to widespread deployment of graywater treatment and reuse systems within the industry at large are due to the need for the installation of separate piping systems to transport graywater. These technologies are most applicable in buildings where plumbing fixtures are concentrated in a small area, thereby reducing the cost of the required piping. Regulatory limitations come to play in states that don't possess codes to address water reuse. It will take more effort on the part of the installation to obtain approval for such systems.

2.3.6 Cost limitations

The primary cost limitations of water conservation and reuse are associated with the retrofit process. For installation of water conservation systems, the replacement of existing systems that may still have many years of service life remaining is a potential barrier. Additionally, as discussed in previous sections, modifying a waste water collection system to segregate gray and black water and installing a separate "purple pipe"[*] distribution system to transport reuse water is cost prohibitive in many existing buildings. This demonstration investigated the opportunities for alternative approaches that are sensitive to these cost limitation issues.

In some regions artificially low water rates will also inhibit any investments in water conservation technologies. That is, even in regions where water supplies are declining, there may not be price

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[*] Most states, as well as code agencies, require pipes to be colored purple if they carry reclaimed water as a means to easily distinguish recycled water from the potable water distribution system (USEPA 2012).

signals to encourage water conservation and improve economic payback for water saving investments.

2.3.7 Social acceptance

Institutional barriers can make it difficult to implement water reuse projects. The most common concern is the potential for health threat. User misunderstanding of potential exposure to non-potable water is possible. Early in the planning process, the project development team implemented public outreach to keep building occupants involved in the planning process and mitigate any public safety concerns. This included signage and surveys. User education is also critical to ensure that liquids that could harm the treatment system aren't disposed of in sink drains.

3.0 PERFORMANCE OBJECTIVES

A summary of the performance objectives, metrics, data required and success criteria is contained in Table 3-1. Results will be extracted from later sections and added to final report.

Table 3-1. Performance objectives and results.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Building Potable Water Usage	Water (Gallons) – overall building water potable usage and water used by showers, faucets, and toilets	Metered/Data Logged potable water use, collected monthly	30% Reduction compared to baseline (pre-retrofit metered data)	Acceptable in some cases. A combination of technologies should be able to achieve 30% water usage reduction in some building types. Water fixture retrofits: 7% reduction in building water demand with limited fixture retrofits*. Under-sink graywater reuse system: Up to 9% reduction in water demand with under-sink system. Building scale graywater reuse system: 16 to 55% reduction in average potable water demand, depending on building type.
Graywater Usage	Graywater (Gallons) – graywater produced by treatment system	Meter readings of graywater produced, collected monthly	20% as compared to total building potable water usage	Under-sink graywater reuse system: Unacceptable. Up to 9% reduction in water demand with under-sink system if applied building-wide. Building scale graywater reuse system: Acceptable in some cases. 16 to 55% reduction in average potable water demand, depending on building type.

* An additional 7% reduction was realized by adjusting toilet automatic flush sensors. CERL would achieve a 47.2% reduction with fixture retrofits, toilets, and urinals. Implementation of waterless urinals and under-sink scale graywater reuse system would save water by 51.3%.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Graywater Quality - continuous	Turbidity, Oxidizing-Reduction Potential Probe [ORP], and pH	Continuous measurements of Turbidity, ORP, and pH, collected monthly	Turbidity < 2 Nephelometric Turbidity Units (NTU) with continuous chlorine residual and 6 < pH < 9.	Under-sink graywater reuse system: Acceptable (Turbidity 0.99 ± 0.29 NTU, Free chlorine 3.1 ± 1.1 mg Cl_2/L, pH 7.2 ± 0.1). Building scale graywater reuse system: Acceptable (Turbidity 0.5 ± 0.4 NTU, Free chlorine 0.1 ± 0.1 mg Cl_2/L, pH 8.0 ± 0.1).
Graywater Quality – grab samples	Chlorine concentration, biological oxygen demand (BOD), Topographic Support System (TSS), and total coliform	Monthly grab sample measurements of Chlorine concentration, BOD, TSS, and total coliform	BOD < 10 mg/L TSS < 10 mg/L Total Coliform (TC) < 1 cfu/100 ml	Under-sink graywater reuse system: Acceptable (BOD 18 ± 4.1 mg/L, TC 0.06 ± 0.12 cfu/100 ml). Building scale graywater reuse system: Acceptable (BOD 2.2 ± 1.4 mg/L, TSS 0.5 ± 0.0 mg/L).
Facility Energy Usage	Facility Energy Usage (MMBtu or kWh)	Meter readings or calculations of energy used by demonstration buildings hot water systems, monthly	10% Reduction compared to baseline (pre-retrofit metered data)	Water fixture retrofits: Acceptable (retrofit showerhead used 90 therms/20% less, faucet used 13 therms/66% less[*]). Under-sink graywater reuse system: No baseline to compare[†]. Building scale graywater reuse system: No baseline to compare[‡].

[*] Fixture energy savings were modeled due to the numerous modifications, that affected overall energy demand, within the demonstration buildings.

[†] Energy consumption was 50 Wh/gal from previous measurement from lab validation studies.

[‡] MCRD Bldg. 573 graywater reuse system used 100 Wh/gal.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Direct Greenhouse Gas Emissions	Direct fossil fuel Greenhouse Gas (GHG) emissions (metric tons)	Measured or estimated release of GHG based on source of energy	10% Reduction compared to baseline, or targeted threshold value	Water fixture retrofits: Acceptable (retrofit showerhead used 1051 lb-carbon/20% avoided, faucet used 151 lb-carbon/66% avoided*). Under-sink graywater reuse system: No baseline to compare. Building scale graywater reuse system: No baseline to compare.
System Integration	Number and level	Number and degree of conflicts/synergies caused by interaction between components in each bldg.	Equal to or less than industry standard or similar facilities at site.	Water fixture retrofits: Acceptable (no conflicts). Under-sink graywater reuse system: Unacceptable (integration with existing plumbing is a major cost driver). Building scale graywater reuse system: Unacceptable (required plumbing integration with existing components is major cost driver)
Life Cycle Cost	%, $, Years	Dollar costs, discount rate, usable life	Payback period of less than 10 years.	Water fixture retrofits: Acceptable (met payback period of <10 years). Under-sink graywater reuse system: Unacceptable (payback period of >10 years at current water rate). Building scale graywater reuse system: Unacceptable (payback period of >10 years at current water rate)

* Fixture greenhouse gas avoided were modeled due to the numerous modifications, that affected overall carbon footprint, within the demonstration buildings.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Reliability	Days (operational/total possible days)	Days that system is operational	Equal to or greater than industry standard or historical data for like facilities at site.	Water fixture retrofits: Acceptable (no failures during demonstration period). Under-sink graywater reuse system: Acceptable (did not experience any unplanned downtime during system evaluation.). Building scale graywater reuse system: Unacceptable (experienced persistent system downtime).
Qualitative Performance Objectives				
System Maintenance	Acceptable, Unacceptable, or Tenuous level of maintenance	Scheduled and unscheduled maintenance events; downtime; survey data (collected from Operations and Maintenance [O&M] staff)	Equal to or less frequent than the historical record of similar facilities at site.	Water fixture retrofits: Acceptable (no greater frequency than historical record). Under-sink graywater reuse system: Acceptable (requires maintenance to add chemicals once every 2 months). Building scale graywater reuse system: Unacceptable (during demonstration period, system required more frequent maintenance than designed maintenance frequency).

Performance Objective	Metric	Data Requirements	Success Criteria	Results
User Satisfaction	Degree of Satisfaction	Informal interviews with DPW, O&M contractors, Military Unit Leaders	% Increase in satisfaction over baseline or similar facilities at site.	Water fixture retrofits: Acceptable (no complaints). Under-sink graywater reuse system: Acceptable (no complaints and no significant disruption to bathroom operations). Building scale graywater reuse system: Unacceptable (too expensive to maintain due to no bypass* valves on the retention tanks).

3.1 Potable water usage (Quantitative)

Definition: Potable water usage is the quantity of potable water entering a building.

Purpose: The demonstration objective is to reduce the amount of potable water usage in each building that is retrofitted.

Metric: The average building potable water usage was measured in gallons-per-day and compared to the baseline building potable water usage as metered or estimated pre-assessment.

Data: Building water meters measured the quantity of water entering the building. These meters were in place or were installed and accessed for data collection on a monthly basis. Meter readings were logged at a frequency of six data points per hour using Meter Master flow recorders. Data was collected from the flow recorders monthly.

Analytical Methodology: Water flow data, as total cumulative flow, was compiled into spreadsheets and used to produce graphs depicting water use profile over a day, month and year. Daily data was summed to obtain an average usage for each day of the week.

Success Criteria: The success criteria for potable water reduction is 30% below baseline potable water use for each building. This is based on the need for a payback period that is less than 10 years. It accounts for expected capital and operating costs of the installed systems and assumes a fully burdened cost of water of $10 per thousand gallons (kgal) for CERL and $10.53 per kgal for the MCRD systems.

* The lack of bypass requires even minor fixes (to tank float sensors) to shut down the entire building water system.

3.2 Graywater usage (Quantitative)

Definition: Graywater usage is the quantity of graywater, i.e., water recovered after use in sinks and showers that is reused in a building for a purpose that would otherwise be served by using potable water.

Purpose: Graywater can be recovered and reused in place of potable water for purposes such as flushing toilets. Therefore, its use can reduce the amount of potable water consumed in a building.

Metric: The average building graywater usage was measured in gallons-per-day and compared to total building potable water usage.

Data: The volume of water that flows out of graywater reuse systems and into pipes that supply water for tasks such as flushing toilets was measured or calculated, as allowed by existing instrumentation of the system(s).

Analytical Methodology: Data loggers were installed on existing water meters in graywater reuse systems to measure the volume and rate of water flowing out for reuse in the building. Total cumulative flow was measured, and rates were recorded every 10 minutes to capture the reuse profile throughout a day. Data was collected from the loggers monthly.

Success Criteria: The average building graywater usage target for this project was 20% of the total potable water used by the building, as measured by metering, for the building-scale system, and 80% of the required flushing water for the under-sink system.

3.3 Graywater quality – Continuous (Quantitative)

Definition: Continuous graywater quality is defined as the level of purity and/or safety of the water in near real-time.

Purpose: For indoor reuse of graywater to be safe, aesthetically acceptable, and compatible with building infrastructure materials, it needs to be of a sufficient quality. Some indicators of water quality can be monitored in near real-time through the use of sensors and data loggers. A sudden shift in water quality is also a good indicator of system malfunction, which can serve as an alarm to building operators.

Metric: Continuous graywater quality was monitored in terms of pH, ORP, and/or turbidity. Water pH was maintained in a range of 6-9 so as to be compatible with pipe materials and toilets. Too high of a pH (> 9) can cause scaling of pipes, and too low of a pH (< 6) can accelerate corrosion. A sudden shift in water pH can also be indicative of a chemical imbalance and malfunction within the treatment system. ORP was monitored in conjunction with pH to ensure that chlorine residual was present in the storage tank and distribution pipes. Maintaining a chlorine residual is important for controlling growth of biofilms and pathogens in the graywater distribution system. Turbidity is an indicator of the extent of particulate concentrations in the water. Too high of a turbidity level is indicative of malfunctioning of the graywater treatment system.

Data: Data from pH, ORP, and turbidity sensors was collected and quantified based on calibration curves for each sensor. pH was measured in standard pH units. Turbidity was measured in NTU. ORP was measured in millivolts (mV).

Analytical Methodology: Inline sensors were placed in either the graywater storage tank or graywater distribution pipes. Data was logged every 10 minutes, stored for analysis, and collected monthly. Values for each parameter were plotted with respect to time to identify trends in treated graywater quality.

Success Criteria: 6 < pH < 9; Turbidity < 2 NTU; ORP > 400 mV.

3.4 Graywater Quality – Grab Samples (Quantitative)

Definition: Periodic detailed analysis of graywater quality.

Purpose: Periodic measurements of additional water quality parameters that are indicative of its suitability and safety for indoor reuse were taken. These measurements serve to ensure that the graywater treatment systems were performing as designed in field conditions.

Metric: The metrics include BOD, TSS, and TC bacteria. BOD is a measure of the amount of oxygen that would be consumed over a 5-day period by microorganisms present in the water as a result of their consumption of organic matter present. High BOD levels indicate that the water is more suitable for the growth of microbes in the treated graywater, which can lead to odor, color, and corrosion problems. TSS is a measure of the particulate matter present in the water. A high TSS level is indicative of inadequate treatment prior to reuse. TC bacteria are organisms associated with the gut of humans and animals. Their presence in water is an indicator of potential contamination with pathogens.

Data: BOD is measured by taking various dilutions of a water sample, measuring the initial dissolved oxygen present, sealing the sample for 5 days at 20ºC, and then measuring the remaining dissolved oxygen. The decrease in the amount of dissolved oxygen is used to calculate the BOD. TSS is measured by filtering a water sample and calculating the change in filter mass resulting from the filtration and associated entrapment of particulates on the filter. The increase in filter mass is the TSS. TC bacteria is measured by filtering a 100 ml sample of water through a 0.45 micron cutoff membrane which collects all the bacteria in the water. The filter is then transferred to selective growth media and incubated. The selective growth media also has components that cause a color or fluorescence associated only with TC values.

Analytical Methodology: Described above.

Success Criteria: BOD < 10 mg/L; TSS < 10 mg/L; TC < 1 cfu/100 ml.

3.5 Facility Energy Usage (Quantitative)

Definition: The facility energy usage performance objective compares the retrofit system to the base case. Any energy savings tied to the retrofits contribute to beneficial project paybacks.

Purpose: The demonstration approach is expected to use less energy than the base case system, supporting both water and energy reduction goals in one technology.

Metric: Potable water systems use both electrical and thermal/Liquefied Petroleum Gas (LPG) energy. Energy is consumed through one of more of the following elements:

- Potable water pumping energy (kWh)

- Potable water heating energy (BTU/hr)
- Graywater system process energy (kWh)

Data: Energy use/savings due to the plumbing retrofits was determined through modeling using the Federal Energy Management Program (FEMP) Energy Cost Calculator for Faucets and Showerheads (USDOE 2017). Graywater system energy use was calculated based on system design data. In addition, voltage meters were installed on the building scale graywater system to record energy use of the system.

Analytical Methodology: Model and compare potable supply and hot water flow in a pre-retrofit and post-retrofit operational mode. Document energy use of the graywater treatment system.

Success Criteria: The retrofit system will be considered successful if energy use is 10% less than the base case.

3.6 Direct Greenhouse Gas Emissions (Quantitative)

Definition: This performance objective quantifies the greenhouse gas savings associated with energy savings for this retrofit.

Purpose: The demonstration approach is expected to generate fewer greenhouse gas emissions than the base case, contributing to DoD GHG reduction goals.

Metric: All energy supporting building water systems at the site relies on fossil fuel combustion producing greenhouse gas emissions. These emissions were quantified in metric tons.

Data: Greenhouse gas emissions were calculated from system energy consumption.

Analytical Methodology: Calculate greenhouse gas emissions mathematically from calculated facility energy usage. Compare the retrofit system value with the base case.

Success Criteria: The retrofit system will be considered successful if greenhouse gas emissions are 10% less than the base case.

3.7 System Integration (Quantitative)

Definition: System integration represents the ease of operation between the retrofit systems and the existing systems as well as interactions among separate components within the demonstration systems.

Purpose: The retrofit systems are expected to have no more system integration conflicts than the base case or similar systems.

Metric: The metric is the number and level of conflicts that occur between system components. Level of conflicts are minor or major.

Data: Number and degree of conflicts or synergies caused by interaction between components within each demval system were obtained from operations and maintenance staff on site.

Analytical Methodology: Determine if any identified conflicts or synergies are minor or major and compare to the based case or similar systems on post.

Success Criteria: The retrofit system will be considered successful if conflicts are equal to or less, and synergies are greater, than industry standard or similar facilities at the sites.

3.8 Life Cycle Cost (Quantitative)

Definition: Life Cycle Cost is an important economic analysis used in the selection of alternatives that impact both pending and future costs. It compares initial investment options and identifies the least cost alternatives for a defined time period.

Purpose: The retrofit system is expected to pay for itself in water, energy, and maintenance savings while providing the expected level of service of the base case.

Metric: Simple Payback Period (years), Savings to Investment Ratio (SIR).

Data: Capital investment cost were obtained from the retrofit contractor; each task was costed separately. Energy and water savings (Usage) data were obtained as described under the Performance Objectives 3.2.1 and 3.2.5. Energy and water rates for the demonstration sites were used to calculate those cost savings.

Analytical Methodology: Computations were done using the National Institute of Standards and Technology (formerly National Bureau of Standards) (NIST) Building Life Cycle Cost (BLCC) program.

Success Criteria: The retrofit system will be considered successful if the project achieves a payback period of less than 10 years.

3.9 Reliability (Quantitative)

Definition: System Reliability is the probability that a system will satisfactorily perform the task for which it was designed or intended, for a specified time and in a specified environment.

Purpose: The retrofit systems are expected to have a level of reliability equal to or greater than the base case or similar systems. Local water supplies can support greater water security and resilience to interruptions.

Metric: The metric is days (operational/total possible days).

Data: Days that system is operational.

Analytical Methodology: Compare the number of days that the system is operational with the base case or similar facilities at the demonstration sites.

Success Criteria: The retrofit system will be considered successful if reliability is equal to or greater than industry standard or historical data for similar facilities at the demonstration sites.

3.10 System Maintenance (Qualitative)

Definition: The System Maintenance performance objective measures the level of maintenance the renovated system requires as compared to the original system or base case. This technology calls for replacing plumbing fixtures and addition of a graywater treatment system. As part of the upgrade and during the course of the demonstration, other devices may also be replaced or repaired on these existing (and aging) systems. These changes can affect the maintenance for better or worse and therefore should be monitored/recorded. The overall DPW impression of the maintenance required by the system is the most useful/practical measure of the maintenance burden.

Purpose: The retrofit systems are expected to not be a maintenance burden on the DPW or contract O&M staff. Increased maintenance cost or difficulty will be an impediment to wider adoption of this technology.

Metric: The metric is acceptable, unacceptable or tenuous level of maintenance, as determined qualitatively through input from the maintenance staff.

Data: Interviews with government operators, maintainers, and managers. Monitor system operational status and track and log system downtime. Obtain and inspect service orders, following up to discern details. Obtain maintenance information such as labor costs and equipment repair/replacement cost.

Analytical Methodology: Determine if any operation mode altered operation and maintenance of the system, for example extended periods of low usage, which would be possible at training sites or barracks experiencing transient occupation. Identify maintenance concerns or problem areas so as to define/address improvements or remedies and related requirements (such as specifications requirements) to avoid or help alleviate future maintenance problems.

Success Criteria: The retrofit system will be considered successful if it achieves an acceptable level of maintenance.

3.11 User Satisfaction (Qualitative)

Definition: The User Satisfaction performance objective measures the level of satisfaction among the building occupants using the retrofit systems.

Purpose: The retrofit systems are expected to provide a level of service currently provided by the base case as reflected in acceptable user satisfaction.

Metric: The metric is Degree of Satisfaction on a five point scale from high to low.

Data: User Satisfaction data was collected during informal interviews with DPW and O&M contractors. Access to Military Unit Leaders and soldier trainees was not possible due to the nature of the basic training mission.

Analytical Methodology: Record and compare the responses to informal interviews on satisfaction with the retrofit systems.

Success Criteria: The retrofit system will be considered successful if there is no decrease in satisfaction as compared to the baseline or similar facilities at the demonstration sites.

4.0 FACILITY/SITE DESCRIPTION

The two demonstration sites for this project are the Marine Corps Recruit Depot (MCRD) in San Diego, CA, and the Construction Engineering Research Laboratory (CERL) located in Champaign, IL and are shown in Figure 4-1.

Source: Google Maps (2016)

Figure 4-1. Demonstration sites.

Water fixture retrofits and decentralized graywater reuse systems are investigated for implementation across the DoD. In particular, administrative buildings are ideal for these improvements as they contain a large number of occupants and contain centralized bathroom facilities. CERL is an office and laboratory environment, home to the authors of this study. CERL was chosen as one location for this study for ease of setting up and testing these water improvements, and because it houses facilities representative of typical DoD administrative buildings.

A second water reuse configuration—building scale graywater systems—were also examined for implementation across the DoD. Barracks with centralized shower facilities are ideal for this technology. This type of barrack is found primarily at basic training facilities. These barracks are also in use at many military installations as transient barracks. MCRD contains three separate building scale graywater reuse systems that were included in new construction of a complex containing a set of barracks and a clinic. Graywater is collected from sinks and showers, treated, and reused for flushing toilets. These unique facilities at MCRD made it an ideal study site.

4.1 CERL site description

CERL is a laboratory within the Army Corps of Engineers (USACE) Engineer Research and Development Center. CERL was established in 1969 in Champaign, IL, a few miles north of the University of Illinois at Urbana-Champaign (UIUC). CERL has a lease agreement with UIUC that encompasses laboratories and offices for approximately 370 people. Bldgs. 1, 2, and 3 are the three main buildings, housing most of the laboratories and offices. Bldgs. 1 and 2 were constructed in 1969 and Bldg. 3 was added in 1990. There are a few other buildings and areas that contain experimental and test equipment (e.g., a shake table and soil laboratory), however the majority of the personnel work and operate in Bldgs. 1-3. Figure 4-2 shows the CERL campus and the three main buildings.

Source: Google Maps (2016)

Figure 4-2. CERL facility with three main buildings highlighted.

In this demonstration, Bldgs. 1-3 were targeted for water efficiency improvements and Bldg. 3 was the location for the bathroom scale under-sink graywater reuse system. The following descriptions are for general information only, and are not intended to imply a detailed description of construction, contents, or material quantities.

4.1.1 Bldg. 1

This facility (shown in Figure 4-3) is a single-story concrete masonry unit (CMU) exterior walled building of 52,892 gross SF housing individual offices, open plan offices, laboratories, and high-bay research facilities. The population of Bldg. 1 varies and is currently 124 personnel. Major research laboratories located in Bldg. 1 include a paint lab, materials lab, soils lab, and several biological/chemical labs. Potable water is supplied via a 4-in. line. Hot water is heated with a State 80-gallon natural gas water heater with a recovery rating of 189 gallons per hour (GPH) and a separate storage tank with recirculating pump.


Source: Google Maps (2016)

Figure 4-3. Aerial view of Bldg. 1.

Bldg. 1 contains four spaces with water fixtures that were included in this demonstration. These spaces are the men's restroom (room 1118), the women's restroom (room 1115), the men's locker room (room 1145/1146), and a small kitchenette (room 1119). Fixture counts are shown in Table 4-1.

Table 4-1. Fixture counts for Bldg. 1.

Room	Lavatory Faucets	Kitchen faucets	Toilets	Urinals	Shower heads Shower wand
1118	3		2	3	
1115	2		2		
1145/46	2		2	1	5 + 1
1119		1			
TOTAL	7	1	6	4	6

The restrooms contain high-flush toilets and urinals and high flow metering faucets. The men's locker room also contains high-flush toilets and urinals and high flow faucets, and in addition contains high flow showerheads. The kitchenette area contains a high flow kitchen faucet. Original fixtures are shown in Figure 4-4.

Figure 4-4. Bldg. 1 pre-retrofit photos, clockwise from top left: bathroom faucet detail, shower detail, kitchenette faucet, and men's locker room shower.

4.1.2 Bldg. 2

This building (shown in Figure 4-5) is a single-story CMU exterior walled building of 56,470 gross SF housing individual offices, open plan offices, laboratories, and high-bay research facilities. The population of Bldg. 2 varies and is currently 139 personnel. Major research functions include an Heating, Ventilating, and Air-Conditioning (HVAC) test facility, replaced during the time frame of this demonstration with a large concrete 3D printer that uses concrete. Potable water is supplied via a 4-in. line. Hot water is heated with a Rheem 76-gallon natural gas water heater with a recovery rating of 169.6 GPH with a recirculating pump.

Source: Google Maps (2016)

Figure 4-5. Aerial view of Bldg. 2.

Bldg. 2 contains four spaces with water fixtures that were included in this demonstration. These spaces are the men's restroom (room 2111), the women's restroom (room 2108), the women's locker room (room 2162/2163), and the cafeteria (room 2011). Fixture counts are shown in Table 4-2

Table 4-2. Fixture counts for Bldg. 2.

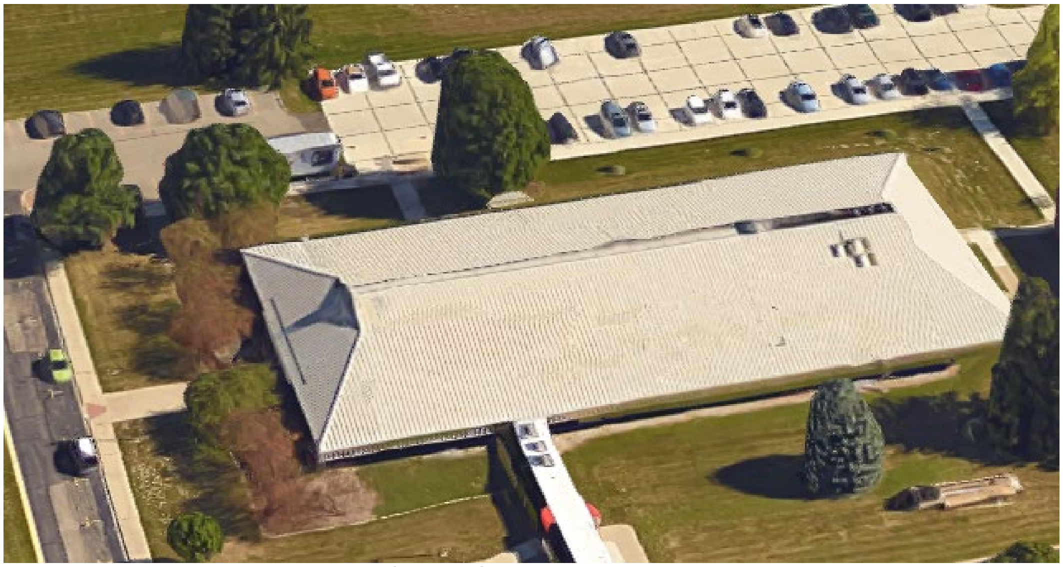
Room	Lavatory Faucets	Kitchen faucets	Toilets	Urinals	Shower heads Shower wand
2111	3		2	3	
2108	2		2		
2162/63	2		2	1*	5 + 1
2011		1			
TOTAL	7	1	6	3	6
* Urinal is legacy from when this was a male locker room and is not in use					

The restrooms contain high-flush toilets and urinals and high flow metering faucets. The women's locker room also contains high-flush toilets and high flow faucets, and in addition contains high flow showerheads. The cafeteria contains a high flow kitchen faucet. Original fixtures are shown in Figure 4-7.

Figure 4-6. Bldg. 2 pre-retrofit photos, clockwise from upper left: existing sinks with lavatory faucets, women's locker room, cafeteria faucet, and detail of shower wand in women's locker room.

4.1.3 Bldg. 3

This building (shown in Figure 4-7) is a two-story CMU exterior walled building of 24,617 gross SF housing individual offices and open plan offices. Bldg. 3 population varies and is currently 68 personnel. Potable water is supplied via a 3-in. line. Hot water is heated with an AO Smith DSE-10 gallon 6 KW commercial electric water heater.



Source: Google Maps (2016)

Figure 4-7. Aerial view of Bldg. 3.

Bldg. 3 contains three spaces with water fixtures that were included in this demonstration. These spaces are the men's restroom (room 3005), the women's restroom (room 3004), and a small kitchenette area. Fixture counts are shown in Table 4-3

Table 4-3. Fixture counts for Bldg. 3.

Room	Lavatory Faucets	Kitchen faucets	Toilets	Urinals
3005	3		2	2
3004	3		4	
Kitchenette		1		
TOTAL	6	1	6	2

The restrooms contain high-flush toilets and urinals and high flow metering faucets. The kitchenette contains a high flow kitchen faucet. Original fixtures are shown in Figure 4-8.

Figure 4-8. Bldg. 3 pre-retrofit photos. Clockwise from top left: proposed location for graywater treatment and reuse system in northwest corner of men's bathroom; view of existing sink deck in men's bathroom; kitchenette sink and faucet detail; and, women's bathroom sink deck.

The men's restroom of Bldg. 3 is the site of the under-sink graywater reuse system. Schematics of the bathroom are shown in Figure 4-9 through Figure 4-11, showing the floor layouts before and after the graywater reuse system was installed.

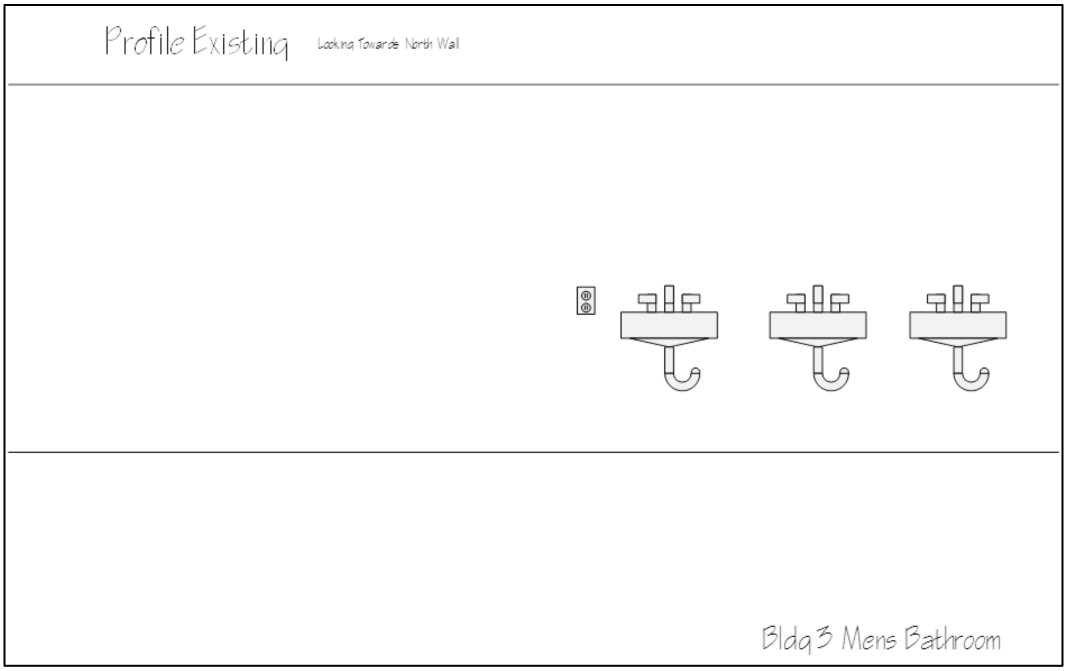


Figure 4-9. Schematic of existing North wall of men's bathroom in Bldg. 3.

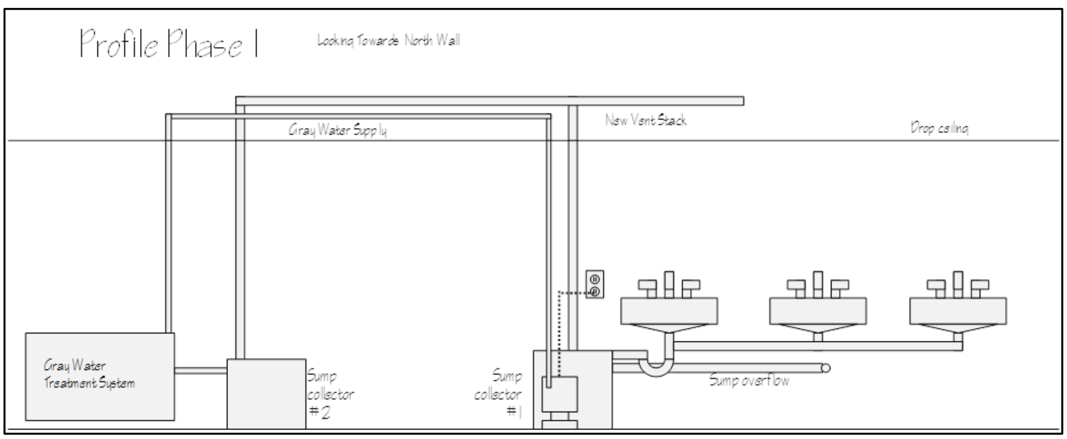


Figure 4-10. Schematic of Phase 1 retrofit of North wall of men's bathroom in Bldg. 3.

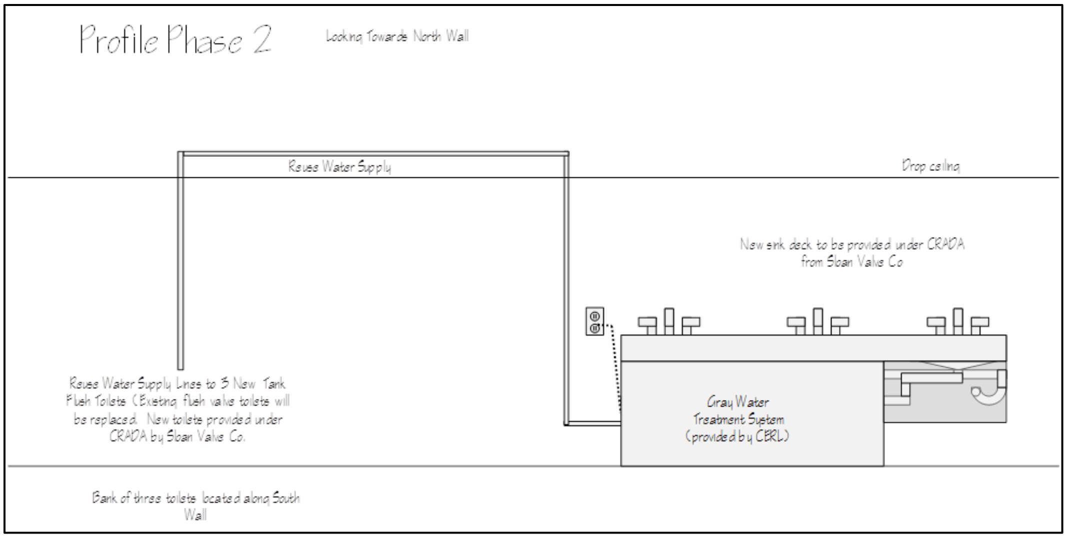


Figure 4-11. Schematic of Phase 2 retrofit of North wall of men's bathroom in Bldg. 3.

4.2 Marine Corps Recruit Depot, San Diego Site Description

The Marine Corps Recruit Depot (MCRD) is located on 388 acres in northwest San Diego, CA abutting the commercial airport, Lindbergh Field. MCRD is surrounded by commercial and industrial (see Figure 4-12). The base was established in 1919. Recruit training became the primary mission through World War II, the Korean War and Vietnam War. Its current name was conferred in 1948. Basic training activities for male recruits west of the Mississippi River takes place at MCRD (USMC 2016).

Source: Google Maps 2016

Figure 4-12. Satellite view of MCRD showing demonstration buildings.

Source: Google Maps 2016

Three buildings at the MCRD contain packaged building scale graywater reuse systems. These buildings were constructed concurrently and encompass 240 KSF Walker Hall, a multi-story reinforced concrete masonry unit building with seismic upgrades. Walker Hall opened in 2012 as the first joint stand-alone sports medicine facility in the Navy and Marine Corps and was built to U.S. Green Building Council's LEED Gold Standard. The SMART Clinic and medical barracks received LEED Platinum, and the non-medical barrack received LEED Gold certification.

During the course of this demonstration, it was discovered that the graywater system in one of the buildings (586), had only been operational the first day it was installed. Additionally, the graywater system in Bldg. 572 was found to be non-operational. Only the graywater system in Bldg. 573 was actually recycling graywater through the course of this project and it was the focus of data collection and analysis efforts at the MCRD site.

4.2.1 Bldg. 573, SMART Clinic.

Bldg. 573 is the SMART (Sports Medicine and Reconditioning Therapy) clinic, which was constructed for recruits injured during training or recruits whom require special attention. It is a two story tall reinforced CMU building containing offices, exam rooms, a therapy pool, whirlpools, and physical therapy equipment.

Source: Google Maps (2016)

Figure 4-13. Aerial view of Bldg. 573.

A graywater reuse system was installed in Bldg. 573 to treat graywater from showers and sinks and reuse for toilet flushing. The system can process up to 3,000 gallons per day and the monthly metered data from the graywater treatment system were available from May 2014 to Nov. 2015. The graywater treatment system in Bldg. 573 provides recycled graywater for toilet flushing with some make up from potable city water. As of May 2017, the system is recommended to be in bypass mode for system operational and maintenance issues.

Figure 4-14. Bldg. 573 photos. Clockwise from top left: staff restroom, sink detail, medical office sink, and therapy pool.

4.2.2 Bldg. 572, Medical Barracks

Bldg. 572 (Figure 4-15) is a medical barrack for patients of the SMART Clinic. Platoon recruits stay an average of 2 to 3 weeks longer than the typical recruits, some up to 6 months, placing additional demands on recruit billeting requirements above normal recruit loading. The medical barrack houses the Physical Conditioning Platoon (PCP) which include recruits that require remedial strength training, weight reduction, or other physical fitness needs above those of the mainstream recruits and of the Medical Rehabilitation Platoon. The occupancy fluctuates based on need but can range between about 100 recruits to over 200. Over FY16, it averaged 179 recruits.

Bldg. 572 is three stories tall with six billeting bays (two per floor). It has spaces for central restrooms and showers, drill instructor (DI) spaces, and company offices. Additionally, it has a detached squad laundry building and outdoor wash stations located in its courtyards.

Source: Google Maps (2016)

Figure 4-15. Outside view of Bldg. 572, Note that left side is connected to Bldg. 573.

A graywater reuse system was implemented in Bldg. 572 during construction (see Figure 4-16), however for the data available (May 2014 to Nov. 2015), it appears that the system was not actually recycling graywater but instead was sending potable city water. Similar to the system installed in SMART Clinic (Bldg. 573), the graywater system has the capability to process 3,000 gallons per day with the same treatment components.

Figure 4-16. Bldg. 572 photos. Clockwise from top left: mechanical room is to the left in the exterior view; emergency by-pass provides potable water make-up to the graywater services; shower rooms are configured for basic training occupants; and, graywater system control panel shows status and total volumes of water.

4.2.3 Bldg. 586, Non-Medical Barracks

Bldg. 586 (shown in Figure 4-17) is a non-medical barrack specifically configured for recruit training, and providing facilities for 984 recruits. It is “H”-shaped and three stories tall with twelve billeting bays (four per floor). It contains central lavatories, toilets, and showers, drill instructor (DI) spaces, and two company offices (see Figure 4-18). Additionally, it has a detached squad laundry building and outdoor wash stations located in its courtyards.

Source: Google Maps (2016)

Figure 4-17. Aerial view of Bldg. 586.

Figure 4-18. Bldg. 586 photos. Clockwise from top left: lavatory room; toilet room; showerhead detail; and shower room.

A graywater system was implemented in Bldg. 586 at the time of construction (Figure 4-19) with a system capacity of 3,000 gallons per minute and the same design sequence as the other buildings.

However the graywater system in the non-medical barrack (Bldg. 586) only processed 20 gallons after its launch before becoming inoperative. Only building potable water consumption was metered and monthly data were collected from May 2014 to Nov. 2015.

Figure 4-19. Bldg. 586 graywater system photos. Clockwise from top left: chlorinator and blue dye system; passive air gap for make-up water; flow meter of make-up water; and pressurized tank for treated water supply to toilets.

5.0 DEMONSTRATION APPROACH

There were three separate technologies included in this demonstration project: bathroom water fixture retrofit with efficient models; bathroom scale under-sink graywater reuse system, and building scale graywater reuse system. Each section in this chapter contains subsections that address these technologies separately.

5.1 TEST DESIGN

5.1.1 Water fixture retrofits

The main tasks of this study were to install and examine the effects of water-saving fixtures, with the main performance objective being to reduce potable water usage. There were several different fixtures used, and a summary of these is shown in Table 5-1.

Table 5-1. Water fixture components.

Component	Status
Low flow faucet aerators	These fixtures were installed in restroom and locker room faucets at CERL. Faucet flow rates for pre- and post-retrofit were measured and compared.
Low flow showerheads	These fixtures were installed in both locker rooms at CERL. Shower flow rates for pre- and post-retrofit were measured and compared.
Waterless urinal	A waterless urinal was tested in a lab setting at CERL.
Low water use shave stand	This fixture was tested in a lab setting at CERL.
Low GPF toilets and urinals and alternate flush sensors	The auto flush sensors were adjusted for sensitivity and time delay. Replacements of these fixtures are planned, as the site upgrades facilities, but had not taken place during the time frame of this demonstration. Water savings for these fixtures were estimated with a model.

The main feature studied with these fixtures was the ability to save water. The types of data gathered and the corresponding performance objectives are provided in Table 5-2.

Table 5-2. Water fixture data gathered and corresponding performance objectives.

Type of Data	Measured By	Performance Objectives
Building water data	Building water use was measured by daily meter readings, monthly facility water bills, and continuous data logger readings.	Building potable water usage
Fixture flow rates	Flow rates were measured pre-retrofit and post-retrofit using flow measurement devices; GPF of current toilets/urinals were measured using data loggers; and potential water savings of low GPF fixtures were estimated with a model.	Fixture potable water usage

Type of Data	Measured By	Performance Objectives
Ease of installation	This data was obtained from CERL facility personnel estimates.	System integration
Cost data	Cost data was obtained from water savings estimates and corresponding money saved, purchase costs of systems, and estimated maintenance costs.	Life cycle cost
System status	Operational or non-operational	Reliability
Interviews with facility personnel	This data was obtained through discussions and surveys.	System maintenance, user satisfaction

5.1.2 Under-sink graywater reuse system (CERL)

The under-sink graywater reuse system was designed and assembled by ERDC research engineers using Cooperative Research and Development Agreement (CRADA) funding from Sloan Valve Company. This system was competed at bench scale with a bioreactor system developed by another contractor, also funded by Sloan. Based on initial results, the ERDC system was chosen for laboratory optimization and validation testing. All of the design work, optimization, and lab scale validation testing was funded under the CRADA. The lab scale validation testing consisted of a 3-month controlled challenge test based on the NSF/ANSI 350 Onsite Residential and Commercial [Gray] Water Reuse Treatment Systems. Based on the lab scale validation studies (summarized below in Table 5-3), the under-sink system was deemed suitable for further optimization and validation in a demonstration setting.

Table 5-3. Lab scale validation summary results.

Parameter	Units	Influent	# Samples tested	Effluent	# Samples tested
Turbidity	NTU	35 ± 8	24	0.2 ± 0.09	24
E. coli	cfu/100ml	>10^3	12	< 1	19
BOD	mg/L	95 ± 11	4	10 ± 5	3
COD	mg/L	194 ± 26	22	22 ± 6	22
Free chlorine	mg/L	0	4	1.9 ± 0.7	18
pH	pH units	7.6 ± 0.4	24	7.4 ± 0.3	24

Demonstration testing of the under-sink water reuse system was planned in two phases for the office building men's office bathroom. The first phase was an 'off-line' test and was fully executed. The second phase with actual graywater reuse was not executed due to limitations identified in the first phase.

The off-line test layout is shown in Figure 5-1 and Figure 5-2. Water was collected from sink drains, each with its own p-trap, into a common collector line and diverted to a Saniswift graywater sump pump (Saniflo, France), labeled Sump #1. The graywater collection line had an overflow drain that diverted water directly to the existing sanitary drain lines in the case of a sump failure or failure of any other downstream components. An isolation valve also provided controlled bypass capability for short term maintenance activities if needed. The sump basin was vented and was also protected from damage or interference by users by a passively-ventilated soffit (not shown).

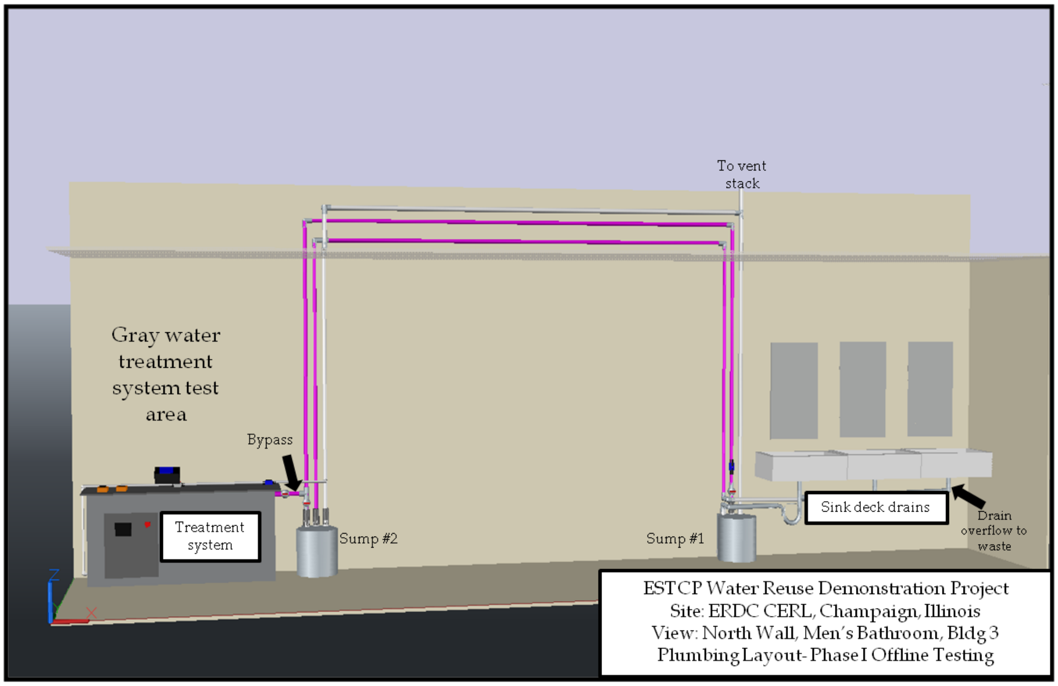


Figure 5-1. General layout for Phase I 'offline testing' of under-sink graywater reuse system.

Water collected in Sump #1 was pumped to the graywater treatment system test area, where valves directed it either to Sump #2 (in bypass mode) or to the graywater treatment system for processing. The influent line to the graywater treatment system also had an overflow line (not shown), which passively diverted the incoming water to Sump #2 in the event of a treatment system failure.

Figure 5-2. Treatment system not connected to sink deck or toilets.

For Phase I testing, the demonstration steps were as follows:

1. *Coordinate demonstration plan with IDPH.* A variance from the Illinois Department of Public Health (IDPH) was signed. The variance stipulated that licensed plumbers would supervise and execute the install, and ERDC coordinated the plans with licensed plumbers who regularly support

CERL facilities. The variance also stipulated that IDPH would be notified 5 days prior to installation and commissioning of the graywater system.

2. *Installation.* Plumbing to sump pumps was installed by licensed plumbers who regularly support CERL. The plumbing layout was designed by the CERL research team in a manner that would support safe testing of the graywater treatment system and safe operation of the bathroom. The design provided multiple bypasses and passive overflows to control any risks of system malfunction. In the case of a sump failure, the sink drains also had a passive overflow to divert the water directly to the existing waste line, with a trap to protect against sewer gas backflow. The design also provided adequate venting of all components (to the sanitary vent stack) to mitigate any odors, as well as grounding of the graywater system to protect against any potential short circuit hazards. Electrical work was performed by licensed electricians that regularly support the CERL facility. Tiled soffits were installed around the sumps to prevent any damage from kicks or carts. This was a temporary setup intended for the duration of the 6-month offline test period (phase I), after which it would be completely removed by licensed plumbers.

Figure 5-3. Site visit by Illinois Department of Public Health, 9 July 2015.

The supply (influent) line, product water (effluent) line, vent line, and waste drain line were connected to the second sump by plumbers. The CERL research team was responsible for setting up all other components other than the power supply outlets, which were run by a licensed electrician. A bypass was installed such that the two sumps could operate without passing water to/through the graywater treatment system. This allowed for independent metering of the water usage as well as maintaining the system while keeping the sink drains operational. Sampling ports were installed to allow for sampling of both the influent and effluent water.

3. *Commissioning.* The graywater treatment system was commissioned by turning on the system power via the control panel and then changing the mode of operation from bypass to graywater treatment via manual adjustment of the valves. A 10-gallon max flow (2 gpm for 5 min) test was performed to inspect for leaks. Valves, pumps, and the aerator were tested to ensure operation. After startup testing, power meters and flow meters were reset to begin data collection, and the pH and ORP meters were inspected.

Testing for Phase II was planned but not executed due to technical issues observed in Phase I that need to be corrected and were beyond the scope of this demonstration. The demonstration approach for Phase II was similar to that used in Phase I, with the exception of the physical layout of the plumbing infrastructure to support sink deck integration and actual reuse of the product water for toilet flushing. The Phase II validation test layout is shown in Figure 5-4. Water is collected from sink drains into a common collector line and directed to the water treatment system. The graywater collection line will have an overflow drain that diverts water directly to the existing sanitary drain lines in the case of a system failure or too much water being added to the sink drains. An isolation valve also provides controlled bypass capability for short term maintenance activities if needed. The drain line and treatment system are separately vented and vents will be protected from damage or interference by users by a passively-ventilated soffit (not shown). Product water from the treatment system will be pumped over to the toilet tanks to aid in flushing. The toilet tanks will be dual plumbed with potable and graywater, with air gaps maintained for both lines using conventional toilet tank designs with a passive overflow to prevent any cross-contamination.

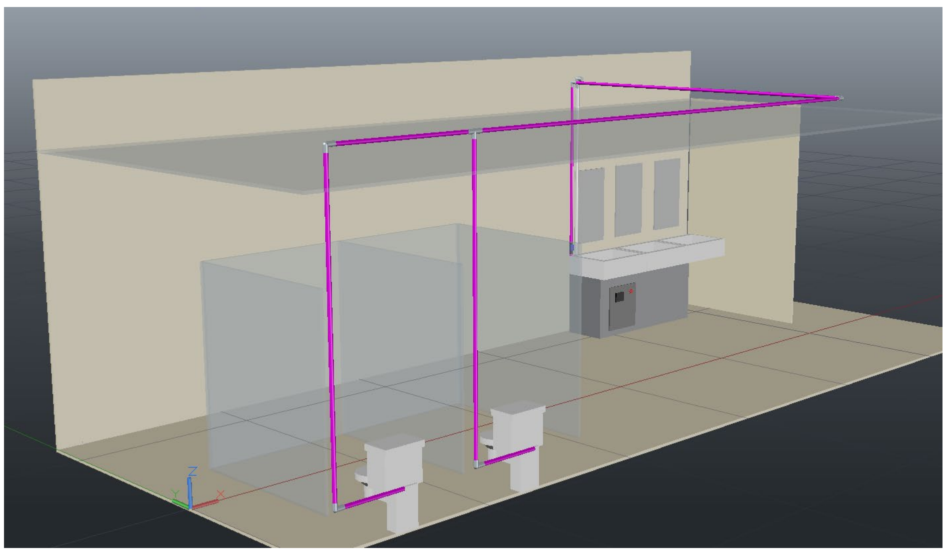


Figure 5-4. General layout for Phase II validation testing of under-sink graywater reuse system.

Table 5-4. Approach for assessment of under-sink water reuse system performance.

Type of Data	Measured By	Performance Objectives
Daily Flow	Cumulative flow meter on influent and effluent lines	50 gpd
Water Quality	Standard Methods for the Analysis of Water and Wastewater (APHA/AWWA)	NSF 350 Compliance
Water Recovery	Ratio of product effluent flow to influent flow	> 80% recovery
Energy Use	Power meter on treatment system	< 20 Wh/gal

5.1.3 Building scale graywater reuse system (MCRD)

This study examined the existing graywater reuse system at the MCRD. Several types of data were recorded in the study to evaluate the performance objectives, and this is listed in Table 5-5. This data was collected during several trips to the MCRD. Since the graywater systems were already installed before this project, the only operational phase of this aspect of the study was data collection. Metered data were obtained by site personnel, and other data, such as continuous data logger measurements and graywater test samples, were obtained by CERL personnel during site visits.

Table 5-5. Building scale graywater reuse system data gathered and corresponding performance objectives.

Type of Data	Measured By	Performance Objectives
Building water data	Water use amounts were read from monthly meter readings by MCRD personnel, and some of this data was supplemented by continuous data logger readings.	Potable and graywater usage
Amount of graywater produced		
Graywater quality	This data was obtained from grab samples during the visits to MCRD with samples analyzed on-site and by contract labs using standard methods (APHA/AWWA).	NSF 350 compliance/ Class A effluent quality
Graywater system energy use	Energy use was measured by continuous data logger readings.	Facility energy use, greenhouse gas emissions
Cost data	Cost data was obtained from water and energy savings estimates and corresponding money saved, purchase costs of systems, and estimated maintenance systems.	Life cycle cost
Ease of installation	This data was obtained from MCRD facility personnel estimates.	System integration
System status	This data was based on the on/off status of the graywater system.	Reliability
Interviews with facility personnel	This data was obtained by discussions during site visits.	System maintenance, user satisfaction

5.2 BASELINE CHARACTERIZATION

5.2.1 Water fixture retrofits

5.2.1.1 Baseline water use measured by meters and water bills

Water meters were installed in Bldgs. 1-3 at the CERL site to understand overall water use and how much would be saved by retrofitting water fixtures (see Figure 5-5). Bldgs. 1 and 2 each have a Hersey Model MVR 650 (4-in.) meter, and Bldg. 3 has a Hersey Model MVR 350 (3-in.) meter. Additionally, a Hersey Model MVR 100 (1.5-in.) meter was installed in the men's restroom of Bldg. 3 for monitoring toilet and urinal flush amounts alone. These water meters were originally planned to interface with CERL's building automation system (BAS), which would track the meter data continuously and save it to a server. However, the physical size of the water meters prohibited sufficiently high signals from being read by the BAS sensors, and thus the BAS could not continuously track the data. Instead, continuous data was obtained through attaching Meter Master flow recorders to the meters for the purpose of data collection (described later). Each of the Hersey meters has some degree of inaccuracy related to the low level water flow rates (Mueller Systems 2012). The meters only accurately measured flows such as toilet flushes (which use several gallons over the span of a few seconds) and high laboratory uses since a meter's accuracy diminishes at low flow rates. Only some fraction of faucet and shower use was monitored accurately by the building meters. Better accuracy could have been attained by using more expensive meters that can track low flow and high flow separately. Installing smaller diameter water pipes and using smaller meters would also have reduced the degree of error. However, physical constraints due to room size and meter orientation limited meter options.

Figure 5-5. CERL water meters. Left: meters for Bldgs. 1 and 2, respectively. Center: meter for Bldg. 3. Right: meter for Bldg. 3 men's restroom.

Meter readings were read manually every workday morning to track the buildings' uses. On November 17, 2015, low flow faucet aerators and showerheads were installed. The water use for the three buildings prior to this date is shown in Figure 5-6. Changes in water use due to these fixture retrofits are not as easily detected due to the size of the building meters.

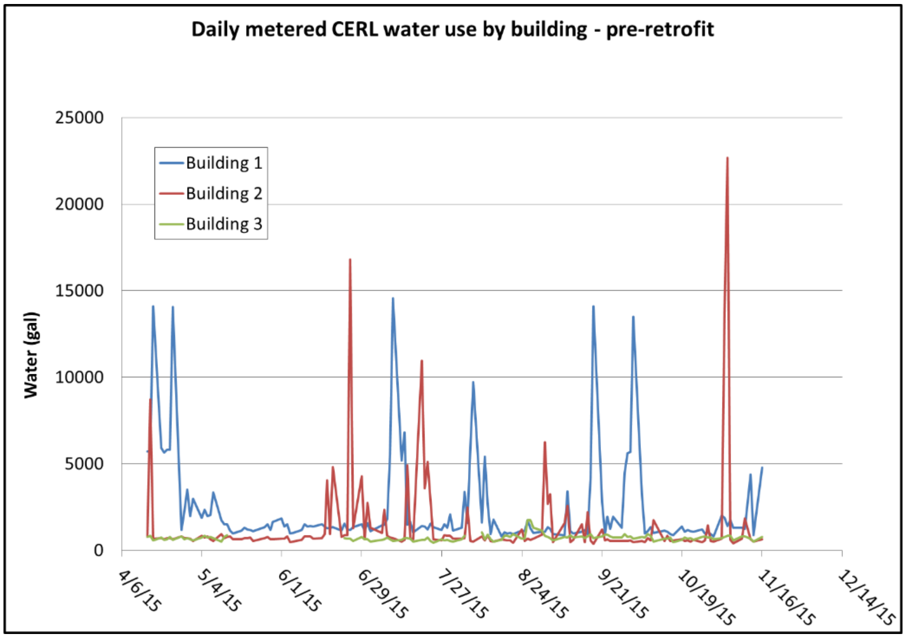


Figure 5-6. CERL water use by building, daily meter readings (pre-retrofit).

Bldg. 1 had the highest water use for the first 5 weeks. It was initially assumed that this amount of water was from the men's locker room and the labs in Bldg. 1. After some calculations and investigating, it was determined that cooling water was unnecessarily being left on for the scanning electron microscope (SEM), a piece of lab equipment in Bldg. 1, when it was not in operation. Once the SEM cooling water was turned off, the Bldg. 1 water use dropped over 15,000 gallons per week on average, as shown by the Bldg. 1 water use after 4/20/15. It still jumped occasionally depending on periodic SEM use. Bldg. 2 and Bldg. 3 have water use levels that are approximately equal and constant, with exception to Bldg. 2, which has a hydraulic pump in the high bay area that can use approximately 50 gallons per minute for cooling purposes (Underwood et al. 2014). Abrupt jumps in Bldg. 2's water use are mostly due to this intermittent operation. Additionally, due to a broken meter, several weeks of Bldg. 3 data are omitted from the plots here, though some of this data was able to be recovered using estimates from flow recorders.

The average daily water uses from the three buildings' meter readings are shown in Table 5-6. In calculating these average values, days were ignored when the SEM was accidentally left on or when the high bay's hydraulic pump was being used. This was due to these days of extremely high water use occurring infrequently. These are low end estimates—due to large water meter sizes—and likely reflect somewhere between 70-90% of actual building water use.

Table 5-6. Average daily metered potable water demand.

Bldg. 1 avg. water use (gal)	Bldg. 2 avg. water use (gal)	Bldg. 3 avg. water use (gal)
1259	670	730

To obtain more continuous data in the absence of a usable BAS, Meter Master 100EL (MM100) Flow Recorders were attached to the meters. These flow recorders (also known as data loggers) have magnetic sensors that track the rotation of the water meter's internals. MM100s have been used in other ERDC-CERL projects and are currently deployed at Fort Leonard Wood, MO

(Jenicek 2016) and Fort Campbell, KY. Data must be physically downloaded via computer interface after a period of time depending on granularity, in contrast to the BAS method, which would send the data to a central server indefinitely. The flow recorders are capable of logging data continuously for up to 90 days, depending on the data interval rate, i.e., how frequently flow rate measurements are taken. For the purposes of this study, data intervals were initially set at every 5 seconds but were later changed to every 60 seconds, which allowed more time to elapse between data downloads.

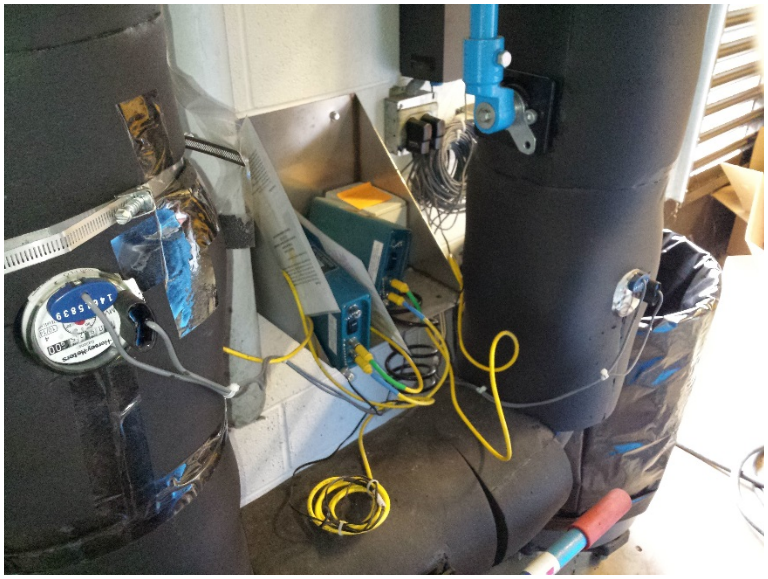


Figure 5-7. Meter Master flow recorders connected to CERL building water meters.

The user inputs the start and stop observed meter readings when initiating MM100 operation, in addition to meter model and diameter. The MM100 program then compares the observed data with the MM100 sensor's measured data, and outputs a percent error of the discrepancy between the MM100 data and the observed metered data. The MM100's magnetic sensor has to be correctly placed to measure the rotation inside the water meter, otherwise the rotations of the meter are miscounted. Percent errors were minimized through careful positioning of the MM100 sensors.

Graphs were produced using the MM100 software to show the instantaneous flow rates over time. Representative plots are reproduced here, showing daily flow rates for each building. The plots are scaled to reflect the actual water use, i.e., if a 5% discrepancy was computed between the actual metered data and the data logger data, the data logger data was multiplied by a scale factor so that the total water amount matched the metered data. Bldg. 1's plot (Figure 5-8) shows a minimum flow rate of approximately 3 GPM from 1:30 p.m. to 4:00 p.m., indicating that the SEM was in operation, which was verified by examining the SEM activity logbook for that day. Bldg. 2's plot (Figure 5-9) shows a minimum flow rate of approximately 50 GPM from 9:30 AM to 12:30 p.m., indicating the large effect of the hydraulic pump operation. The plots for Bldg. 3 and the men's restroom (Figure 5-10) show that Bldg. 3's flow rate peaks sometimes follow those of the men's restroom. On average, the water use of the men's restroom (again, just of toilets and urinals) is approximately a third of the total Bldg. 3 use, and therefore the other peaks of the Bldg. 3 flow rate are likely from women's restroom use and to a much lesser extent from men's restroom sink use and kitchenette faucet use. Full flow recorder data of CERL is available on request.

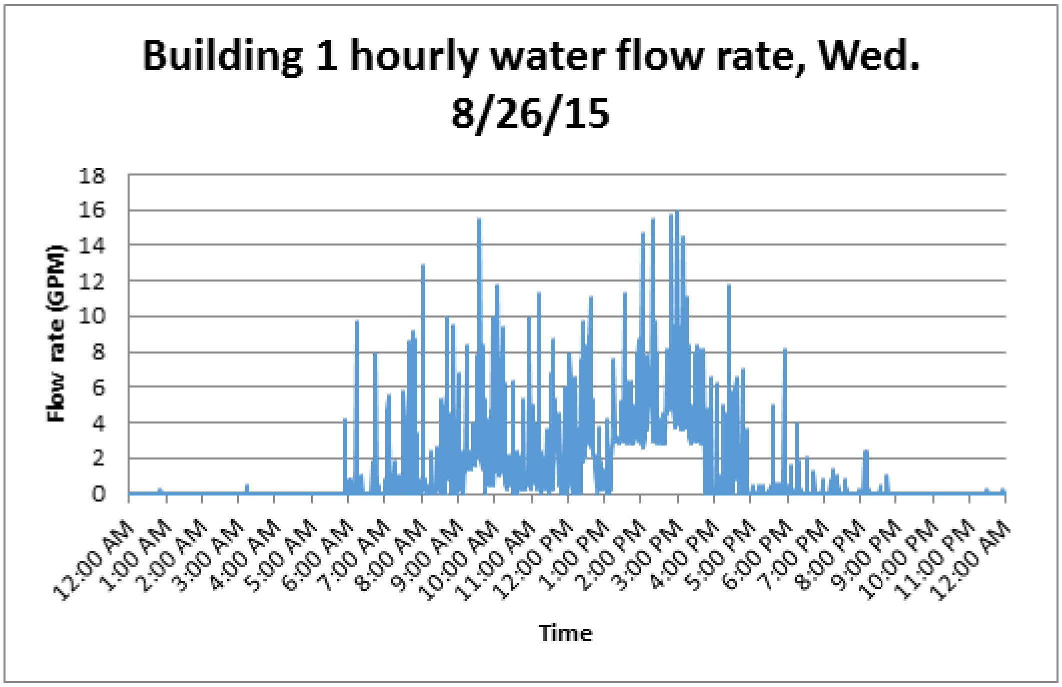


Figure 5-8. Bldg. 1 hourly flow rate for Wed., 8/26/15.

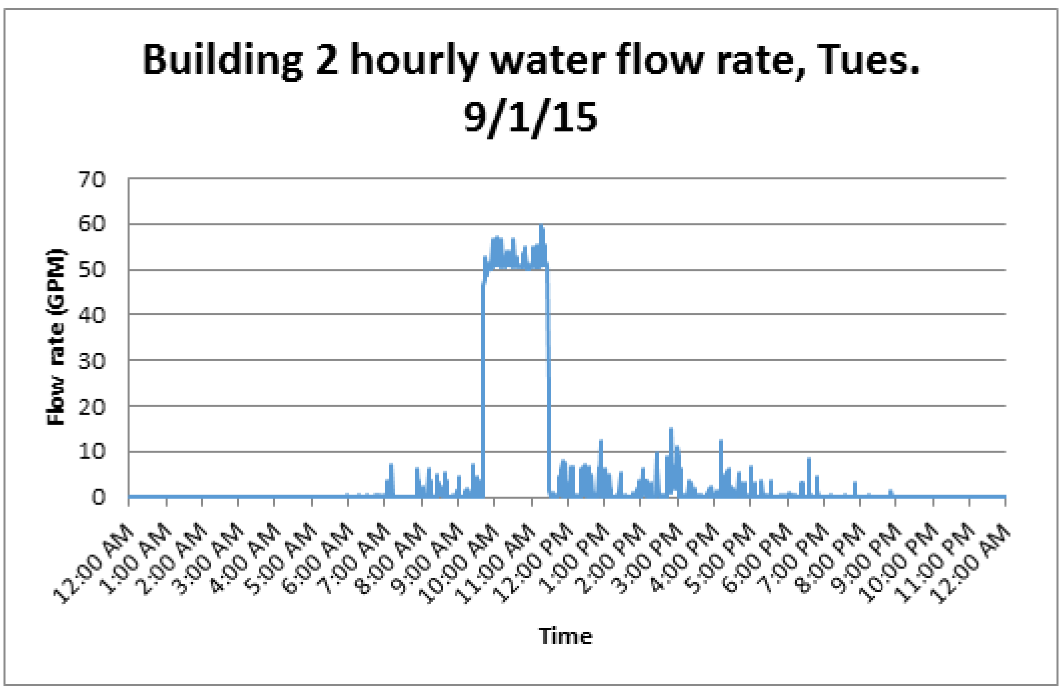


Figure 5-9. Bldg. 2 hourly flow rate for Tues., 9/1/15.

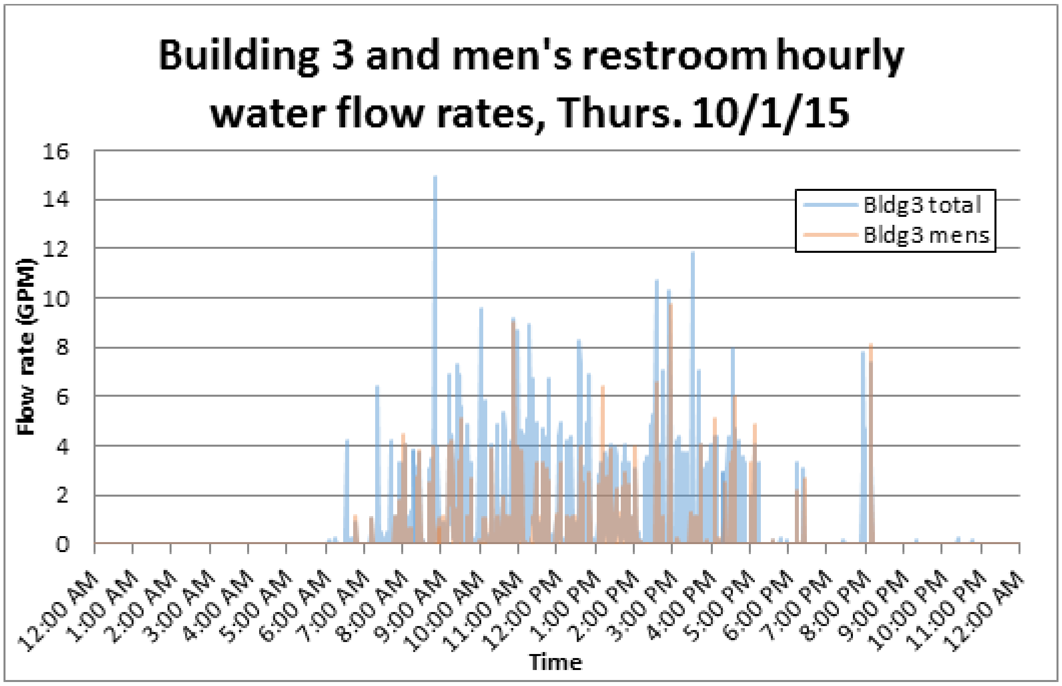


Figure 5-10. Bldg. 3 and men's restroom hourly flow rates for Thurs., 10/1/15.

In addition to the newly installed building water meters, there are also existing water meters for CERL's point of water supply. The main CERL complex has a single meter unit composed of two internal meters at sizes 3 and ⅝-in., which are used to measure low and high water flow. The main complex's water use is the sum of Bldgs. 1-3, the Shake Table building, the Boiler Plant, a Plant Laboratory, and any other source, such as outside water. (At CERL however, turfgrass is not being watered, and rainwater is primarily used for watering shrubs.) The water flow through this meter is tracked via monthly water bills by the utility company.

The main complex's water use over the past several fiscal years, as indicated by monthly billing, is shown in Figure 5-11. In general, water use is lowest during the winter and highest during the summer months. This is due to the large amount of cooling water that is used in the summer. Overall, after fixing the SEM cooling water issue described earlier in May 2015, water use per month dropped substantially by over 100,000 gallons in some months. To a much lesser extent, the low-flow water fixtures have reduced water use between 5,000-10,000 gallons per month (discussed later), however this impact is more difficult to discern when looking at the facility use as a whole.

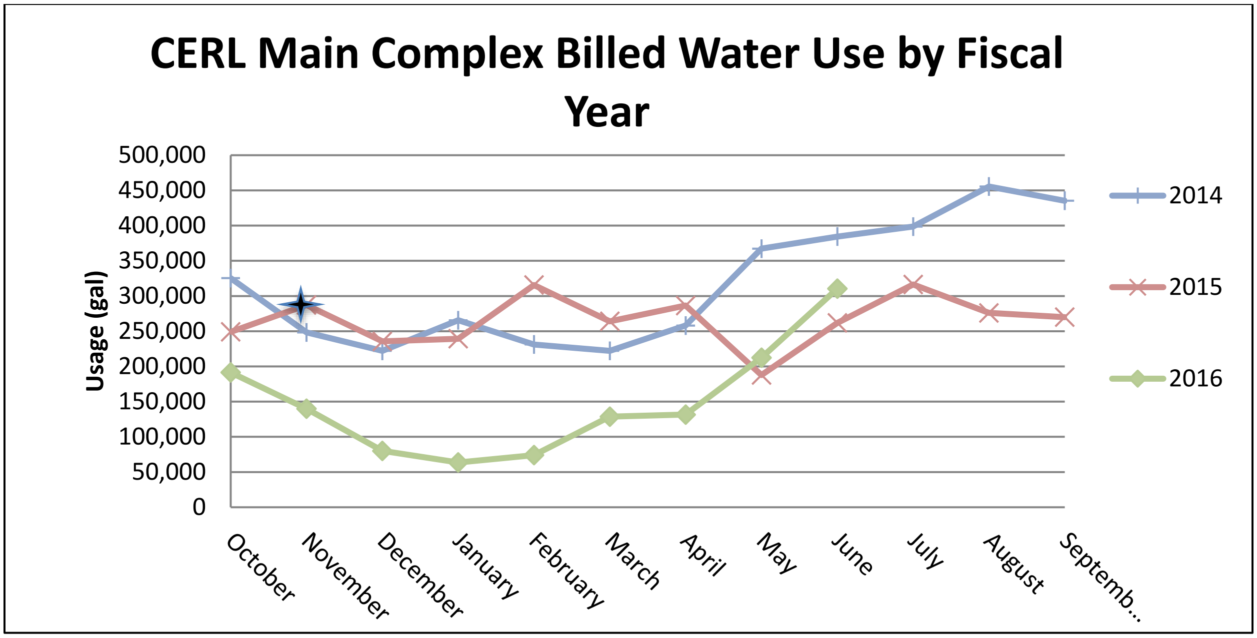


Figure 5-11. CERL facility water use by FY, with retrofits in Nov2015.

5.2.1.2 Baseline CERL population

Various metrics exist for evaluating water systems and reducing water consumption, such as gallons of water per facility square foot and potable water distribution system linear feet (Jenicek 2013). To understand the effect of the water retrofits and graywater reuse system at CERL, it is important to know the daily population. This allows an estimation of the gallons of water used per person. This is a key metric of this study, as it is desired to decrease the number of gallons used per person through water savings technologies.

At CERL, the listed population for each building is tracked by CERL's Directorate of Public Works (DPW), and it fluctuates frequently due to personnel changes and moves (e.g., it changed 260 times during FY14). The average daily population is lower than the listed population due to employees who work remotely, work 4 days a week, travel, or are on a leave status. Ideally, the daily water use would be divided by the daily number of people present, which would yield a water use per capita estimate. However, it was impossible at CERL to get a daily count, so an overall daily average was obtained instead. This average amount gave an estimate to the percent of employees who work on-site, and it also helped provide an estimate to the number of males and females who use the restrooms in each of the three buildings.

To get an average daily actual population, the CERL security officer examined the number of people who had scanned their common access cards (CACs) to get into CERL as well as daily visitors without CACs. Over an 8-week period, he estimated an average of 245 people per day. Examining only Bldgs. 1, 2, and 3, this approximated to a daily occupancy fraction of 67%.

For other sites with CAC scanners, a similar option may be available for estimating daily population, though this would likely depend on security restrictions. For CERL, this CAC information is sent to a central repository in Vicksburg, MS, and obtaining this information was slow due to the security issues involved. Additionally, some facilities may not have strict CAC scan rules for all people entering the site. Therefore, this method is not likely to be easily implemented. Another possible option is to use satellite date like Google Maps to count the number of cars at a facility. However, this is a very rough approximation due to people carpooling, using alternate transportation, and also due to the possibility that the satellite image does not reflect a typical workday.

For estimating total population, it might be possible to use a facility's Voice over IP (VoIP) phone system to count the total number of VoIP users. Potential issues with this method include people who do not have a computer and/or phone line; people leaving the facility and not having their accounts removed; and people who use a separate network instead of the VoIP network.

Building population estimates for both male and female employees (for purposes of understanding the respective restroom use) is shown in Table D-1 in Appendix D.

5.2.1.3 CERL Water Attitudes and Practices Survey

A Water Attitudes and Practices Survey was conducted to gauge water use perceptions and habits of CERL employees. The goal of the survey was to assess water use, identify potential water-related areas of focus, and gauge understanding of graywater technology. Approximately 330 surveys were distributed to offices and labs, which correlates well with CERL's population of approximately 330 (for Bldgs. 1-3). 164 responses were received, with response rates proportional to each building's population. This corresponds to a response rate of at least 50%, which is high for a survey, though response rate is difficult to estimate, as a few office areas were likely vacant but name placards and computers were still present. To increase the survey response, a small chocolate bar incentive was taped to each survey. Survey responses were anonymous, and collection boxes for completed surveys were placed in the main areas of Bldgs. 1, 2, and 3. Electronic means of conducting the surveys were examined, however these methods would have resulted in non-anonymous responses, which is prohibited by policies regarding personally identifiable information.

The Water Attitudes and Practices Survey was modeled off a similar survey from 2011 that was distributed to soldiers at Camp Atterbury, IN (Jenicek et al. 2012). Information on this older survey included questions on basic habits, levels of education regarding resource conservation, water use and waste observations, daily resource considerations, and general demographic information. For the CERL survey, some questions from this previous survey were modified to reflect general civilian life instead of that of a soldier. Questions were also added about graywater reuse systems to gauge employee understanding of graywater. These questions were adopted and modified from other surveys on graywater (Khong 2009, Christova-Boal 1995, City of Guelph 2012). Additionally, some CERL-specific questions were included for the purpose of understanding CERL's water use. Survey results can be found in Appendix B.

Information on water perceptions, water habits at CERL, and opinions of graywater were gathered from the responses of CERL employees. This information was used to create the CERL water model, and it was also used to address concerns related to the recently installed graywater reuse system. Efforts to address comments on the survey were made, facts on graywater reuse systems were posted on the walls of the bathroom where the graywater system was installed.

5.2.1.4 CERL water model

In conjunction with the building-level metering system installed at CERL, a water audit of Bldgs. 1, 2, and 3 was conducted. The audit team used a tablet with the Mobile Information Collection Application: Water Equipment Tracking (MICA:WET) software to record data and information regarding restrooms and kitchen areas. The methodology followed that from previous audits where toilet flush lengths, urinal flush lengths, faucet flow rates, and shower flow rates were measured and recorded. These measurements are found in Appendix C. Any available information on the fixtures was also recorded. In contrast to previous site assessments where only a handful of fixtures were measured and held as representative, all fixtures at CERL (with a few exceptions) were audited. Assumptions based on population and frequency of use were also made.

In addition to MICA:WET, interviews were conducted with personnel on laboratory water use. Bldg. 1 has over a dozen areas where water is used for special purposes, such as for cooling, washing lab equipment, and sterilization. These lab uses were found to be unique compared to bathroom or kitchen fixtures, and consequently a specialized spreadsheet was set up to track each of the individual water users instead of using MICA:WET.

In general, the model estimated a higher amount of water use than what was actually measured. This is likely due to the meters' lower accuracy at low flows. Furthermore, for the lab uses in Bldg. 1, it is possible that some operators overestimated the amount of water used their labs. Details of the model can be found in Appendix D. A summary of the results is shown in Table 5-7.

Table 5-7. Model results vs. actual metered data.

	Bldg. 1	Bldg. 2	Bldg. 3	Total difference (est. vs. actual) for Bldgs. 1-3
Estimated from model (GPD)	2023	1096	799	3917
Actual averaged daily data (GPD)	1259	670	730	2659

5.2.2 Under-sink graywater reuse system (CERL)

5.2.2.1 Baseline restroom water use

As described earlier, a meter was installed in the restroom to monitor toilet and urinal water use. The average daily value pre-retrofit was 236 gal. Additionally, the graywater reuse system had a meter attached to the sinks to monitor sink water use. The average daily sink use was 42.7 gal.

5.2.2.2 Men's restroom daily population

The main goal of the graywater reuse system is to reduce the amount of potable water use. More specifically, it is to reduce the average water used per person. Therefore, it was necessary to track the number of daily users in the men's restroom by using people counters. A description of the method for this is in Appendix F. On average, the men's restroom has 138 daily visitors. This correlates well with Bldg. 3's daily male population of approximately 33 (an exact number is not possible due to some percentage of the population teleworking or traveling). At 4 uses per day, this equates to 133 total uses for the daily population.

The results from the people counters and the meters also provide important information on the amount of water used per person. The average person used 0.3 gal of sink water per restroom visit. For toilets, the average amount of water changed over the course of the study. At the beginning of the study the average person used 1.82 gal of toilet water per visit. However, the toilets and urinals have infrared sensors that automatically flush the toilets, and the sensors on the toilets were observed to be flushing too often (e.g., when someone would move while seated on the toilet). These sensors were adjusted to be less sensitive, and after this, water use dropped to 1.50 gal per person per visit.

5.2.2.3 Graywater model

The daily water use of the men's restroom in its pre-retrofit state was modeled based off of measured water use values. This estimate was compared against the predicted water use of having the fixtures replaced and a graywater system implemented. For the pre-retrofit case, a daily water use of 283.5 gal was modeled (close to actual metered data of 278.7 gal). Assuming a complete retrofit of the bathroom fixtures, a daily water use of 62.9 gal was predicted, or 22.2% of the original bathroom water use. Details of this analysis are in Appendix G.

5.2.3 Building scale graywater reuse system (MCRD)

5.2.3.1 Fixture flow rates and water model

Building level water meter data at Walker Hall was not tracked prior to this study. Over the course of the study, MCRD Public Works personnel provided water meter readings and personnel data where it was available.

In August 2014 and July 2015 the bathroom fixtures in buildings 572, 573, and 586 were audited for performance and to estimate overall building water demand. These buildings were chosen as they each were designed and constructed with a graywater reuse system that treated and diverted sink and shower water for toilet flushing. Only one of the graywater systems (building 573) was fully operational for the duration of this study. Further analysis on the systems is discussed in the remainder of the report.

A major factor affecting water demand is the number of occupants within a building. Depending on the type of occupants for administrative or barracks buildings, certain assumptions were made to account for the assumed overall time the building is occupied. For example, interviews with the clinic staff for building 573 stated there were 21 staff members occupying the building daily with an average client load of 103 recruits. This includes the average daily patient population and an average daily 30 recruits/marines who use the Special Training Company gym located in 573. The staff members occupy the building up to 10 hours throughout the day whereas the clients occupy the building for only a portion of the day averaging approximately 4 hours. MICA:WET is limited to one overall occupancy number for its calculations; therefore the number of clients who are part-time occupants was halved in order to capture "fulltime" occupant loading onto the clinic. Therefore we assumed the overall building load was 73 persons (=103/2 + 21) daily between 8 to 10 hours.

Occupancy of training barracks such as 586 can change from zero to over one thousand from 1 week to the next. The average occupancy during this project was 429 trainees and staff. Occupancy of Bldg. 572, the medical barracks, averaged 140 in FY14-15 and 179 in FY16.

For barracks 586 and 572 the historical occupancy data was tracked by building staff and provided by MCRD DPW staff, but each barrack is used very differently from the other. The historical occupancy data for 573 the SMART clinic was provided by clinic personnel.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

5.3.1 Water fixture retrofits

Water fixture retrofits were carried out in restrooms and locker rooms at the CERL demonstration site.

5.3.1.1 Faucet aerators

The lavatory faucet aerators are Zurn rated for 0.5 gpm. The auto sensors that control the faucets are set for 1.5 seconds duration per activation.

Figure 5-12. Faucet with retrofit Zurn 0.5 gpm aerator.

5.3.1.2 Low flow showerheads

The shower heads are Delta 112.18.1M rated for 2 gpm.

Figure 5-13. New low-flow showerheads in locker room.

5.3.1.3 Waterless urinal

Installation of waterless urinals were considered as part of the revised plan to retrofit the Men's bathroom in CERL Bldg. 3, which has two existing urinals. However, the bathroom downtime requirements (up to 3 weeks) estimated by the building contractors for this proposed retrofit made the retrofit infeasible. Therefore, waterless urinals were studied in the context of training areas and associated test facilities on-site at CERL. Specifically, CERL's on-site test bed for closed loop water frameworks and the component technologies needed to achieve Net Zero water consumption in expeditionary environments was used. Concepts for containerized latrines with waterless urinals, low flush toilets, and under-sink water reuse capabilities were integrated into the test bed plan based on this ESTCP project.

The particular waterless urinal being studied in this demonstration project is the Sloan WaterFree Hybrid (HYB-7000) models that consumes about 0.33 gpd of water due to its use of Jetrinse Solution Technology to automatically flush the drain lines, which prevents scaling and corrosion issues that have been observed with previous generations of waterless urinals.

5.3.1.4 Shave stand with razor cleaning capability

Another issue identified during the progression of this demonstration was the need for faucets with the capability to efficiently clean razors, particularly in expeditionary settings and training areas where shaving is required but faucets are often water intensive and provide poor flow velocity. Similar concepts could also be employed in specific high water intensity bathrooms at installations, such as locker rooms and multi-user bathrooms in training barracks.

To this end, a new hybrid faucet with a mechanical auto-shutoff and button-activated high velocity flow mode was installed on a set of stainless steel sinks similar to those employed in training and expeditionary environments. The Custom SMART Faucet technology was tailored to DoD requirements for training areas, barracks bathrooms, or locker rooms where water efficiency and razor cleaning capability are both needed.

Figure 5-14. Custom SMART Faucet technology.

5.3.2 Under-sink graywater reuse system (CERL)

A flow diagram of the graywater treatment system is shown in Figure 5-15. After installation and approval from Illinois Dept. of Health, the graywater system was commissioned. Graywater from sump #1 was passed at up to 1.5 gpm through an upflow biologically-active activated carbon (BAC) filter. The BAC filter unit was vented to the stacks and contained a passive overflow to bypass the system in case of downstream clog and a pump-controlled drain that empties the filter bed each night to passively aerate the filter bed and remove biomass. A small aerator was used during draining to agitate the activated carbon media to remove accumulated biomass, which flows down the drain to waste.

The treated BAC filter effluent water flows through a passive chlorinator that provides 1-4 mg/L as Cl_2 of free chlorine via a slow-dissolving calcium hypochlorite tablet. Chlorinated water flows by gravity into a stack-vented storage tank, which aids in equilibrating chlorine concentration and providing temporary storage in times when sink usage exceeds toilet flushing demand. The influent port to the storage tank contains a wick that passively adds blue dye to the water. The storage tank has a passive overflow port to divert flow in case of a downstream flow stoppage, and the tank is also drained each night.

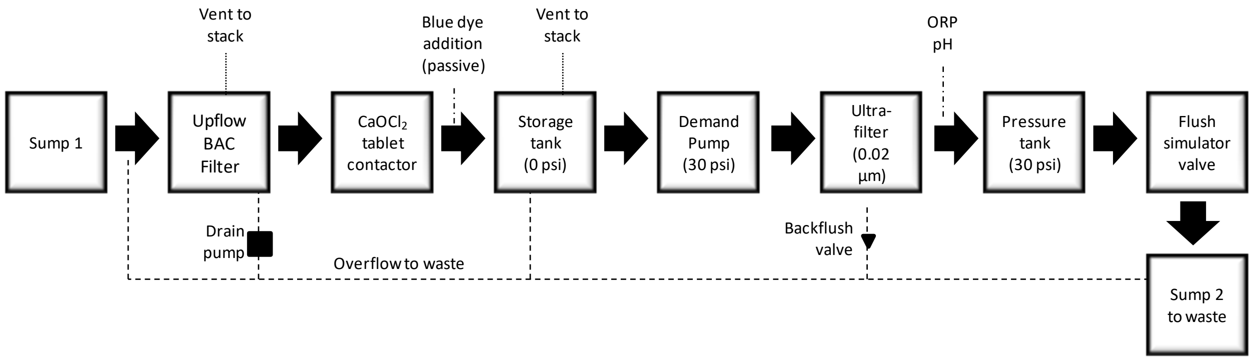


Figure 5-15. Process flow path for Phase I "offline testing" of under-sink graywater reuse system.

Water from the storage tank flows by gravity to a demand pump that pressurizes the water to 30 psi and also contains a pressure switch that stops the pump once the target pressure is reached at zero flow. The demand pump pushes the water through a hollow fiber polyethersulfone (PES) ultrafilter (UF) module. The UF module is back flushed each day through the automated opening of the backflush valve. Opening the backflush valve depressurizes the system between the pump and the feed side of the membrane, which simultaneously drains the storage tank and causes water to flow backwards through the UF membrane. This reduces fouling of the membranes and allows them to operate at a higher flow rate over at least 6 months.

Effluent from the UF module was monitored (by external meters just for the test phase) for pH and ORP levels, with ORP providing a real time tracking of the oxidation potential and by inference the approximate level of chlorination achieved. During normal design operation the pressurized effluent will be stored in a 5-gallon pressure tank at 30 psi. The pressure tank will allow for the infrequent high rate but short duration flushing demands to be met. Toilet flushing in Phase I was simulated using a timer controlled solenoid valve.

The arrangement of the treatment components is shown in Figure 5-16a. The system was designed and assembled such that all processes work together, and the system was tested and optimized over 4 months in a laboratory environment using a modified version of NSF 350 graywater that is representative of sink effluent based on published studies.

A system control panel provides power to the electrical components at prescribed intervals and contains internal fuses. It also has a battery backup to remember the programmed timer intervals. The system frame was grounded to the building electrical ground. A stainless steel cover was installed on the system to restrict access to the components (Figure 5-16b).

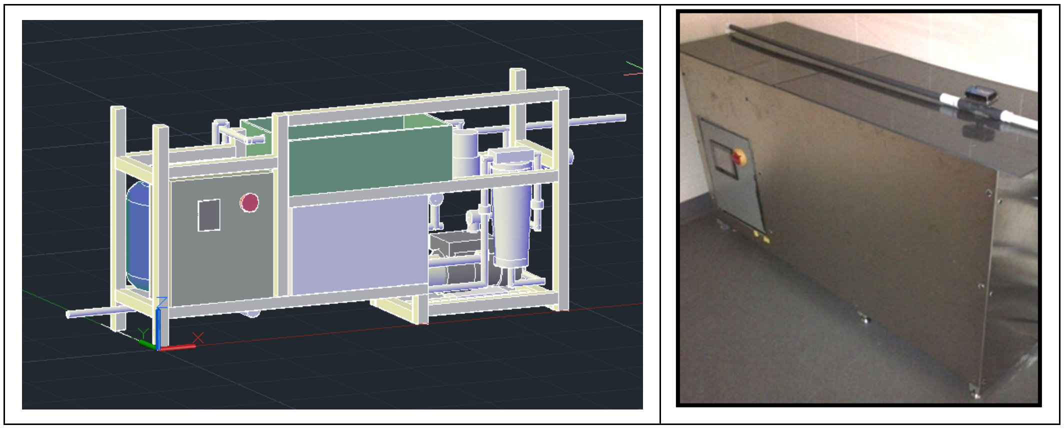


Figure 5-16. Under-sink graywater reuse system to be installed in CERL Bldg. 3 bathroom for offline testing: (a) schematic view, and (b) assembled treatment unit.

5.3.3 Building scale graywater reuse system (MCRD)

The following information is taken from system specifications of the graywater systems for the three buildings at the MCRD, provided by Wahaso (Bailin 2010, Wahaso 2011).[*]

In each of the three buildings at MCRD there exists a graywater reuse system. Graywater from sinks and showers is sent to a concrete graywater collection vault underground. This tank flushes once a day so that any graywater is not stored longer than 24 hours. This graywater is then pumped through a filtration system, which removes particles larger than 5-10 microns, and the cleaned water is then sent to a clean water vault. Chlorine is added to kill any organisms in the water before and after the filter stage.

Next to the clean water vault is a pump vault which pumps the cleaned water to the toilets and maintains the water pressure and flow to the toilets. The pump vault also houses a potable make-up system, where municipal make-up water is added if not enough cleaned graywater is available. This municipal water is added via an air gap, which prevents any contamination from reaching the potable system. If the filtration or chlorination systems fail, the graywater processing system is shut down, and only municipal water is pumped through. Finally, at the outlet of the system, blue dye is added to the water. In order to comply with the International Plumbing Code, it is recommended to use a programmable auto flushing system in order to remove graywater from the toilet tanks once a day[†].

A diagram of this process is shown in Figure 5-17.

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[*] System technical specifications and diagrams are labeled proprietary by the vendor who did not respond to researcher requests to include said information in this report.

[†] While there is no explicit retention time for graywater in toilet tanks, the IPC limits retention time in graywater storage tanks to 24 hours.

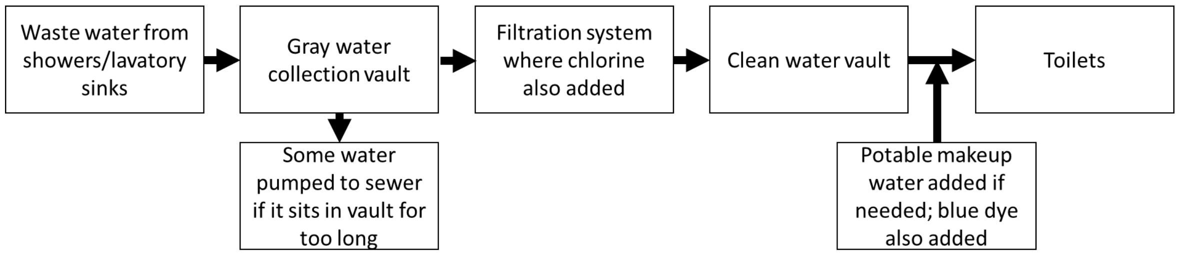

Figure 5-17. General graywater reuse system process.

Regarding controls, a system monitors the processes of the graywater system. Various sensors measure water levels in the graywater and cleaned water tanks; these determine when municipal make-up water should be added. Other sensors monitor the filter system and chlorine levels, and pump speeds are regulated for optimal use. Data is instantaneous and can be accessed users via a touch screen menu. Output data includes tank water levels, processed water amounts, equipment conditions, and more. This system can also be interfaced with a building automation system, however, was not set up in this manner at the MCRD and was not recording data over time.

There are several maintenance tasks required for this system. In general, the system is designed to have minimal maintenance, but it is recommended that the system be inspected 1-2 times a year to ensure regular operation. Specific maintenance tasks that need to be performed periodically include the following:

- Chlorine tablets added weekly/monthly (depending on system's frequency of use)
- Inspection of filters: manual professional cleaning should occur 2-3 times a year, and replacement should occur every 5-7 years
- Annual maintenance of the following: cross-connection tests, inspection of floating filter in graywater tank, performance tests, and leak inspections

Additionally, it should be noted that Bldg. 586 has an irrigation add-on for the graywater system, which would presumably use cleaned water for plant watering. However, the system has never been operated.

Photos of the graywater system are shown in Figure 5-18.

Figure 5-18. Clockwise from top left: status screen of graywater system, air gap for potable make-up water, filtration system, and water sample collection.

5.4 OPERATIONAL TESTING

5.4.1 Water fixture retrofits

There were three main phases for the water fixture retrofits: pre-retrofit, retrofit, and post-retrofit. During pre-retrofit, the baseline characterization described in Section 5.2 was performed. This consisted of daily meter readings of Bldgs. 1-3, analyzing CERL's water bills, and measuring water flows. For the flow measurements, a special measuring bag was placed under each faucet and showerhead while water was run. This provided an estimate of the fixture flow rates. For the toilet flush amounts, each toilet at CERL was flushed, and the resulting water use was recorded by the MM100 flow recorders attached to the building water meters. A water attitudes survey was administered to personnel at this time and the CERL water model was developed.

The second phase was the retrofit phase. Here, the aerators of the bathroom faucets at CERL were swapped with low flow versions (0.5 GPM). Additionally, showerheads were replaced with 2.0 GPM fixtures, and sensors on toilets were adjusted to eliminate any extra flushing associated with incorrectly triggering the motion sensor.

The third phase was the post-retrofit phase. In this phase, water use was measured and compared against that of the pre-retrofit phase. Water fixtures were left in place at CERL.

For water efficient shave stands as well as drain-flushing waterfree urinals, which were considered later in the program, fixtures were tested off-line for flow validation and installed into a containerized bathroom for future testing in operational training areas at installations. Demonstration of the updated water-free urinals in the CERL building bathroom was planned, but the retrofit was deemed cost- and time-ineffective for the building.

5.4.2 Under-sink graywater reuse system (CERL)

Operational testing of the under-sink graywater reuse system consisted of performance monitoring. The system was inspected visually each business day at 0630, 1200, and 1700 by the CERL research team for the first week of operation and daily thereafter. Flow data to and from the graywater treatment system was documented at least daily. Oxidation reduction potential and pH were monitored continuously using external meters with data loggers. Water quality of the influent and effluent was measured three times each week for the following parameters- Turbidity, pH, free and total chlorine concentration, and Chemical Oxygen Demand (COD). Effluent samples were also analyzed for *E. coli* and 5-day Biochemical Oxygen Demand (BOD-5) at least once per week. American Public Health Association/American Water Works Association (APHA/AWWA) Standard Methods for the Evaluation of Water and Wastewater were used for measuring all water quality parameters in the study. All laboratory analysis data was recorded manually in a notebook. All data files were saved into an Excel file that was updated at least weekly and saved with a new file name that reflected the date.

The key performance criteria for graywater reuse systems are summarized below in Table 5-8:

Table 5-8. Performance criteria.

Criterion	Measured Parameter(s)	Target Level
Particulate removal	Turbidity	< 1 NTU
Pathogen removal	E. coli MS2 phage	< 2.3 cfu/100 mL 99.99% removal
Organics removal	BOD COD	< 10 mg/L < 25 mg/L
Disinfection residual	Free chlorine	0.5-4 mg/L
Acidity	pH	6-9

Cumulative energy and flow data for the system were logged daily using a Kill-A-Watt EZ power meter and inline digital paddle flow meters, respectively.

5.4.3 Building scale graywater reuse system (MCRD)

There was only one phase for the building scale graywater system study, which was monitoring the water use and performance of the existing graywater system and respective MCRD buildings. Water use and graywater system performance was recorded on a monthly basis by site personnel, and additional meters were installed by CERL personnel to record water and electrical data on a continuous basis. Several visits were conducted over the course of the study, where CERL researchers set up these data loggers, obtained water samples from the graywater reuse system for laboratory testing, and interviewed facility and Public Works personnel.

5.5 SAMPLING PROTOCOL

5.5.1 Water fixture retrofits

For the water fixture retrofits, there were several different types of samples taken. This data was also taken during the baseline characterization. Therefore, information can be found in 5.2.1.1 about meter readings, water bills, and data loggers.

Flow rates of the faucets and showers were also measured pre- and post-retrofit. These flow rates were taken using a marked plastic bag, shown in Figure 5-19. By holding the bag under a stream of water for 5 seconds, the water use in GPM can be determined by looking at the tick mark on the bag that matches the water level. Some interpolation was used for water levels in-between tick marks.

Figure 5-19. Specially labeled plastic bag used for measuring flow rates.

A testbed for hybrid waterless urinal systems and efficient shave stands was assembled at CERL for the expeditionary equipment integration and evaluation.

Paddle flow meters were used to assess the daily water flow through the hybrid waterless urinal systems and efficient shave stands at the expeditionary equipment integration and evaluation testbed at CERL. System performance was monitored under continuous operation with simulated loads that were representative of diurnal usage cycles. Razor cleaning efficiency was measured through direct observation of razor cleanliness as a function of time in the flow stream.

Table 5-9 summarizes the sample information for water fixture retrofits.

Table 5-9. Water fixture retrofit samples.

Sample	Description
Faucet & shower flow rates	Flow rates of the showers and faucets were obtained using flow bags. Flow rates were compared with the pre-retrofit flow rate values.
Meter readings	Meter readings of the three CERL buildings were obtained every weekday morning, excluding holidays.
Monthly facility water use	This data was obtained by examining CERL's water bills.
Waterless urinal, shave stand info	Flow rates of the faucets for shaving were examined using flow bags. Flow rates of flushing for waterless urinals were also examined in same manner. These data were compared with the pre-retrofit condition.

5.5.2 Under-sink graywater reuse system (CERL)

For the under-sink graywater reuse system, there were several different types of samples taken, mostly dealing with water quality and metered water amounts.

The sample information for the under-sink graywater reuse system is summarized in Table 5-10.

Table 5-10. Under-sink graywater reuse system samples.

Sample	Description
Graywater test sample quality	Water quality analysis for both influent and effluent samples from under-sink graywater system was performed three times each week in the lab at CERL.
Effluent/influent meter readings	Daily flow data for influent and effluent were collected from inline digital paddle flow meters.
Energy meter readings	Cumulative energy for the system was logged daily using a Kill-A-Watt EZ power meter.

5.5.3 Building scale graywater reuse system (MCRD)

For the building scale graywater reuse system, there were several different types of samples taken. These samples were similar to that of the under-sink graywater reuse system. The initial site visit to survey the system was conducted in Aug. 2014 for the purpose of surveying the three candidate buildings and selecting one for detailed analysis. Subsequent trips to obtain data samples were conducted Mar. 2015, Jul. 2015, Aug. 2015, Sept. 2015, Feb. 2016, May 2016, and Nov. 2016.

In order to assess the water conservation of the graywater reuse system, CERL implemented a sampling protocol consisting of ultrasonic, digital, and external meter monitoring. The first assessment of the system consisted of the installation of two clamp-on ultrasonic water meters on Bldg.

573, however the low flow of the system resulted in data which was too noisy. Because of this, a new metering scheme was developed in order to take advantage of the existing meters tied into the existing control and display panel. Specifically, a building water meter measured total water consumption for the facility and individual line meters measured the makeup, reclaimed, and treated water. For the existing building water meter, researchers connected a Meter Master M100 flow recorder to the external surface of the meter body, Figure 5-20. The M100 utilizes Hall Effect sensors in order to non-invasively track the spinning of the meter register, the movement of which can be translated into flow rates. Such a system could not be utilized for the smaller sub-system meters, requiring improvisation of external data loggers connected to each meter's pulse output. These data loggers, built from Arduino microcontrollers and custom circuits, were connected to each available meter, Figure 5-21.

Figure 5-20. A Meter Master flow recorder stores building water demand data.

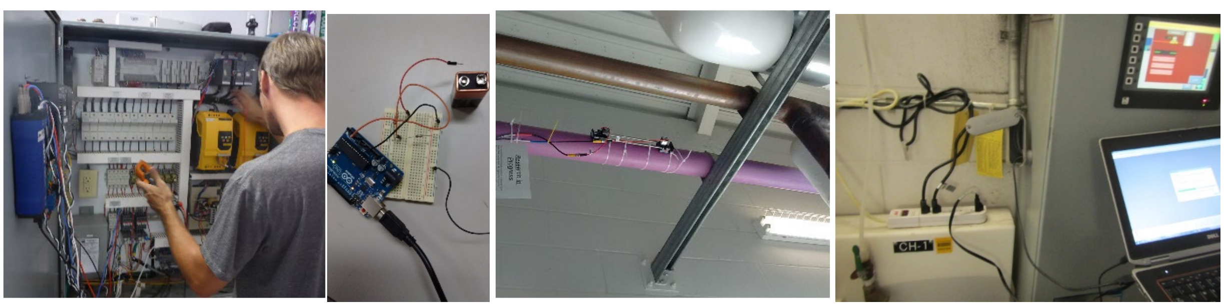

Figure 5-21. L to R: (1) voltage meter installation, (2, 3) external data logger on a paddle meter, and (4) download of energy logger data.

While custom-built data loggers are economical, this research did find a lack of available information on translating meter pulses to flow with sufficient accuracy. Additionally, lack of on-board clocks of suitable precision (as opposed to traditional data logging) hinders directly comparing flows by timestamp. Such technical challenges can be overcome with minimal investment, however it is advised that future graywater systems incorporate improved logging functionality directly into their controls, with data transmission or collection instituted as a routine part of operations and maintenance.

A GE voltage meter was installed on the graywater reuse system electric panels for buildings 272 and 273 in August 2015, Figure 5-21. Data was collected through May 2016.

Figure 5-22. Sample collection for building scale graywater reuse system.

Table 5-11 summarizes the sample information for the building scale graywater reuse system. Collection of samples is shown in Figure 5-22.

Table 5-11. Building scale graywater reuse system samples.

Sample	Description
Graywater test sample quality	Samples of pre and post treatment graywater were collected during site visits. Pre-treatment samples were collected by disconnecting the water sampling connected to the treatment system chlorinator. Post-treatment samples were collected from either directly after the membrane filter or from the water storage tank. The water sampled from after the membrane filter has not been diluted with makeup water, while the water in the storage tank is both mixed with makeup water and subject to residence times.
Graywater system water amounts	The graywater system outputs metered data corresponding to the amount of graywater cleaned. This data was collected almost every month over late 2014 and 2015 by MCRD facility personnel. Continuous data logging was not built into the system panel.
Graywater system continuous water data	To obtain continuous data on the amounts of graywater produced by the systems, an Arduino data logger system was connected to the system panel of Bldg. 573.
MCRD building meter readings	Water meter readings for each building were collected every month over late 2014 and 2015 by MCRD facility personnel. This provided data on the potable water use for each of the three buildings.
MCRD building continuous water data	To obtain continuous data on the amounts of potable water used at MCRD, a MM100 data logger was connected to the main potable water line of Bldg. 572.
Graywater system continuous energy data	Continuous energy use data via data loggers were gathered by using a GE voltage meter. The graywater systems of Bldg. 572 and 573 were studied over the period from Sept. 2015 to May 2016.

Sample	Description
Facility personnel feedback	Interviews were conducted with facility personnel about their opinions on the graywater system.

5.6 SAMPLING RESULTS

5.6.1 Water fixture retrofits (CERL)

The new faucet flow rates were measured at 0.47 GPM on average (rated 0.5 GPM), and the new showerhead flow rates were measured at 1.8 GPM on average (rated 2.0 GPM). Raw data on pre- and post-retrofit measured flow rates is found in Appendix C.

Daily meter readings for the three buildings is shown in Figure 5-23. Monthly metered use (including post-retrofit) is shown earlier in Figure 5-11. Box and whisker plots were also generated for the three buildings, showing the data distribution for each day of the week. This information is contained in Appendix E.

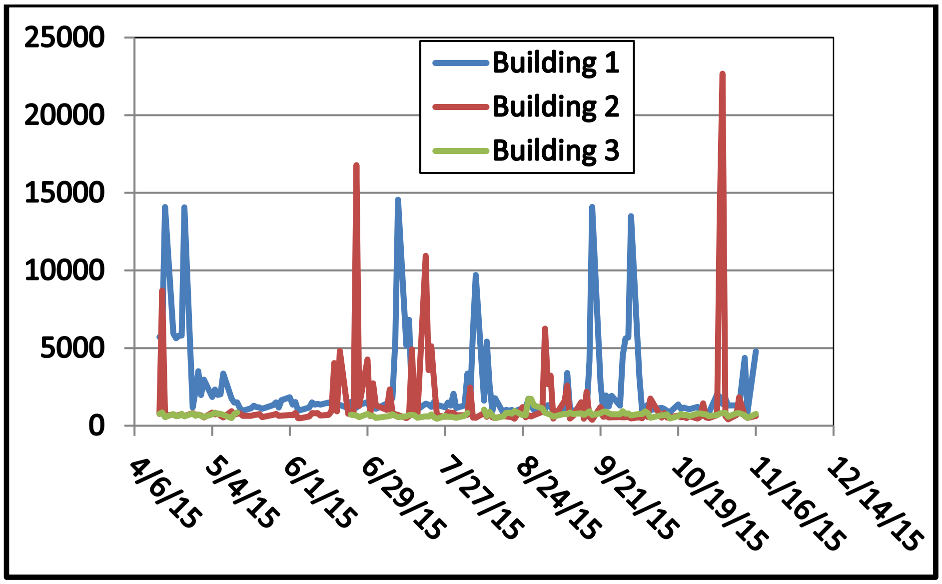

Figure 5-23. Daily metered CERL water use by building.

Due to the large sizes of the building meters, effects from the sink and shower retrofits cannot be discerned from this data. Instead, the CERL water model discussed in 5.2.1.4 was used to determine daily water use estimates for the three buildings by incorporating the measured post-retrofit fixture flow rates.

In general, the water model was used to estimate the following, both actual and potential water savings:

- The baseline water use of CERL (shown in Table 5-6);
- The water use after adjusting the flush sensors on the toilets;
- The water use after the sinks and showers were retrofit;
- The water use if 1.28 GPF toilets and 0.125 GPF urinals were then implemented; and,

- The water use if waterless urinals and graywater systems for each restroom were implemented.

Overall, the fixture retrofits were modeled to save 253 GPD, dropping the water use of the three buildings by 7.0%. Additional water savings of 7% were realized by adjusting the toilet automatic flush sensors, for a total building potable water reduction of 14%. (Note: If the toilets and urinals were replaced along with the fixture retrofits, the water use would have dropped by 1707 GPD, or 47.2% instead; these retrofits were in the planning stages by CERL DPW and weren't included in this demonstration.) Finally, the implementation of waterless urinals and graywater reuse systems throughout CERL would save the greatest amount of water. This data is shown in Table 5-12.

Table 5-12. CERL water model results.

Notes	Bldg. 1	Bldg. 2	Bldg. 3	Total for 3 bldgs.	Bldg. 3 men's room toilets
Base water use model (GPD)	2023	1096	799	3917	239
Water use after fixing flush sensors (GPD)	1908	986	720	3614	199
Water use after retrofitting sinks and showers (GPD)	1793	894	674	3361	199
Water use with all toilets 1.28 GPF and all urinals 0.125 GPF (GPD)	1116	539	252	1907	72
Water use with all urinals waterless and GW systems in each bathroom (GPD)	1061	485	215	1761	59

5.6.2 Under-sink graywater reuse system (CERL)

The under-sink graywater reuse system was challenged for 5 months (144 days) in an off-line (no reuse) capacity treating graywater flows from the bathroom sinks. The sump system supplying the graywater from the sinks delivered water at a flow rate exceeding the design flow rate of the system (up to 4 gpm), which resulted in a significant volume overflow to waste due to a safety bypass that was installed to prevent bathroom flooding. Therefore, the system was challenged with approximately 15 gpd of graywater, well below its 50 gpd design capacity. The intermittent delivery of high flows to the system may have also decreased system treatment performance by reducing hold times in the biofilter module. The system also discharged about 5 gpd during its cleaning cycle, resulting in about 10 gpd recovery of treated water.

In terms of water treatment performance, the system performed less effectively than in the lab validation tests. The test results shown in Table 5-13 are averages ± 95% confidence intervals based on n samples; samples were collected over a 144 day test period. While the water quality was significantly and consistently improved over the test period, the effluent product water fell short of treatment objectives in several areas. While good performance was observed with respect to *E. coli* removal/inactivation and turbidity reduction, which are mediated by the ultrafilter and/or chlorine disinfectant, other effluent water quality factors were above goal levels. Specifically, the organic contaminants that are measured indirectly in the form of BOD and COD were higher than the target effluent levels by about 80%. Even though the system provided a sustained 75-85% removal of organics, this was not sufficient to meet effluent objectives given the levels of organic contamination in the influent graywater.

Table 5-13. Summary of influent and effluent water quality measurements for the under-sink graywater reuse system.

Measured Parameter(s)	Units	Influent Level	Target Effluent Level	Measured Effluent Level	Number of Samples Analyzed (*n*)
Turbidity	NTU	22 ± 2	< 1	0.99 ± 0.29	51
E. coli	CFU/100 ml	29 ± 32	< 2.3	0.06 ± 0.12	17
BOD COD	mg/L mg/L	91 ± 21 186 ± 19	< 10 < 25	18 ± 4.1 34 ± 7.2	18 51
Free chlorine	mg Cl_2/L	0	0.5-4	3.6 ± 1.1	51
pH		7.5 ± 0.1	6-9	7.2 ± 0.1	51

The 95% confidence interval ranges on many of the parameters indicate large variability in measurements for several parameters. Some of this variability is likely associated with the variability in the influent graywater. To provide a better representation of the variation observed in measured values for samples collected during the study over time, plots for each parameter over time are presented in Figure 5-24 through Figure 5-29.

For turbidity, a measure of water clarity, the target effluent level is 1 NTU or lower. The influent turbidity was fairly variable, and 13 of the 51 samples taken during testing exceeded the target effluent value, Figure 5-24. This result was unexpected because the system has an ultrafiltration membrane, which should screen out almost all turbidity-causing particulates. However, it is possible that biofilms were growing and sloughing downstream of the ultrafilter, resulting in periodic increases in turbidity values.

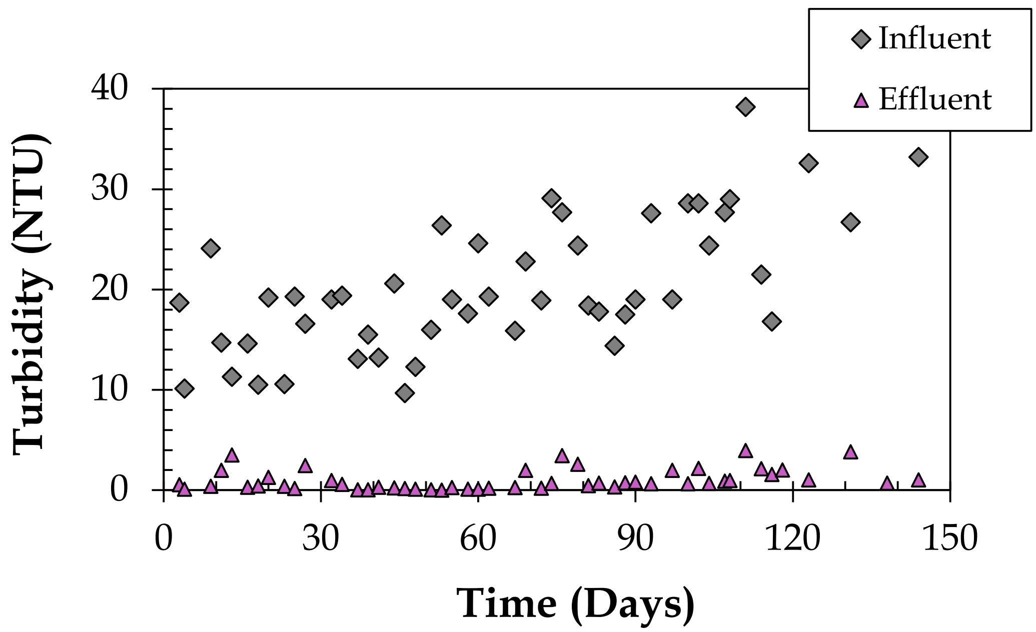

Figure 5-24. Measured values of turbidity over time for untreated (influent) and treated (effluent) graywater from bathroom sinks.

For pH, a measure of proton activity in the water, the effluent target range is 6.0-9.0 pH units. Both the influent and effluent pH values were very consistent for the duration of these tests, Figure 5-25. The slightly lower effluent pH values observed are likely due to proton-liberating biological processes such as nitrification within the biofilter.

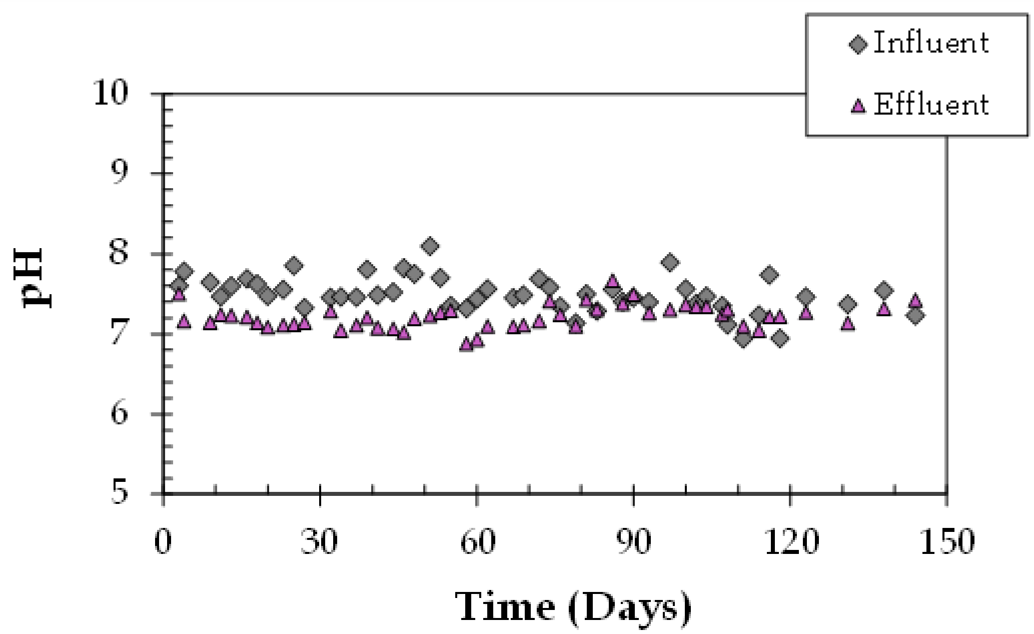

Figure 5-25. Measured values of pH over time for untreated (influent) and treated (effluent) graywater from bathroom sinks.

For COD, an indirect measure of biodegradable and non-biodegradable organic contaminants in water, the target effluent concentration is 25 mg/L. Based on the 51 samples collected, nearly 50% of samples exceeded this target level, Figure 5-26. Some sample values were particularly high (spikes) and were ascribed to fouling/clogging of the biofilter module which reduced biodegradation activity. Manual cleaning of the filter restored performance after these spikes.

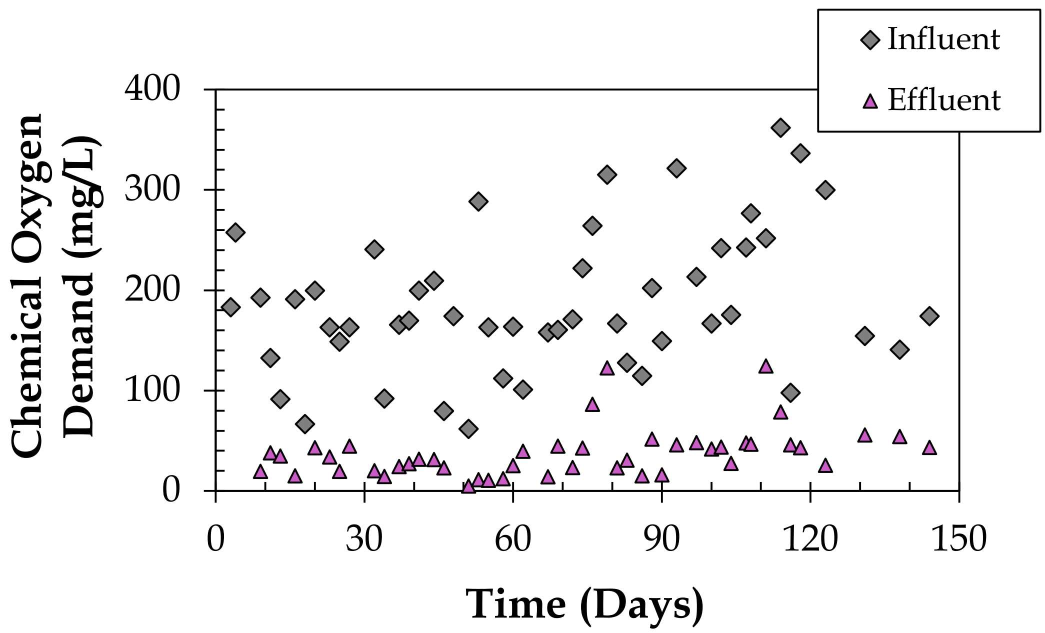

Figure 5-26. Measured values of chemical oxygen demand (COD) over time for untreated (influent) and treated (effluent) graywater from bathroom sinks.

For BOD, an indirect measure of biodegradable organic contaminants in water, the target effluent concentration is 10 mg/L. Of the 18 samples collected, 13 of the samples exceeded this target level, Figure 5-27. As with COD levels, manual cleaning of the filter improved performance after levels increased, though the spikes were less apparent in this data.

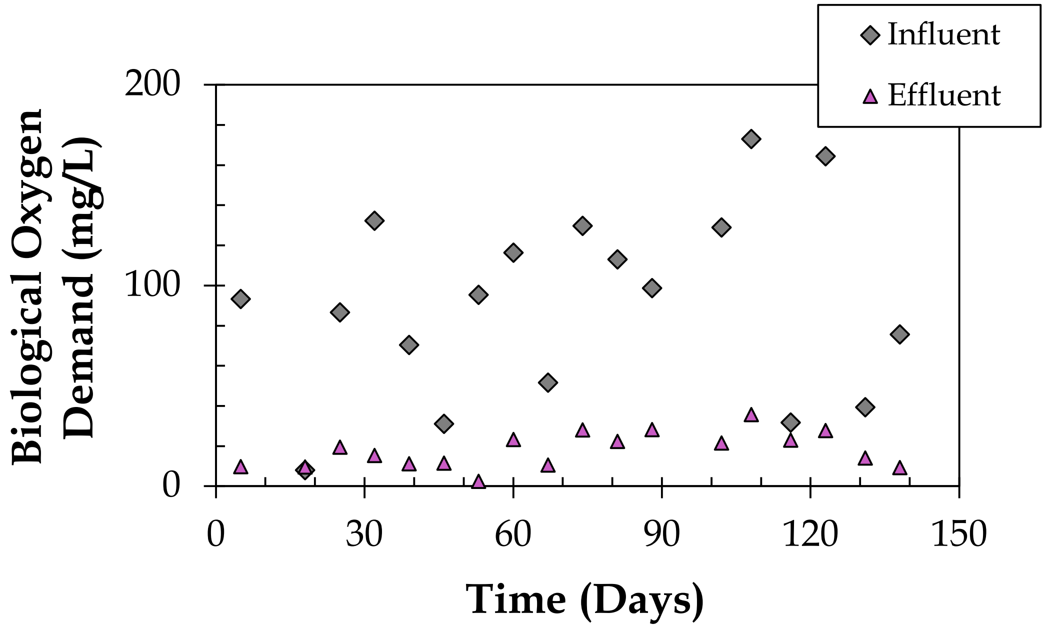

Figure 5-27. Measured values of biochemical oxygen demand (BOD) over time for untreated (influent) and treated (effluent) graywater from bathroom sinks.

For free chlorine, a measure of the disinfectant hypochlorous acid and/or hypochlorite ion, the target effluent levels were 0.5-4.0 mg/L. While the average value over the 144 test period fell in range, the effluent values varied extensively, Figure 5-28. In the early phase of testing, the effluent values were generally too high, whereas they were too low in the late phases of testing. This shift was due to a physical adjustment that was made to the chlorine dosing system that reduced the residence time in the chlorinator. Unfortunately, the adjustment was too extreme.

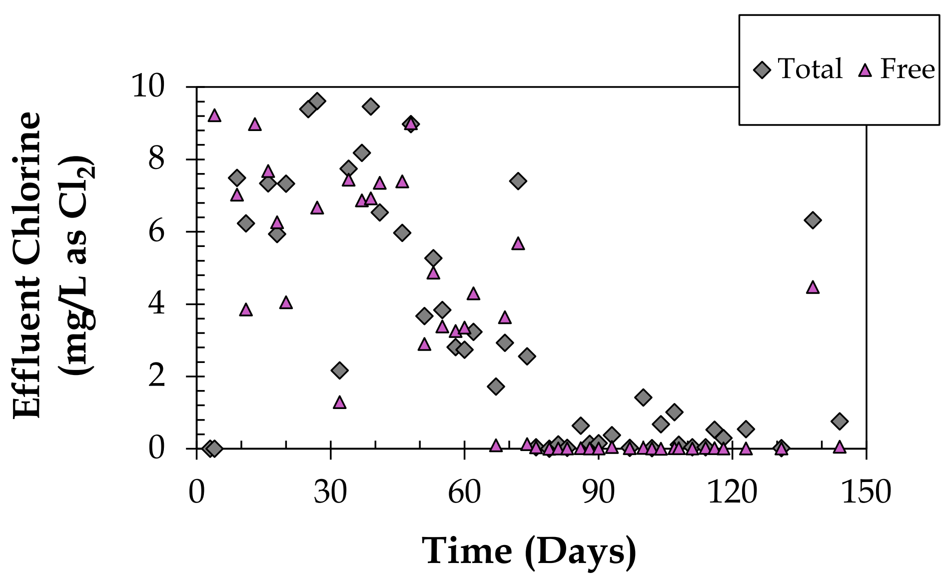

Figure 5-28. Measured values of free and total chlorine over time for treated (effluent) graywater.

While chlorine levels varied extensively in the system effluent, the resultant control of bacteria was still very good in the system. The effluent target levels are only established for E. coli bacteria at < 2.3 cfu/100 mL. Influent values of total coliforms were always very high (> 10,000 cfu/100 ml), and only a few coliforms were detected in the effluent over the 144-day test period, Figure 5-29. *E. coli* bacteria in the influent were intermittently above the influent detection limit of 100 cfu/100 ml but rarely exceeded this level. Only one instance of *E. coli* detection in the effluent occurred, and this was below the target level.

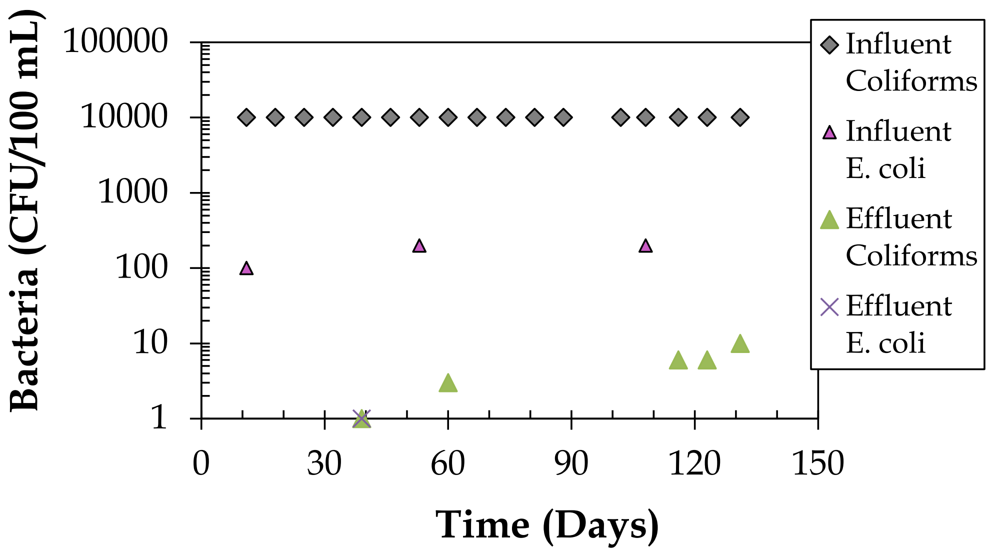

Figure 5-29. Measured values of bacterial concentrations over time for untreated (influent) and treated (effluent) graywater from bathroom sinks.

5.6.3 Building scale graywater reuse system (MCRD)

Water treatment performance of the building scale graywater reuse systems at MCRD was evaluated in terms of removal of chemical, biological, and physical parameters. Results are presented as average values with standard deviations based on six samples collected over a 2-year period. Influent values reflect water quality of samples collected from the graywater storage tank. Effluent values reflect water quality of samples collected from the water storage tank that supplies the toilets. Point-of-use values reflect water samples collected from toilets directly that were cleaned and flushed multiple times before sample collection. Target effluent values based on the NSF350 guidance are presented as a reference (Table 5-14), though this system was installed prior to NSF350 guidance being a requirement.

The data highlights several key issues relating to water reuse for toilet flushing. First, the water quality at point-of-use (in the toilet) is lower than the water supplied to the toilets from the reuse system (effluent), particularly with regard to microbiological contamination. This is a conservative assessment in that the toilets were cleaned and flushed multiple times prior to sampling. The result indicates that treated graywater (effluent) is cleaner than the system (toilet) it is supplying, obviously due to contamination of the system (toilet) during usage. Another issue that is evident from the data is that the chlorine levels are not high enough. Residual chlorine above 1 mg/L is a target for the NSF350 guidance, which is based on the need to maintain residual disinfectant to control pathogens in distribution and at the point of use. The low chlorine levels may be attributable to ammonia reacting with and consuming free chlorine as it is dosed into the treated water, a reaction that is generally referred to as breakpoint chemistry in the water industry. Inadequate hypochlorite dosing could be another factor.

Table 5-14. Target effluent values.

Parameter	Units	Influent	Effluent	Point-of-Use	NSF 350 Effluent Standard
		AVG ± SD	AVG ± SD	AVG ± SD	
COD	mg/L	115.5 ± 40.2	25.7 ± 14.0	12.5 ± 3.6	NA
BOD-5	mg/L	64.0 ± 18.9	2.2 ± 1.4	2.0 ± 1.3	< 10
TOC	mg/L as C	25.0 ± 5.0	2.0 ± 0.1	2.1 ± 0.1	NA
TSS	mg/L	15.0 ± 5.4	0.5 ± 0.0	0.5 ± 0.0	< 10
Turbidity	NTU	80.0 ± 33.8	0.5 ± 0.4	0.3 ± 0.1	< 1
NH3-N	mg/L as N	6.1 ± 2.4	0.1 ± 0.1	0.1 ± 0.2	NA
TKN	mg/L as N	8.6 ± 0.3	0.4 ± 0.1	0.3 ± 0.1	NA
Phosphorus	mg/L as P	2.1 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	NA
Surfactant (MBAS)	mg/L	3.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	NA
Alkalinity	mg/L $CaCO_3$	180.0 ± 25.1	115.0 ± 5.0	122.5 ± 10.9	NA
Free Chlorine	mg/L Cl_2	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.0	1 to 4
Total Chlorine	mg/L Cl_2	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	1 to 4
HPC	cfu/ml	34,000.0 ± 18000.0	39.0 ± 29.0	490.0 ± 140.0	NA
Total Coliforms	MPN/100ml	1,600.0 ± 751.2	3.3 ± 5.5	13.5 ± 16.9	< 10
E. coli	MPN/100ml	23.0 ± 49.4	0.0 ± 0.0	5.8 ± 12.2	< 1
Calcium	mg/L	63.0 ± 1.0	58.0 ± 1.0	58.5 ± 0.5	NA
Magnesium	mg/L	24.0 ± 0.5	22.5 ± 0.5	22.0 ± 0.0	NA
Total Hardness	mg/L $CaCO_3$	260.0 ± 5.0	235.0 ± 5.0	240.0 ± 0.0	NA
pH	SU	7.3 ± 0.3	8.0 ± 0.1	8.0 ± 0.2	6 to 9

While the data in the preceding table indicate that the system is generally working okay, with the exception of the chlorine residual maintenance, further investigations were conducted based on the fact that the effluent water samples were being collected from a tank that could be influenced by makeup water that dilutes any contaminants present in the treatment system effluent. To this end, a series of additional samples were collected immediately downstream of the treatment system (before the effluent storage tank). Initial results indicate that the water quality at this point is poor and out of compliance, and that the treatment system itself is under-designed.

5.6.3.1 Bldg. 573

As previously discussed, Bldg. 573 contained the most operational graywater demonstration unit by the completion of the study. As such, Bldg. 573 was instrumented and observed in accordance with Section 5.5.3. Multiple approaches to instrumenting flow rates were evaluated. First, the team utilized ultrasonic flow recorders, but as previously discussed found flow rates too small to thoroughly separate out noise. The team next used an Arduino-based circuits parasitically connected to the existing metering schema. This approach proved more tolerant to low flows, however it lacked the integrated clocks of more expensive meters. Finally, the team experienced the most success employing commercially available Meter Master M100 flow recorders.

Figure 5-30 shows flow rates for the system as collected. Each time stamp presents three pieces of information: the total building consumption, the amount of recycled graywater, and the amount of makeup water provided to the toilets.

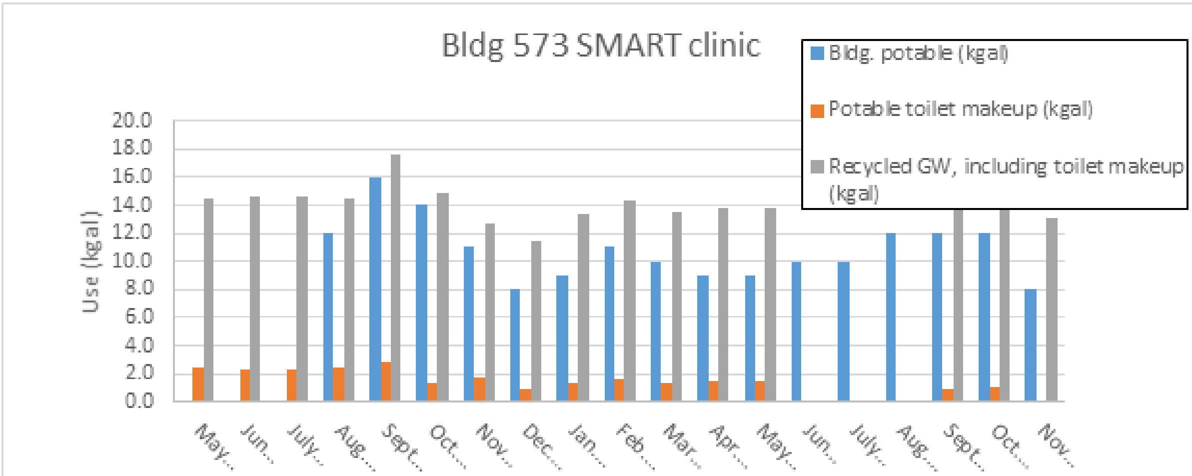

Figure 5-30. Water meter data, Bldg. 573.

The average daily demand for water during this study was 762 gallons, for which toilet consumption represented 468 gallons of flow. Reclaimed graywater was able to displace an average of 420 gallons of toilet flushing, with an average of 48 gallons of potable makeup water provided to the system per day. It should be noted that these numbers are expected to contain inaccuracies due to low meter flow, which may over count the amount of graywater produced.

For the medical barracks in Bldg. 572, the graywater system was not operational enough to save significant water for the majority of the study system. Meter recordings for the building (Figure 5-31) demonstrate a higher daily average consumption of approximately 6,736 gallons per day, of which toilets are estimated to consume 1173 gallons on average. The system was found to be capable of producing enough graywater to provide 90% of this toilet demand, however validation of this is dependent upon system repair.

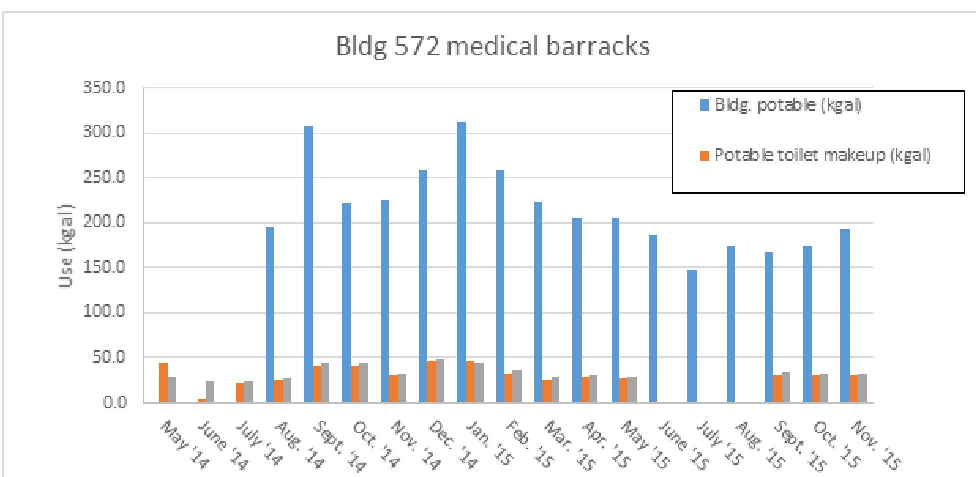

Figure 5-31. Water meter data, Bldg. 572.

5.6.3.2 Bldg. 586

The graywater treatment system at Bldg. 586 was not operational at the commencement of this project, and thus the team was limited to observing water use characteristics to estimate savings potentials. Figure 5-32 shows water consumption for Bldg. 586.

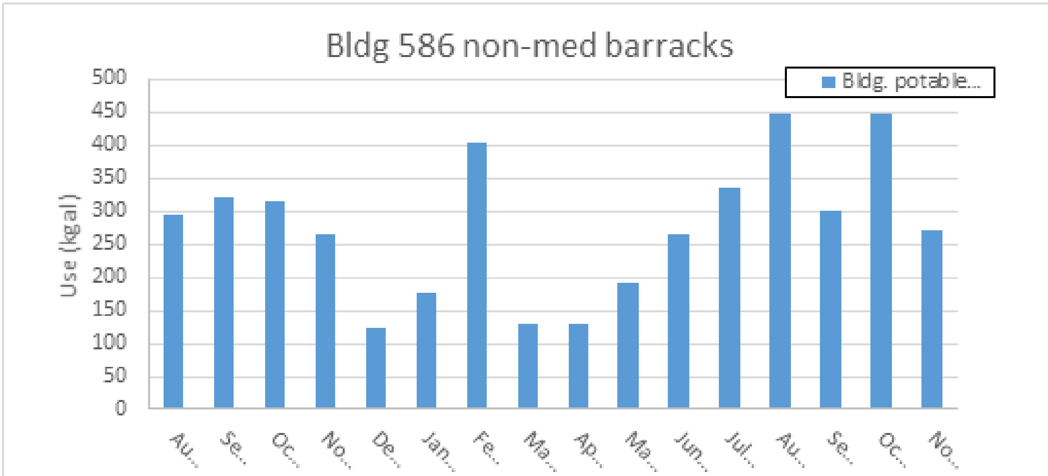

Figure 5-32. Potable water demand, Bldg. 586.

Bldg. 586 presents the largest potential for water savings, consuming an average of 8,458 gallons per day. If average daily toilet demand for Bldg. 586 is similar to that of Bldg. 572, average water consumption for toilet flushing would be approximately 1,500 gallons. Because the graywater system produced only 200 gallons before failing, no potential for savings was observed or realized.

Figure 5-33 compares the monthly water consumption for each building over the study period. Figure 5-34 through Figure 5-36 compare monthly rolled-up water consumption for each facility along with reported occupancy. The water use of plumbing fixtures at the MCRD were documented through performance testing. Further, total building potable water demand was obtained by recording interval meter data. The data indicates that total building water demand correlated well with building occupancy for the two barracks, which can be expected in facilities where major water use is occupancy based. The total water demand of the medical clinic did not correlate as well. It is possible that major water usage of medical devices (whirlpools, etc.) will be the same whether used by a few or many patients.

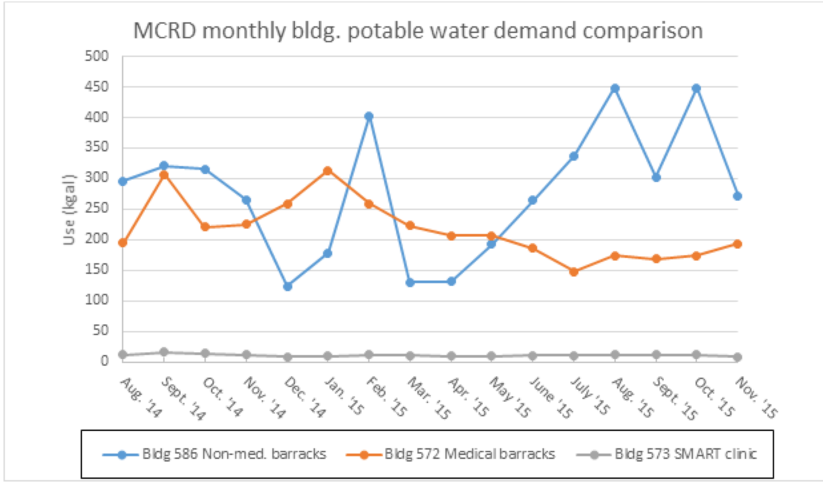

Figure 5-33. MCRD monthly building potable water demand.

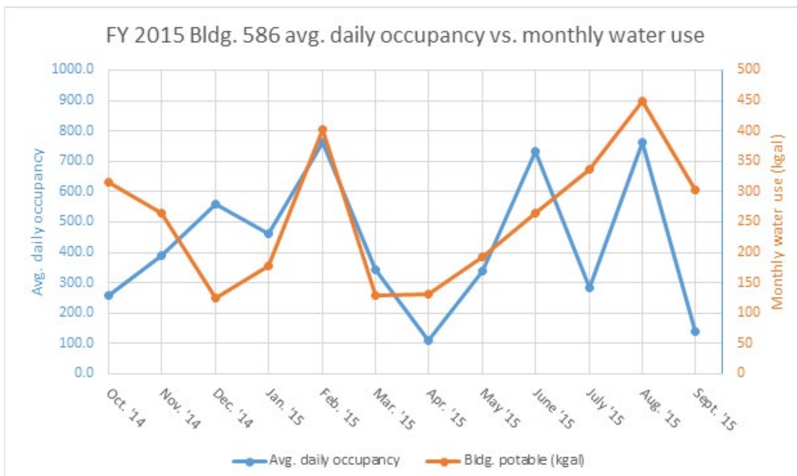

Figure 5-34. Average daily occupancy vs. monthly water use, Bldg. 586.

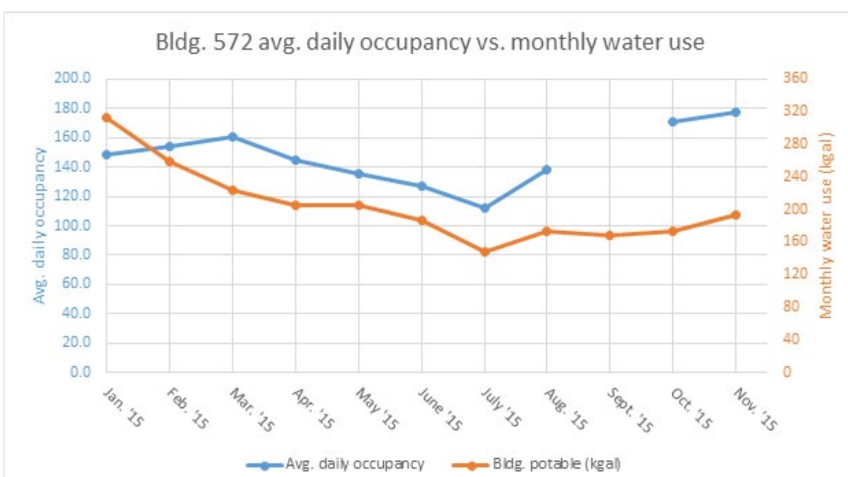

Figure 5-35. Average daily occupancy vs. monthly water use, Bldg. 572.

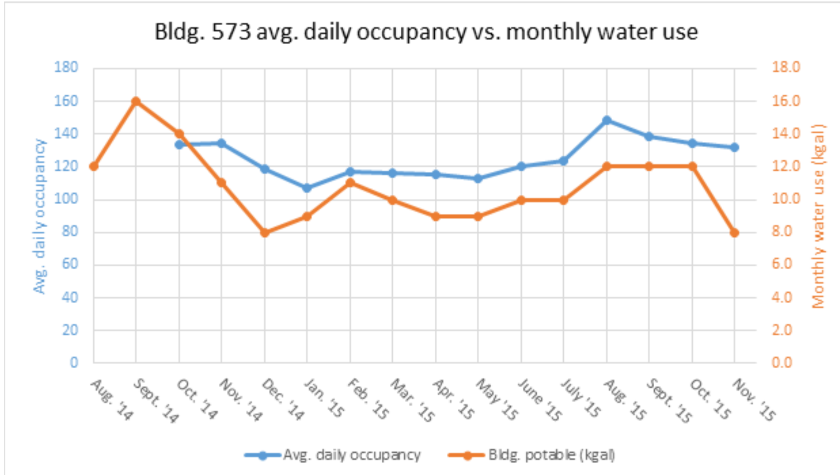

Figure 5-36. Average daily occupancy vs. monthly water use, Bldg. 573.

5.6.3.3 Graywater system continuous energy data

Voltage meters were installed on the electrical panel of the graywater treatment systems in Bldgs 572 and 573. Data is shown in Figure 5-37. Because the system installed for Bldg. 572 did not remain operational throughout the study period, energy consumption of this system is significantly lower than that of the system installed for Bldg. 573. For the system installed for facility 572, a significant corresponding decrease in energy consumption is observed in December of 2015, likely because of changes to operational status. For Bldg. 573, the system consumed an average of 54.8 kWh per day over the study period.

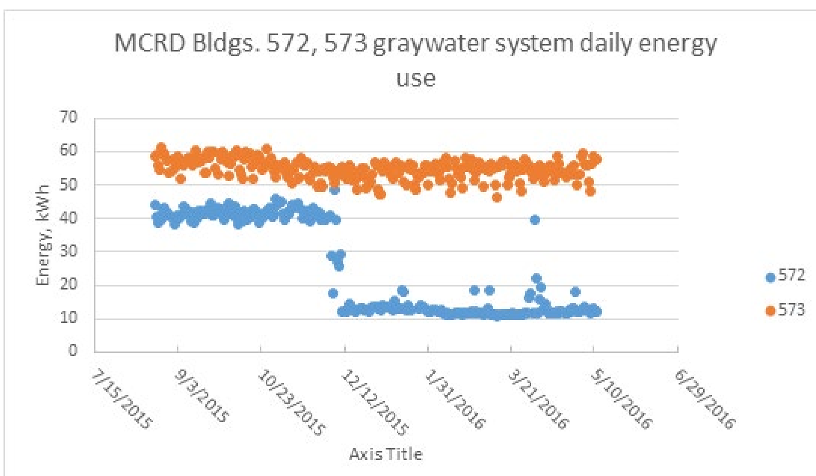

Figure 5-37. Energy use of graywater systems, Bldg. 572 and 573.

5.6.3.4 Facility personnel feedback

A user satisfaction survey was administered to MCRD personnel in November 2016 (Hatcher 2016). The survey audience was limited to Public Works employees due to the nature of the building occupants, basic trainees, being inaccessible to the project team. The following answers pertain to the survey instrument contained at Appendix H.

1. Satisfaction with the MCRD graywater systems on a scale of 1 to 5: FAIL (no number given): Lack of maintenance by dedicated mechanical staff (more given later)
2. Public Works staff understanding of the graywater systems on a scale of 1 to 5: (2)- Actually seemed to have much better understanding than he gave himself credit for
3. Issues encountered, e.g. O&M, manufacturer, etc.: Float sensors; no bypass into sewer avoiding the collection tank; working equipment in the tank must take down entire building and pump dry then secure for several days due to lack of bypass straight to sewer
4. Ease to perform maintenance and repair on a scale of 1 to 5: n/a- no dedicated staff provided. With the exception of the lack of bypass it should be relatively easy, but due to lack of bypass simple repairs to the float sensors (the primary area of failure) become excessively expensive
5. Interval that systems required maintenance and repair: weekly by plan, but can shift to monthly/quarterly if filters look okay. The primary work which has been done is replacing sensors in the tanks.
6. Whether MCRD staff can address maintenance issues: One year warranty, not used. Company does not take credit card and wants payment through PayPal, "nightmare," go through 3rd party. With proper training and resource allocations, yes. However, no dedicated staff provided.
7. How long systems operated before going off-line: Bldg 586 lasted for 20 gallons. Bldg 572 online since January 2012 through early this year.
8. Filter cleaning interval: Once a week, can be adjusted if see condition has not changed much
9. Performance of graywater systems on a scale of 1 to 5: See (1)
10. Whether a drop in potable water use has been noticed (for Bldg 573): Pretty steady, except for training cycles (most changes can be attributed to that)
11. Whether the graywater system is considered cost effective: No
12. Whether any comments from others on base about the graywater system: No, after the initial install people don't know they are here except for the blue in the water
13. Whether the irrigation system add-on to the graywater system is used: No, just makeup water
14. Whether system documentation is adequate: Yes
15. Satisfaction with graywater system data collection on a scale of 1 to 5: (4): can see what need to see at any time, however nobody is responsible for water and black water except for irrigation
16. Satisfaction with graywater system controls on a scale of 1 to 5: Unanswered- My interpretation is that the system isn't being actively controlled. CERL team members were able to accomplish everything we needed through the user interface with no training.
17. Lessons learned or comments: Bypass straight to the sewer so that you can maintain and isolate the tank; Can only store water 24 hours, a lot of what you treat gets wasted; should be lined up with maintenance ahead of time, cannot be the regular plumbed; need regular training; need extended warranties, can pay upfront as NAVFAC already holds contingency- take some of contingency as operations and maintenance expenses and create a service contract

18. Recommendations for others interested in graywater systems: Extended warranty and operations and maintenance contracts unless have specialists on staff
19. Whether to recommend graywater systems to other installations: Yes, like the concept. Thinks Bldg 586 will work, but need accurate data for estimating the amount of water which can be saved.

6.0 SYSTEM PERFORMANCE ASSESSMENT

6.1 Water Fixture Retrofits Performance Assessment

The increased flow efficiency of the water fixture retrofits resulted in potable water savings. Adjusting the metering faucets for the correct running time and the toilet sensors for sensitivity and length of flush also contributed to savings. Additional water savings could be realized with the retrofit/replacement of toilets and urinals. A total of 138,693 gallons of potable water are estimated to be saved during a year of operation with the retrofits as executed, with a total of 1,277,121 gal/year potentially saved including toilet/urinal retrofits. This represents a water cost savings of $1,386.93 for accomplished retrofits and $12,771.21 including toilets/urinals at the demonstration site. Sections 4.1 and 5.1 contain information on how these values were obtained.

6.1.1 Potable water savings

The water fixture retrofits reduced building water demand by 7%, with an additional 7% savings by adjusting toilet automatic flush valves, for a total reduction of 14%.* Savings were limited because plumbing fixtures represent only part of the facilities' water load, which includes some water-intensive research uses. Greater water savings would be expected in many other building types where restrooms dominate building water demand. The demonstration results were modeled using algorithms contained in the MICA: WET water audit tool, as described in 5.2.1.4, due to insufficient low-flow accuracy of the building water meters. The data in Table 6-1 shows a breakout of potable water savings within the CERL demonstration buildings as modeled.

Table 6-1. CERL facilities plumbing fixture potable water and cost savings.

End Use	Gal/day Savings	Days/yr	Gal/yr savings	Cost/Kgal	Annual Cost Savings
Building 1 Total	230	365	83,950	$10	$839.50
toilets & urinals*	907	365	331,055	$10	$3,310.55
Building 2Total	202	365	73,730	$10	$737.30
toilets & urinals*	557	365	203,305	$10	$2,033.05
Building 3 Total	125	365	45,625	$10	$456.25
toilets & urinals*	3,665	365	1,337,725	$10	$13,377.25
3 Building Total			**203,305**		**$2,033.05**
toilet/urinal total*			1,872,085		$18,720.85

* The CERL site would achieve a 47.2% reduction with fixture retrofits, toilets, and urinals. Implementation of waterless urinals and under-sink scale graywater reuse system would save water by 51.3%.

6.1.2 Facility energy savings*

A reduction in potable water demand results in a reduction in energy demand. For the plumbing fixtures, energy savings are realized through reduced demand of hot water, hence lower water heating energy. These calculations assumed a 249 day work year, though the labs are in use on weekends and holidays by a handful of personnel.

For the gas water heater at the CERL demonstration site, the retrofit showerhead model with a flow rate of 2 gpm uses 80% of the heating energy of the old 2.5 gpm model. At the local gas rate of $0.69/therm this represents a savings of 143 therms or $74 per year for 12 showerheads.

The retrofit faucet with a flow rate of 0.5 gpm uses 33.3% of the heating energy of the old 1.5 gpm model. This represents a savings of 515 therms or $355 per year for 20 faucets.

The total energy savings for 12 showerheads and 20 faucets is 658 therms/year and $429/year.

6.1.3 Greenhouse gas emissions†

The reduction in greenhouse gas emissions due to plumbing fixture retrofit is realized through reduced demand for hot water, and thereby reducing emissions from water heating source energy. The effects can be calculated using the following equation:

$$\frac{0.1\,mmbtu}{1\,therm} \times \frac{14.46\,kg\,C}{1\,mmbtu} \times \frac{44\,kg\,CO_2}{12\,kg\,C} \times \frac{1\,metric\,ton}{1{,}000\,kg} = 0.0053\,metric\,tons\,CO_2/therm$$

The total avoided carbon for the CERL plumbing retrofits is 7.816 tons-carbon/year, with 151 lb-carbon/year from retrofit faucets and 1051 lb-carbon/year from retrofit showerheads.

6.1.4 User satisfaction

No user complaints were received about the plumbing retrofits throughout the project performance period. Complaints were received about the baseline condition for this study, primarily relating to the seemingly random nature of toilet flushing due to the sensors/automated flush valves prior to adjustment by the research team.

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* Energy Cost Calculator for Faucets and Showerheads, Department of Energy, Office of Energy Efficiency and Renewables, https://energy.gov/eere/femp/energy-cost-calculator-faucets-and-showerheads

† Greenhouse Gases Equivalencies Calculator, US Environmental Protection Agency, https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references

6.2 Under-sink graywater reuse system

The under-sink graywater reuse system provides treated product water to reduce potable water demand for toilet flushing. With the system, a total of 13,500 gallons of potable water are estimated to be saved per year, assuming 300 days of operation during a year.

6.2.1 Potable water savings

Based on the data collected during the demonstration phase of this study, CERL achieved under 9% reduction in total building potable water demand with the under-sink graywater reuse system. The system could not meet the success criteria of 30% reduction from pre-retrofit due to significant volume loss (overflow to waste) caused by the sump pump system. Table 6-2 shows potable water savings within the men's bathroom in building 3 where the under-sink graywater reuse system was demonstrated.

Table 6-2. CERL under-sink graywater reuse system potable water and cost savings

End Use	Gal/day Savings	Days/yr	Gal/year Savings	Water Cost/Kgal	Annual Cost Savings
Under-sink graywater reuse system	45	300	13,500	$10	$135.00

6.2.2 Facility energy savings

There was no baseline to compare energy savings for the system. Based on previous measurement from lab validation studies, the under-sink graywater reuse system would consume 50 Wh/gal.

6.2.3 Greenhouse gas emissions

There was no baseline to compare greenhouse gas offset by the system during the project performance period.

6.2.4 User satisfaction

No user complaints were received during the demonstration period. Also, there were no significant disruptions to bathroom operations.

6.3 Building scale graywater reuse system

The building scale graywater reuse system installed at MCRD provides reduction in building potable water demand by supplying product water for toilet flushing. Unfortunately, one out of three systems was fully operational during the demonstration period.

6.3.1 Potable water savings

Bldg. 573 achieved 90% reduction in toilet water demand and 55% reduction in building potable water demand. In contrast to the atypical water end use in Bldg. 573, the SMART Clinic, a typical barrack like Bldg. 572 would achieve 16% reduction in total building potable water demand if the system was in operation as designed. These values were obtained based on metered data, with 17.4% of total building water demand for toilet water flushing and 90% of recycled graywater for toilet flushing[*]. The data in Table 6-3 shows actual and potential potable water savings within the MCRD building scale graywater reuse systems.

Table 6-3. MCRD facilities potable water and cost savings using graywater reuse systems.

End Use	Gal/day Savings	Days/yr	Gal/year Savings	Water Cost/Kgal	Annual Cost Savings
Bldg.586 Graywater System	1,324*	365	483,260	$10.53	$5,088.73
Bldg.572 Graywater System	1,053*	365	384,345	$10.53	$4,047.15
Bldg.573 Graywater System	420	365	153,300	$10.53	$1,614.25

6.3.2 Facility energy savings

There was no baseline to compare energy savings for the building scale graywater reuse system. Based on measurements during the demonstration period, the system consumed 100 Wh/gal.

6.3.3 Greenhouse gas emissions

There was no baseline to compare greenhouse gas offset or targeted threshold values of the system during the demonstration period.

6.3.4 User satisfaction

The user responsible for the contractor-furnished treatment system at MCRD expressed general dissatisfaction with the system as implemented. In particular, the system was deemed too expensive to maintain due to the lack of flow bypass valves on the retention tanks. The lack of bypass requires shutting down all building operations for even minor fixes (for example, to replace float sensors), which this study has deemed infeasible for any designs to be adopted by the Army.

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[*] Estimated values based on building 573 graywater system, which was fully operational during the demonstration period.

7.0 ECONOMIC ANALYSIS

Several cost models are presented here, each referring to different elements of this project: water fixture retrofits, an under-sink graywater system, and a building scale graywater system.

7.1 COST ELEMENTS

7.1.1 Water fixture retrofits

Table 7-1 lists the cost elements for implementing low flow faucet aerators and showerheads. The cost elements are as follows:

1. *Fixture cost*. This refers to the off-the-shelf cost of the water fixtures, which was $5/aerator and $40/showerhead.

2. *Installation cost*. This refers to the cost of a plumber/building maintenance person to install the fixtures. The cost scales with the number of retrofits. The average cost of a plumber per hour is $100, and it takes approximately 5-10 minutes to install a retrofit.

3. *Facility operational costs*. This refers to how much water is saved using water saving fixtures. Additionally, energy is saved because less water use means less electricity or natural gas to generate hot water. The water and energy savings scale with the number of fixtures and how frequently the fixtures are used. The cost of water is $10/kgal. Faucet water use for this study was based on the following assumptions: existing faucet flow of 1.27 GPM, replacement faucet flow of 0.5 GPM, faucet use of 16 minutes/day over 249 days/year based on each occupant washing hands for 16 seconds, four times a day. This produces annual water savings of 3,067 gallons, annual natural gas savings of 399 therms, and annual cost savings of $401.34. Lifetime cost savings for the faucet retrofit are $4,013.40 based on a 10-year expected life for this technology.

   Showerhead water use for this study was based on the following assumptions: existing showerhead flow of 2.5 GPM, replacement showerhead flow of 2.0 GPM, showerhead use of 50 minutes/day over 249 days/year based on each user showering for 5 minutes/day. Shower use varies and this is a conservative estimate; use is likely higher during mild weather when more occupants exercise outside of the site's fitness center. This produces annual water savings of 6,225 gallons, annual natural gas savings of 809 therms, and annual cost savings of $815. Lifetime cost savings for the showerhead retrofit are $7,523.34 based on a 10-year expected life for this technology.

   Total water savings for these retrofits are 9.292 kgal/year for a cost savings of $93.25/year, with lifetime savings of 92.920 kgal and $929.20 over a 10 year time period. Total energy savings for both retrofits are 1,208 therms/year for a cost savings of $1,123.01, with lifetime savings of 12,080 therms and $11,230.10 over a 10 year time period. Total lifetime water and energy cost savings are $12,159.30 for a 10 year time period.

   It should be noted that faucet and shower retrofits do not have much, if any, maintenance needs past the initial installation, so maintenance cost is assumed negligible.

Table 7-1. Cost model for water fixture retrofits.

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Fixture cost	Cost to buy water fixture retrofits for faucet aerators and low-flow showerheads.	$5 per aerator, $40 per showerhead
Installation cost	Labor required to install these retrofits.	Plumber fee of $100/hr., ~5-10 min. for each retrofit
Facility operational costs	Water & sewer savings ($10/kgal) Natural gas savings ($0.93/therm)	9.292 kgal/year reduction @ $93.25 savings/year 1208 therms reduction @ $1,123 savings/year

Table 7-2 lists the cost estimates for waterless urinals. The cost elements are as follows:

1. Fixture cost: This refers to the off-the-shelf cost to buy a waterless urinal. The waterless urinals bought in this study cost $250.
2. Installation cost: This refers to the cost for a plumber/building maintenance person to install a waterless urinal. The cost scales with the number of retrofits. The average cost of a plumber per hour is $100, and it takes approximately 1 hour to install a retrofit. Installing a waterless urinal also requires certain existing facility features, such as waterless urinals cannot drain to copper pipes, otherwise the pipes corrode. If a facility requires substantial rework to accommodate a waterless urinal, the costs could exceed the water-saving benefits of using the fixture.
3. Consumables: The key part of a waterless urinal is a cartridge containing chemicals and sealant that has to be replaced approximately every 7,000 uses. These cartridges cost approximately $40 each. Assuming a building male population of 33 and a urinal use of 3 times per day for 2 urinals. This equates to a single urinal being used ~50 times per work day, requiring a cartridge change approximately twice per year.
4. Facility operational costs: This refers to how much water is saved using the waterless urinal. The cost of water scales with the number of fixtures and how frequently the fixtures are used. The cost of water is $10/kgal. Again assuming a single urinal use of ~50 times per work day at a flush rate of 0.6 GPM (averaging 1 GPF and 0.125 GPF urinals), this equates to 30 gal per day that would be saved if a waterless urinal was used instead.
5. Maintenance: This refers to the labor cost for maintaining the waterless urinal. The required maintenance for a waterless urinal is to replace a cartridge every 7,000 uses.
6. Hardware lifetime: 20 years of lifespan of urinal is assumed based on expected lifetimes of the components.
7. Operator training: Cleaning personnel have to be trained to properly clean the urinal and dispose of the cartridge. This is an initial cost. The average janitor salary is $11 per hour, and the training time is estimated at a half hour. There is no formal training required for someone to use a waterless urinal. However, signs must be placed near the urinal for people to prevent pouring foreign liquids in the urinal, such as coffee. This can ruin the cartridge, requiring cartridge replacements to occur more frequently.

Table 7-2. Cost model for waterless urinals.

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Fixture cost	Cost to buy 1 waterless urinal.	$250
Installation cost	Labor and material required to install waterless urinal. This estimate does not include facility work needed to accommodate the urinal. If significant work is needed, the benefit of a waterless urinal would likely not exceed the work required.	Plumber fee of $100/hr., ~1 hour per waterless urinal
Consumables	Cost to buy cartridges.	~$40 per cartridge; these are replaced every 7,000 uses
Facility operational costs	Water & sewer savings ($10/kgal)	30 gal reduction in water For $3.65 savings/year
Maintenance	Frequency and amount of maintenance required.	Janitor fee of $11/hr., ~30 min. to replace cartridge every 7,000 uses
Hardware lifetime	Sustained performance.	20 years (assumed)
Operator training	Estimate of costs to train janitors to properly clean urinal and dispose of cartridge.	Janitor fee of $11/hr., ~30 min. for cleaning training

Table 7-3 lists the cost elements for the shave stand. The cost elements are as follows:

1. *Fixture cost*. This refers to the off-the-shelf cost of the water fixtures that have capability to clean razors effectively, which was $8/fixture.
2. *Installation cost*. This refers to the labor for installing the fixtures.
3. *Facility operational cost*. This refers to how much water is saved using the water fixtures. Energy is also saved because less water use means less heating energy needed to make the water warm. The cost of water and energy scales with the number of fixtures and how frequently the fixtures are used. The average cost of water is $10/kgal in this study. The fixtures are rated as 0.9 GPM at 32 psi for main flow and 0.125 GPM at 32 psi for razor with high flow velocity.

Table 7-3. Cost model for shave stands.

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Fixture cost	Cost to buy water fixture retrofits for shaving	$8 per fixture

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Installation cost	This refers to the cost of a plumber/building maintenance person to install the fixtures. The cost scales with the number of retrofits.	Plumber fee of $100/hr., ~5-10 min. for each retrofit
Facility operational costs	Water & sewer savings ($10/kgal) Natural gas savings ($0.93/therm)	Prototype technology uses 40% less water than conventional faucet currently used for shaving

7.1.2 Under-sink graywater reuse system

Table 7-4 lists the cost elements for the under-sink water reuse system. The cost elements are:

1. *Hardware Cost*: $928.94, based on following costs for one-off assembly. Costs would be expected to decrease with production scale up and use of more efficient manufacturing processes and materials.

Item	Unit	Unit Cost	Qty	Cost
Unistrut Framing	lf	$2.20	22	$48.40
Unistrut Fittings	ea	$1.80	10	$18.00
Water Storage Tank (18" cube)	ea	$34.78	1	$34.78
Biofilter Housing & Lid	ea	$25.49	1	$25.49
Activated Carbon	kg	$8.40	5	$42.00
PVC pipe (3/4")	lf	$0.41	30	$12.30
PVC fittings (3/4")	ea	$0.92	30	$27.60
PVC pipe (2")	lf	$0.68	10	$6.80
PVC fittings (2")	ea	$2.44	10	$24.40
Chlorinator	ea	$9.50	1	$9.50
Demand Pump	ea	$82.49	1	$82.49
Waste Valve	ea	$54.68	1	$54.68
Ultrafilter Housing	ea	$29.64	1	$29.64
Ultrafilter Membrane	ea	$32.22	1	$32.22
Pressure Tank	ea	$48.01	1	$48.01
Power Controller Timer	ea	$108.63	1	$108.63
Assembly	MH	$54.00	6	$324.00

2. *Installation Costs:* $348, based on 6 man-hours at a burdened cost of $58.00 per hour for a plumber. Amount of time is based on observation of system installation in a bathroom setting. However, this installation was in an off-line capacity, which included two additional sump pumps and extra drain lines, but did not include connections to the toilets.

3. *Consumables:* Consumable costs were measured based on field observations, component specifications, and chemical consumption rates. The main consumables are the hypochlorite tablets and the ultrafiltration membranes.

4. *Operational Costs/Savings:* The primary facility costs and savings are for electricity consumption and water savings, respectively. The energy consumption measured during the demonstration was higher than expected (100 Wh/gal or more) due to a float switch fault resulting in longer pump run times. As such, a previous measurement from lab validation studies of 50 Wh/gal was used for the LCCA. Water savings were estimated to be up to 45 gpd for the system, based on laboratory recovery data, the system capacity of 50 gpd, and the bathroom sink usage rates.

5. *Maintenance:* The maintenance required for the system is to add chemicals (hypochlorite tablets) once every 2 months.

6. *Lifetime:* A system lifetime of 10 years was assumed, based on expected lifetimes of the components and other water systems.

7. *Operator training:* A 30 minute training (or review of the instruction manual) would be sufficient for orienting a worker on system operation and maintenance.

Table 7-4. Cost model for under-sink graywater reuse system.

Cost Element	Data Tracked During the Demonstration	Estimated Value
Hardware capital costs	Unit material costs and assembly	$928.94
Installation costs	System integration with sink decks (off-line)	$348
Consumables	Hypochlorite usage rate Membrane replacement (projected)	$2.77/yr $16.11/yr
Facility operational costs/savings	Energy consumption (100 Wh/gal) Water Savings (up to 45 gpd @ $10/kgal)	$73.00 cost/yr $164.25 saved/yr
Maintenance	Time for chemical addition	$38.00/yr
Hardware lifetime	Sustained performance, component specifications	10 years
Operator training	Estimated 15 minutes/yr	$16/yr

7.1.3 Building scale graywater reuse system

Table 7-5 lists the cost elements for the building scale graywater reuse system. The cost elements are as follows:

1. *Equipment cost*: This refers to the price of a building scale graywater system, including water storage tanks, for a facility similar to a training barracks. For the MCRD, installation of the graywater system was part of a larger project, and thus no explicit bill existed for the system by itself. It was estimated by the contractor who built the system that the cost of the graywater system by itself was about $291,900 for the three buildings, or approximately $97,300 per building. The general cost for a building scale graywater system would likely vary depending on a building's layout, the extent of piping needed, and the supplying company used.

2. *Installation costs*: This refers to the cost of materials and labor to install a building scale graywater system. For the MCRD, installation cost was estimated by the contractor who built the system since no explicit bill existed for the system by itself. The estimated system installation cost was about the same as fixture cost of $97,300 per building. Similar to the fixture cost, the general cost to install a building scale graywater system would likely vary depending on a building's layout, the extent of piping needed, and the contracting company used.
3. *Consumables*: This cost refers to purchase of consumables during system operations. For the system installed in MCRD, chlorine tablet (or briquettes) must be added to the automatic chlorinator hopper once per week or once per month depending on the overall load on the system. The estimated cost for consumable is $10 per month per 1,000 gpd of graywater system treatment capacity.
4. *Facility operational costs*: This refers to how much electricity is used to operate the graywater system. In most cases, energy consumption is mainly driven by the pumps associated with the building scale graywater system. For the MCRD, daily average energy use was 54.8 kWh at utility cost of $0.0778/kWh in San Diego, CA.
5. *Maintenance*: This refers to the labor cost for maintaining the building scale graywater system. Recommended system maintenance occurs at three different frequencies. These activities are: consumable (i.e., Chlorine briquettes) by a plumber (1 hour per month); system inspection, UF replacement, and manual cleaning by a plumber (8-12 hours per year); and, system inspection and performance test by a plumber (8 hours per year).
6. *Hardware lifetime*: This refers to the material cost of the system hardware. Two UF membranes are suggested to be replaced within the life-time of the hardware (once every 5-7 years).
7. *Operator training*: This cost includes operations training, manuals, engineering assistance, and 1-year system warranty.

Table 7-5. Cost model for building scale graywater reuse system study.

Cost Element	**Data Tracked During the Demonstration**	**Estimated Costs**
Fixture cost	Approximate cost to buy a building scale graywater system for 1 building	$97,300
Installation costs	Approximate cost to install a building scale graywater system (i.e., plumbing materials and labors) for 1 building	$97,300
Consumables	Cost to buy chlorine briquettes (once a week or once a month)	$10/month per kgpd $1,556.2 per year
Facility operational costs/savings	Energy consumption (54.8 kWh/day @ $0.0778/kWh) Water Savings (up to 1324 gpd @ $10.53/kgal)	$1,556.20 cost per year $5,090 saved per year

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Maintenance	Mainly labor cost ($55/hour): add consumables: plumber, 1 hour once per month system inspection, UF replacement, and manual cleaning: plumber, 4 hours 2-3 times per year system inspection and performance test: plumber, 8 hours once per year	$1,760 per year
Hardware lifetime	Replacement of two UFs every 5-7 years	$480 per UF membrane
Operator training	Cost of operations training, manuals, and 1-year system warranty	$10,815

7.2 COST DRIVERS

7.2.1 Water fixture retrofits

The main cost driver for water fixture retrofits is the cost of water in the region. A higher cost means more money saved using low flow water fixtures. At $10/kgal combined water and wastewater treatment rate, costs were relatively high at the demonstration site and this technology achieved a simple payback of less than four months. Expected payback periods and annual water cost savings for a range of rates are shown in Figure 7-1. Other drivers include the cost of energy, which is usually sufficient to provide a quick payback for fixtures that use hot water. The capacity of the waste water treatment plant can also drive water conservation as the cost to expand the plant, for example to accommodate waste water generated by newly constructed facilities, will exceed the investment in simple water conservation measures. An additional related drive is the age of the facility being retrofit. An older facility with greater baseline flow rates will see a greater amount of water being saved and hence a smaller water bill.

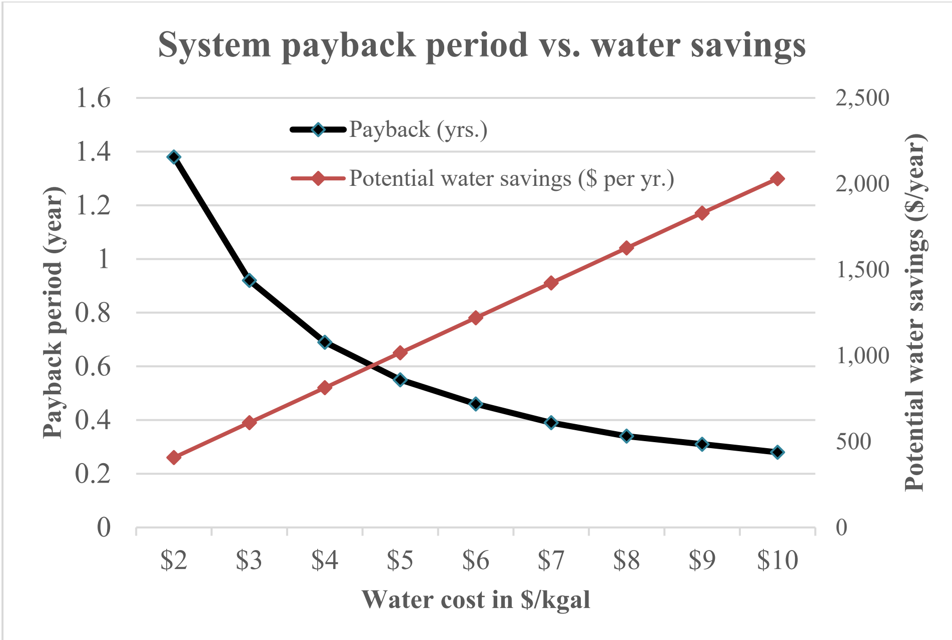

Figure 7-1. System payback period and potential water savings for water fixtures.

Waterless urinals have facility requirements that may require additional work for implementation, such as ensuring waste pipes are not made of copper. The amount of necessary work[*] may outweigh any water-saving benefits of having a waterless urinal.

7.2.2 Under-sink graywater reuse system

Given that the volume of water reuse will be limited to the number of bathroom users and system capacity, the key variable cost drivers for the under-sink water reuse system are water and wastewater treatment costs and the capital cost of the system, including installation costs. Figures 7-2 and 7-3 show the payback period versus each of these variables for several scenarios. Water cost includes potable water supply plus wastewater treatment for that supply. Capital cost includes equipment plus installation. The analysis underlying Figure 7-2 assumes a capital cost of $1,276.94, a relative water escalation rate of 2%, and water recovery of 90% (45 gpd) for 300 days per year. The analysis underlying Figure 7-3 assumes a present day water cost (potable supply plus wastewater treatment) of $10.00 per 1000 gallons, a relative water escalation rate of 2%, and water recovery of 90% (45 gpd) for 300 days per year.

[*] Urinal change-out may result in different mounting requirements, requiring trade groups such as masonry.

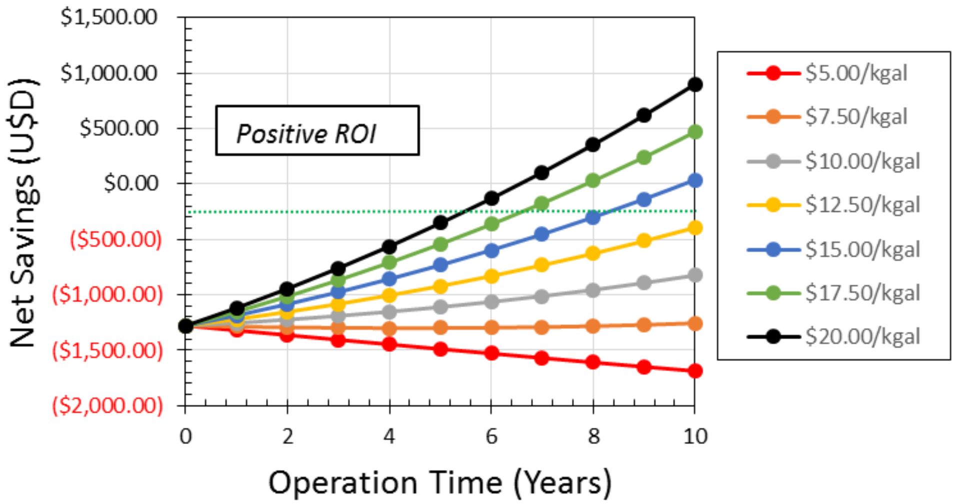

Figure 7-2. Effect of water cost on ROI for under-sink graywater reuse system.

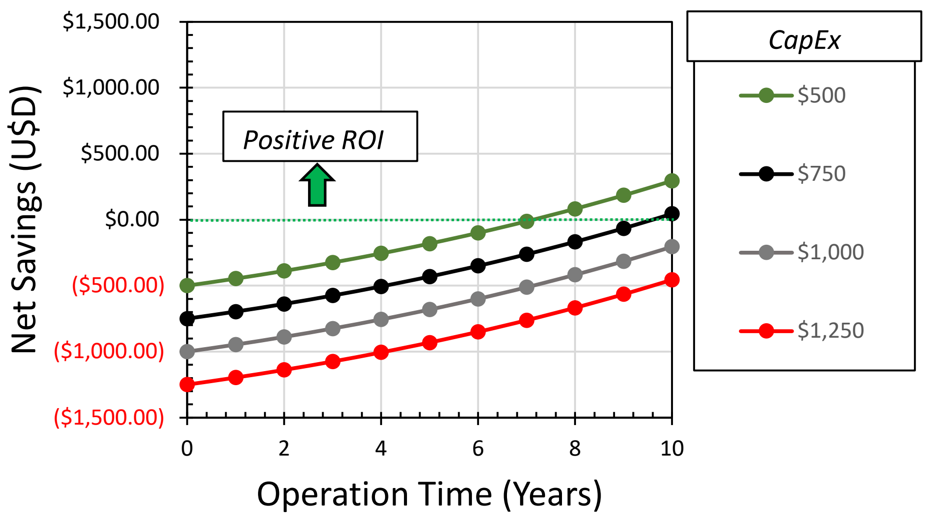

Figure 7-3. Effect of capital expenditures (CapEx) on ROI for under-sink graywater reuse system.

7.2.3 Building scale graywater reuse system

Sensitivity analysis was performed to determine the cost drivers for the building scale graywater reuse system. Uncertain parameters (water cost, % graywater reuse, capital cost, maintenance cost, electricity cost, replacement cost, training cost, and consumable cost) are differentiated from baseline values of life cycle cost model. Due to lack of information about ranges of uncertain parameters, conservative values (+15%, -15%) were selected and prioritized in terms of percent change of system payback period from baseline result (Figure 7-4).

One of the major cost drivers for the building scale graywater reuse system was the cost of water in the region. A higher relative cost of water would result in greater water cost savings and shorter payback periods. Another key driver was the percent of total building water demand that could be met with reuse. Increasing the fraction of reuse water to support a wider range of demands (i.e., toilet, laundry, and shower) would result in a better payback period, assuming other parameters are held approximately constant. One thing to note is that both variables mentioned above have even greater impacts on system payback period when the parameters have proportionally lower values than baseline. This implies that the system may not be appropriate in some regions where cost of water is cheap and water reuse opportunities are more restricted. The third cost driver for the system is capital cost which includes system and installation costs. As expected, increase in capital cost leads to longer system payback period, whereas low payback period can be achieved by technology developments. Other parameters had relatively limited impact on payback period when adjusted by 15% in either direction.

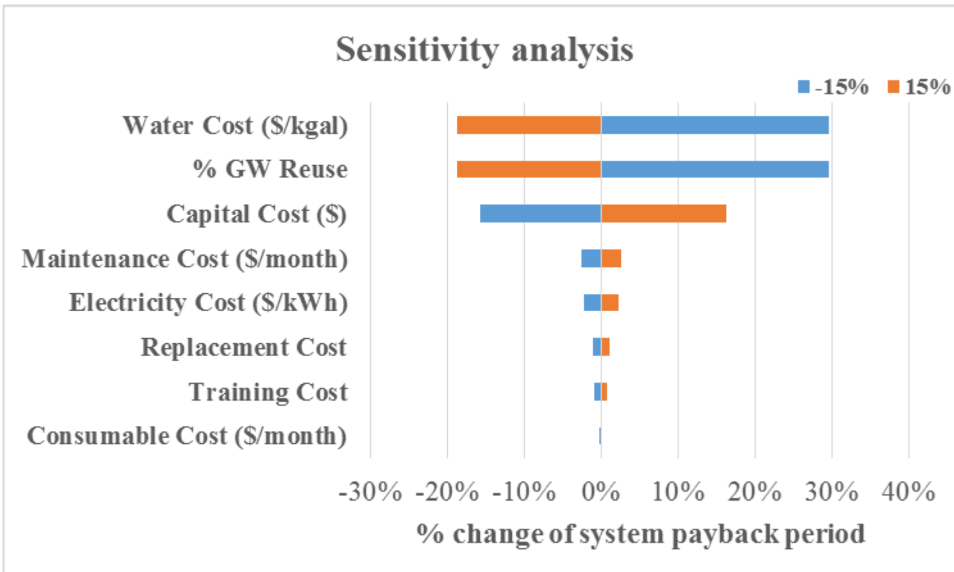

Figure 7-4. Sensitivity analysis of the building scale graywater reuse system.

7.3 COST ANALYSIS AND COMPARISON

7.3.1 Water fixture retrofits

The analysis presented below uses CERL as the site location to compare water use without retrofits to water use with retrofits. This allows for using actual measured pre-retrofit flow rates for comparison to retrofit flow rates. The retrofits that are considered in this analysis are 0.5 GPM bathroom faucet aerators and 2.0 GPM showerheads. In calculating the following costs, information is used from the CERL water model (5.2.1.4), the cost element information (Table 7-1), and pre-retrofit flow rates (Appendix C). The time frame is over a 10-year period and uses the local water cost of $6.52 per 1000 gallons. The comparison data is shown below in Table 7-6.

Table 7-6. Comparison of water use costs for both with and without retrofits for CERL.

Cost	No retrofit	With retrofit
Fixture cost - one-time cost	—	$470.00
Installation cost - one-time cost	—	$362.50

Cost	No retrofit	With retrofit
Facility operational costs over 10 years - bathroom sink and shower use only	$9,611.64	$5,954.05
Total cost	$9,611.64	$6,786.55

Over 10 years, these retrofits result in a savings of $2,825.09 for CERL. Including the wastewater treatment cost of $3.97/kgal increases the 10 year savings to $5,052.17. This savings will be greater for areas of the country where water costs are higher.

The waterless urinal economic analysis was performed to compare water use without retrofits to water use with retrofits (Table 7-7). The retrofit that is considered in this analysis is 2.08 gpm urinal that flushes 39 seconds per day. In calculating the following costs, information is used from the CERL water model and the cost element information shown in Table 7-2. A 10-year time frame is used with a local water and wastewater treatment rate of $10.00/kgal.

Table 7-7. Cost comparison for the waterless urinal retrofit at CERL.

Cost	No retrofit	With retrofit
Fixture cost - one-time cost	—	$2,250
Installation cost - one-time cost	—	$905.5
Consumable costs over 10 years – cartridge replacement	—	$1,800
Maintenance costs over 10 years – labor	—	$833.09
Facility operational costs over 10 years	$3,044.23	$305.42
Total cost	$3,044.23	$6,094.01

The results show that the retrofit cost exceeds the non-retrofit cost by more than $3,050 over the 10 year analysis period. This is due to the high first cost of installation and the relatively high cost of urinal cartridge replacement. However, this technology achieves a 90 percent reduction in facility operational costs, therefore, a quicker payback will be achieved over longer project analysis time frames. Cost savings could be enhanced for new buildings, where installation is less expensive than retrofit, and in regions where water cost is higher. In addition, the large amount of water savings may make this technology appealing in regions with limited water resources even if scarcity is not reflected in higher water rates.

The shave sink economic analysis was performed to compare water use without retrofits to water use with the retrofit fixture. The retrofit that is considered in this analysis is a 0.9 gpm faucet fixture that also provides 0.125 gpm high velocity flow for razor cleaning. In this demonstration, only the 0.9 gpm faucet fixture flow rate was considered due to the lack of information about water consumption needs for shaving. Cost analysis was performed using the cost element information shown in Table 7-3.

A 10-year lifetime is used with a local water and wastewater treatment rate of $10.00/kgal.

Table 7-8. Comparison of water use costs for both with and without shaving fixtures for CERL.

Cost	No retrofit	With retrofit
Fixture cost - one-time cost	—	$88.00
Installation cost - one-time cost	—	$137.50
Facility operational costs over 10 years - shaving sink use only	$4,712.44	$3,392.96
Total cost	$4,712.44	$3,618.46

The result showed that these retrofits result in a savings of $1,100 over the 10-year study period. A single water fixture with razor cleaning is relatively easy to achieve water savings and has a short payback period. In addition, the capability to clean razors with high flow velocity allows users to remove hairs from a razor blade effectively. Due to lack of information regarding water consumption required for shaving at CERL, further benefits of using the water conservation technology could not be observed. However, the capability of the fixture could address Army specific challenges in expeditionary settings and training areas where shaving is required but faucets are often water intensive and provide poor flow velocity.

7.3.2 Under-sink graywater reuse system (CERL)

Life cycle cost analyses were performed for the under-sink water reuse system based on the data collected in the demonstration phase of this study, associated estimates for operational costs, and assuming a 10-year lifetime (Table 7-9). Despite saving up to 135,000 gallons of water over a 10-year period, the under-sink water reuse system would not provide a positive return on investment. This analysis considered a fairly optimal scenario of 45 gpd water recovery for 300 days each year. Figure 7-5 shows the results of the net savings analysis over a 10-year period, resulting in a net loss of $823.95 at 10 years. Assumptions include data from the demonstration study, estimated operational costs, and design specifications. These data indicate that without reductions in either capital cost or a substantial increase in water costs, the current design will likely not be cost effective over its lifetime.

Table 7-9. Comparison of net costs both with and without under-sink graywater reuse system at CERL.

Cost	No retrofit	With retrofit
Equipment cost - one-time cost	—	$928.94
Installation cost - one-time cost	—	$348.00
Facility operational costs over 10 years - bathroom sink and shower use only	$1350.00	$1,271.35
Total cost	$1,350.00	$2,548.02

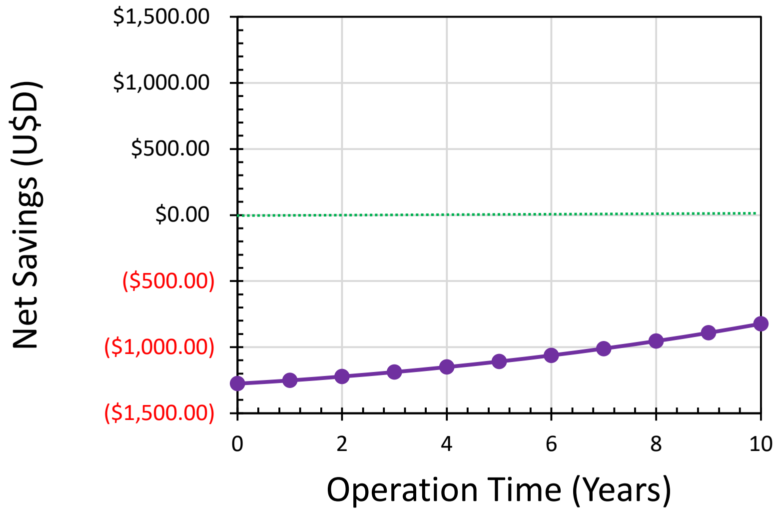

Figure 7-5. ROI versus operational time for under-sink graywater reuse system.

7.3.3 Building scale graywater reuse system (MCRD)

The life cycle cost analysis of the building scale graywater reuse system was performed based on the data collected from the barracks at MCRD. The results of the LCCA of the system represent potential economic feasibilities in the field.

From the SMART clinic (Bldg. 573) graywater system data, 90% of toilet water is recycled graywater. Since the average daily demand for the SMART clinic is not suitable to analyze the life cycle cost of building scale graywater reuse system for barracks, daily potable water demand and occupancy data from non-medical barracks (i.e., Bldg. 586) was used in the LCCA. The inputs for the life cycle cost model for the barracks reuse system were:

- Average daily potable water demand: 8458 gpd
- Average daily occupancy: 428.8 ppl/day
- Percent recycled graywater for toilet flushing: 90%
- Water cost: $10.53/kgal
- Graywater system cost (one-time cost): $97,300
- Installation cost (one-time cost): $97,300
- Operator training cost (one-time cost): $10,815
- O/M cost:
  - Consumable: $120/year
  - Maintenance: $1,760/year
  - UF replacement: $960 per 5 years
- Energy cost: $1,556.2/year (at $0.0778/kWh)

The results presented in Figure 7-6 indicate that the building scale graywater system is not economically feasible with less than 35% of daily graywater reuse relative to total potable demand. However, more graywater reuse would generate greater water savings, and thus result in earlier payback periods. With existing state-of-the-art technologies, a target of 50% of total water consumption being recycled can only be achieved with graywater directed toward more end uses than toilet flushing.

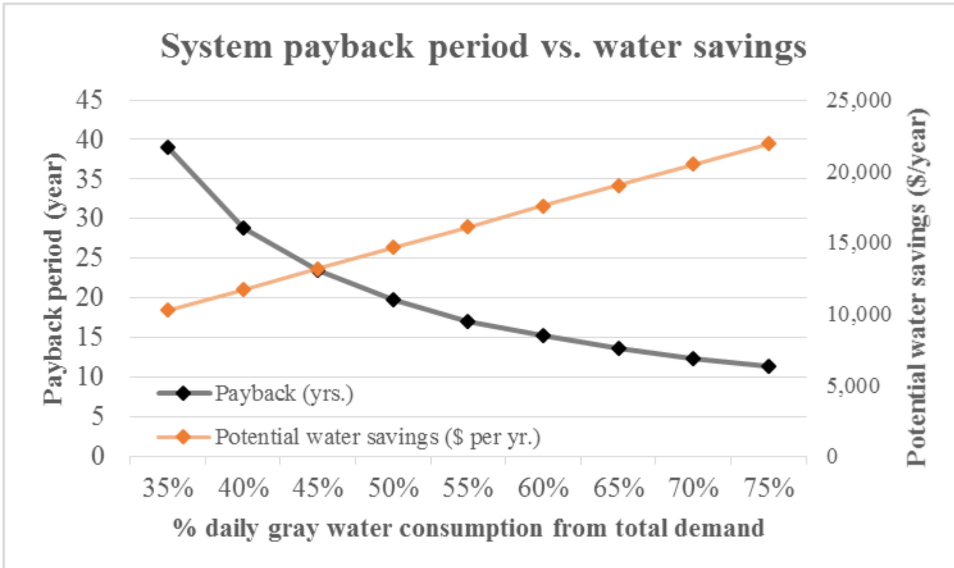

Figure 7-6. System payback period and potential water savings for a building scale graywater system for barracks.

Although 20 years for a system payback period is relatively high and economically not favorable, a designer may be able to overcome the issue with slight modifications to the approach. One way to make the system economically feasible is to optimize system size with respect to total water demand. This can be achieved by clustering multiple buildings into one centralized graywater system. Another way is to increase the percent of graywater consumption by developing new water reuse framework to extend the water reuse capabilities, though this would face regulatory barriers under current codes.

8.0 IMPLEMENTATION ISSUES

Water conservation and reuse is an attractive opportunity for reduction of potable water at the building scale. Use of these systems building wide could result in 50% reduction in potable water consumption. However, the water reuse systems require piping infrastructure that is unconventional, and therefore substantial retrofit of existing building infrastructure. For this reason, reuse of all available graywater is generally not economically beneficial for built infrastructure. In this demonstration project, graywater reuse systems were directed at buildings for scenarios where an economic benefit could be realized. This constraint can be met by targeting facilities with large numbers of users and centralized water use systems (bathrooms, laundry) and accessible infrastructure. Given that constraint, a number of implementation factors need to be addressed in order for conservation and reuse technologies to succeed. The following issues were encountered during the execution of this project.

8.1 Water fixture retrofits

For plumbing fixture retrofits, implementation challenges included regulations, end user concerns, procurement issues and others.

Potential regulations that may apply to the use of the technologies include the relevant legislation, Executive Orders, Federal criteria, DoD requirements, Service Policy, and industry standards and codes. The most stringent regulation may not be the overriding requirement. It may not be advisable to use the most efficient equipment. For example, ultra low flush toilets are not recommended for buildings with long horizontal drain lines.

Building water metering and monitoring in this project was a microcosm of issues encountered by DoD installations. In the absence of meters it is difficult to ascertain water savings due to technology retrofits. Selection of meters is critical, taking care to ensure accuracy at low flow volumes that are encountered in administrative buildings. Meters must be compatible with building automation systems in order to record data at a small enough time interval to support analyses.

Technologies sometimes carry special installation, operations and maintenance requirements that might not be anticipated by O&M staff or building occupants. For example, water free urinals cannot have copper waste pipes. It is imperative that liquids such as coffee are not disposed of into urinals or risk damaging the cartridge. Cartridge changes in water free urinals are also required yet may not be accomplished due to reluctance of, or lack of training of, maintenance personnel.

Procurement issues are less significant for plumbing fixtures that have been on the market for many years and are simple in operation. Ideally all fixtures and parts available through an installation's supply system comply with Federal, DoD and Service criteria. The use of WaterSense® certified fixtures is mandated and installation staff are encouraged to ensure that this mandate is followed.

One issue of concern is automated controls for plumbing fixtures. Faucets, toilets and urinals in this study were fitted with such sensors. User feedback included both multiple flushes per toilet use and no flushes at all. The WaterSense® program recommends adjusting flush sensors every two years yet this maintenance action is often not performed.

Another issue related to toilets is the need to 'match' bowl with flush valve. Retrofitting an old bowl with a new efficient flush valve will not produce the flush volume associated with the new valve. Although it is a costly retrofit, the entire toilet must be replaced.

8.2 Under-sink graywater reuse system

For the bathroom scale under-sink graywater reuse system, further technical improvements are required to meet some of the water quality requirements for toilet flushing. While the system generally worked well to clarify and disinfect the water, the level of organics removal of 83% fell short of the 90% removal level that would be needed to bring the biochemical oxygen demand (BOD) below 10 mg/L.

In addition, physical system modifications are necessary to improve the energy efficiency, self-cleaning capability, chlorine dosing levels, and controls. These improvements are key for making the system cost-effective. The approval process and retrofit times for installing the under-sink system were also longer than expected, and the associated costs may be a limiting factor for achieving a target payback period.

To improve future deployments of similar technologies, the pre-validation phase should target a more extensive level of treatment than the standards in order to provide a margin of safety, and the validation testing should be performed under flow conditions representative of bathroom usage (i.e., weekend downtimes). Overall, the challenges faced with autonomous performance and cost require improvements before such a bathroom scale water reuse approach can be considered.

8.2.1 Regulatory factors

Due to lack of formal water reuse regulation in the State of Illinois, this demonstration required a special variance from the Environmental Health Department, which was a considerable investment of time. Additional Army reviews were also required.

The NSF350 certification compliance is recommended because of the small size of the under-sink system, as it is not practical to monitor performance through water sampling and testing.

8.2.2 End-user concerns, reservations, and decision-making factors

The capital cost of the current under-sink water reuse design needs to decrease to achieve payback within a 10-year period. Since this demonstration was the first prototype of its kind, there may be substantial opportunities for cost reductions. However, it is unlikely that installation costs could be decreased much because a considerable amount of the installation relates to integrating the plumbing with the existing bathroom infrastructure. With further design optimization, a capital expenditure (CapEx) of $750 may be achievable. If not, cost-effective adoption would require a relatively high water escalation rate compared to CapEx costs in the future.

The automation of the current under-sink water reuse design needs to be improved to maintain appropriate chlorine levels (1-4 mg/L) in the product water and to keep the biofilter from clogging over time and during extended downtimes.

8.3 Building scale graywater reuse system

For improving future deployments of similar systems, pre-validation of the systems using protocols based on the ANSI/NSF 350 standard should be required, with modifications made to reflect the expected graywater generation schedule for the building and design. A more extensive level of treatment should be targeted in the validation phase in order to avoid water quality concerns. On-site performance and automation validation over a three month startup period, as well as an annual maintenance requirement, should be included in contracts for installing these systems in buildings, in order to ensure that systems do not fail after installation. Systems that can reuse a larger fraction of the building water demand should be explored to improve life cycle costs. Life cycle cost analysis tools should be used up front to project return on investment and confirm that the payback period will be acceptable. However, non-market valuation factors, such as emergency operation of critical facilities, need to be considered, and associated models to support this analysis need to be developed.

8.3.1 Regulatory factors

There are state/other regulations that may apply to these types of systems but NAVFAC was not able to identify code authority for the MCRD graywater reuse system.

It is difficult to determine water savings accurately due to the lack of sub-meters in the systems and the buildings.

8.3.2 End-user concerns, reservations, and decision-making factors

A survey from MCRD Public Works expressed dissatisfaction with the systems as implemented. Adequate system instrumentation and installation are required to have end-users operate and maintain the system on-site.

As identified from sensitivity analysis of the systems, the major cost drivers (cost of water, percent reuse from total demand, and capital cost) should be understood in order for the Army to adopt building water reuse system. Feasible payback periods could be achieved by determining the fully burdened marginal value of water, high-tier reuse to support a wider range of demands, and technology development to decrease system and installation costs.

8.3.3 Procurement factors

Procurement contracts should include detailed specifications and operating instructions for the system as well as maintenance for at least the first year of operation. In addition, system specifications should include detailed monitoring and control systems, with data logging capability, and provide necessary isolation valves to allow by-pass for maintenance and repair without taking the system off line and disrupting all water supply for the building. Lastly, contracting mechanisms for operation, maintenance and repairs by the system's manufacturer should be seamless.

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APPENDICES

Appendix A: Points of Contact

Point of Contact	Organization	Phone, Fax, e-mail	Role In Project
Elisabeth Jenicek	Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL)	217-373-7238 elisabeth.m.jenicek@usace.army.mil	Principle Investigator
Martin Page	Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL)	217-373-4541 martin.a.page@usace.army.mil	Principle Investigator
Gary Anguiano	NFESC	gary.anguiano@navy.mil	Navy POC
Larry Isaacs Kevin Leachman	AFCEC	larry.isaacs@us.af.mil kevin.leachman@us.af.mil	USAF POC
Richard Hatcher	MCRD San Diego	Richard.hatcher@usmc.mil	Site POC
Les Gioja	ERDC-CERL	Leslie.m.gioja@usace.army.mil	Site DPW

Appendix B: CERL Water Attitudes and Practices Survey

B.1 Survey results

CERL employees were asked about their general water and energy habits (Table B-1). These questions were meant to gauge overall behaviors related to resource conservation. On average, CERL employees were shown to be resource conscious, with most answers regarding conservation indicating that employees conserve resources somewhere between half of the time and most of the time. The main outlier was a question about combat showers, which is expected as most CERL employees are non-military. Negative behaviors, such as using showers for non-hygiene purposes, were mostly observed to occur somewhere between never and some of the time.

For questions about having heard of the importance of using less energy and water, hardly any respondents indicated they were unaware of this, which is expected due to CERL being a lab where energy and water conservation are well researched (Table B-2). The main sources for learning these topics came from TV, family, work/job, school, and as a kid. The relative popularity of these responses are shown in the word clouds of Figure 1 and Figure 2, where the size of the word indicates the frequency of a response.

Water use restrictions were shown to exist for roughly 20% of the respondents (Table B-3). Reasons for these water limitations included using less for saving money, for daily activities, from homeowners' association rules, from living in a shared hot-water apartment, when living abroad, during deployment, during a drought, during camping, during a hot/dry season, when at water-restricted installations, and during water pipe construction.

CERL employees were then asked CERL-specific questions (Table B-4). Half of these questions were to gauge water use activities, which were then used to model CERL's water use. The other questions were to identify bathroom sink water habits to better understand potential inputs into the graywater reuse system that has been developed for the Bldg. 3 men's restroom. Results show that CERL employees use toilets and bathroom sinks on a daily basis, water fountains a few times a week, and kitchen/cafeteria sinks between a few times a month and a few times a week. Other water uses were indicated to occur somewhere between rarely and never. Write-in water uses included for making coffee, for drinks, watering plants, cooking, washing dishes, washing equipment, and use in a lab. Write-in bathroom sink uses included washing dishes, personal hygiene (e.g., shaving, rinsing mouth, rinsing face), and washing items such as food and contacts.

A significant portion of CERL employees have noticed water wasted at CERL (Table B-5). Responses were observed to be independent of a respondent's amount of time worked at CERL. About half of the water waste responses (Table B-6) mentioned that automatic flush toilets are too sensitive and unnecessarily flush. Other sources of water waste that were highly mentioned included bathroom fixtures, kitchen/cafeteria areas, labs, faucets being left on, water being left on to warm up, unnecessarily long irrigation/landscaping, and leaks. Regarding reporting the water waste, only 22% of the respondents knew how to do this (Table B-7), which is to report it to the CERL Department of Public Works (DPW). Newer employees were least likely to know this.

General questions were then asked regarding graywater familiarity and personal water saving. The majority of respondents had heard of graywater prior to answering the question (Table B-8), though an explanation of graywater reuse systems was given when handing out surveys, which may have affected the results. A word cloud was also generated for where the term graywater had been learned (Figure 3).

Survey respondents were then asked whether they have a graywater recycling or rainwater system set up at their homes. Only 11% responded "yes" (Table B-9), and most answers specified rain barrels/roof collection for gardening and landscaping purposes. A few answers mentioned using sump water for gardening, and there was an answer for radiative dew collection. No one owned a graywater reuse system. A related question showed that about half the respondents had another type of water conservation system set up at home (Table B-10). Specific answers included water saving or energy star washers and dishwashers; low flush toilets, showers, and faucets; and smart irrigation.

Regarding drinking water quality, most respondents think filtered faucets are best, with water bottles and fountains equally ranked next, with cafeteria sinks as tolerable and bathroom faucets closer to low quality (Table B-11).

CERL employees answered that they think about energy use between some of the time and half of the time, whereas they think about water just a little over some of the time (Table B-12). For rating importance on how daily tasks are performed, effectiveness was ranked highest, followed in order by efficiency, safety, standing operating procedures, and resource conservation (Table B-13).

Approximately 2/3 of the respondents were aware that the Army has water reduction goals (Table B-14), and similarly about 2/3 of respondents were aware that CERL is trying to reduce its water use (Table B-15). Employees who had worked at CERL longest were most likely to be aware of these efforts. However, only 1/3 of respondents were aware of CERL's planned modifications to the water system (Table B-16), with newest employees the least likely aware. Of those who were aware of water reduction goals, approximately 17% responded that they had changed their habits to meet these goals (Table B-17). It should be noted that some of those who answered "no" mentioned that they already use a minimal amount of water, and a few others remarked that they were not sure what they could do to help. For the people who answered "yes", a few ways mentioned to reduce water use were being more water conscious, making sure lab faucets are shut properly, using a rainwater catchment for lab needs (which saves 1200 gallons over the summer), and reducing the time letting a faucet run.

Questions were then asked to ascertain CERL employees' opinions on graywater reuse systems. Approximately 64% of respondents answered that they would be interested in setting up their home with a graywater or rainwater reuse system for reasons mostly related to water conservation and reduction of costs. The rest of the respondents were either unsure or said "no" for reasons mostly due to concerns of system cost, system complexity, or water quality (Table B-18). CERL employees were also asked their opinions on using a graywater reuse system for their bathroom sink (Table B-19) or laundry (Table B-20) for watering plants. Responses for both questions were similar, with slightly more respondents indicating they would be concerned about laundry chemicals interacting with plants. Reasons for having a graywater reuse system also included water conservation and cost reduction, with caveats that the system would be inexpensive, easy to use, not visible, not messy, and not used for food producing plants. Reasons against these systems included not having plants, difficulty in ensuring water quality, and potential to cause health and environmental issues.

Questions regarding graywater for toilet flushing use were asked. Most respondents answered that graywater would be safe for use in toilet flushing (Table B-21). Over 80% of respondents answered that they would use graywater systems for flushing toilets (Table B-22 and Table B-23), and approximately 90% of respondents answered that they would not object to a graywater system installed at CERL (Table B-24).

It appeared from the responses that some CERL employees were not clear on the concept of graywater reuse systems. Some respondents seemed to indicate that they understood “graywater reuse systems” to be systems where untreated graywater would be used, in contrast to treated graywater. Approximately 61% of respondents said that they would be interested in learning more about graywater from sinks used for toilet flushing (Table B-25) – it is expected that further graywater education would clarify any existing misconceptions. Ways of learning more about reducing water use were also provided (Table B-26).

B.2 Survey raw data

Table B-1. Survey Question 1.

In general, how often do you:	Mean response	Standard deviation
Turn off the lights when you leave a room	3.99	0.867
Turn down the thermostat at night or when leaving for the day	3.48	1.618
Report plumbing problems at CERL to the DPW	3.29	1.646
Shower more than once a day	1.79	0.925
Take “combat showers” (turning off water for soap and lather portion)	1.45	0.898
Use the shower to wash clothes/boots or do other tasks	1.24	0.604
Lower the water level of the washing machine for smaller loads	4.03	1.380
Turn off the faucet while brushing teeth/shaving	3.80	1.386
Turn off air conditioning and/or heating when leaving a room	2.10	1.234
Use the toilet to dispose of garbage	1.19	0.545
1 – never, 2 – some of the time, 3 – half of the time, 4 – most of the time, 5 – always		

Table B-2. Survey Questions 2 and 3.

	Have you ever heard about the importance of using less energy? If so, how? (as a kid, school, family, TV, etc.)	Have you ever heard about the importance of using less water? If so, how? (as a kid, school, family, TV, etc.)
Yes	99.4%	97.5%
No	0.6%	2.5%

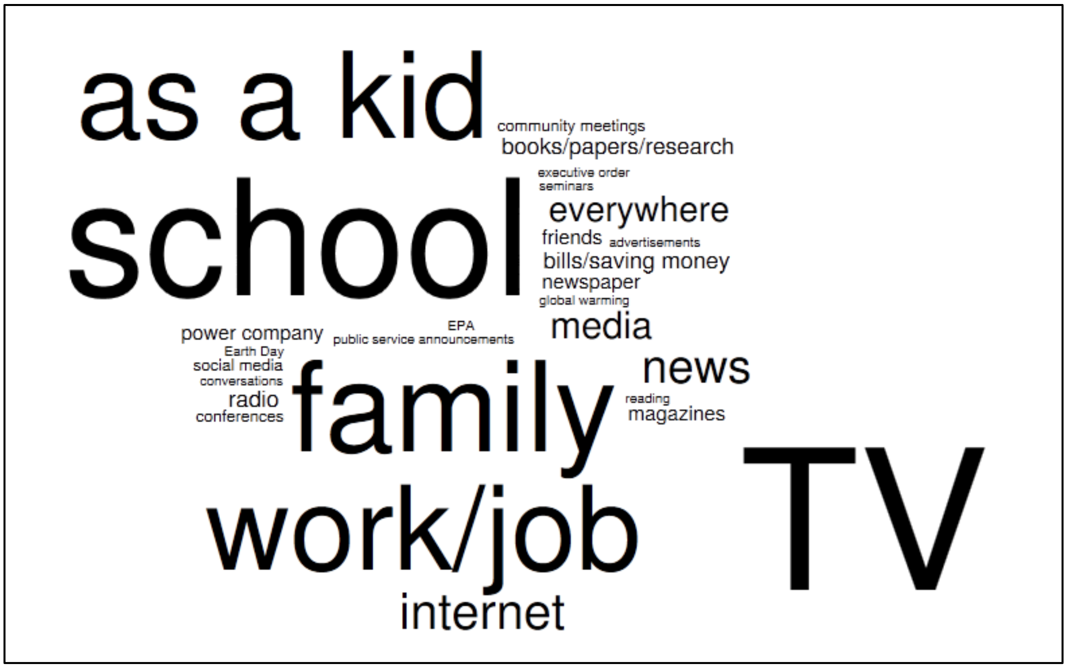

Figure 1. Survey Question 2 – word cloud on how using less energy has been learned.

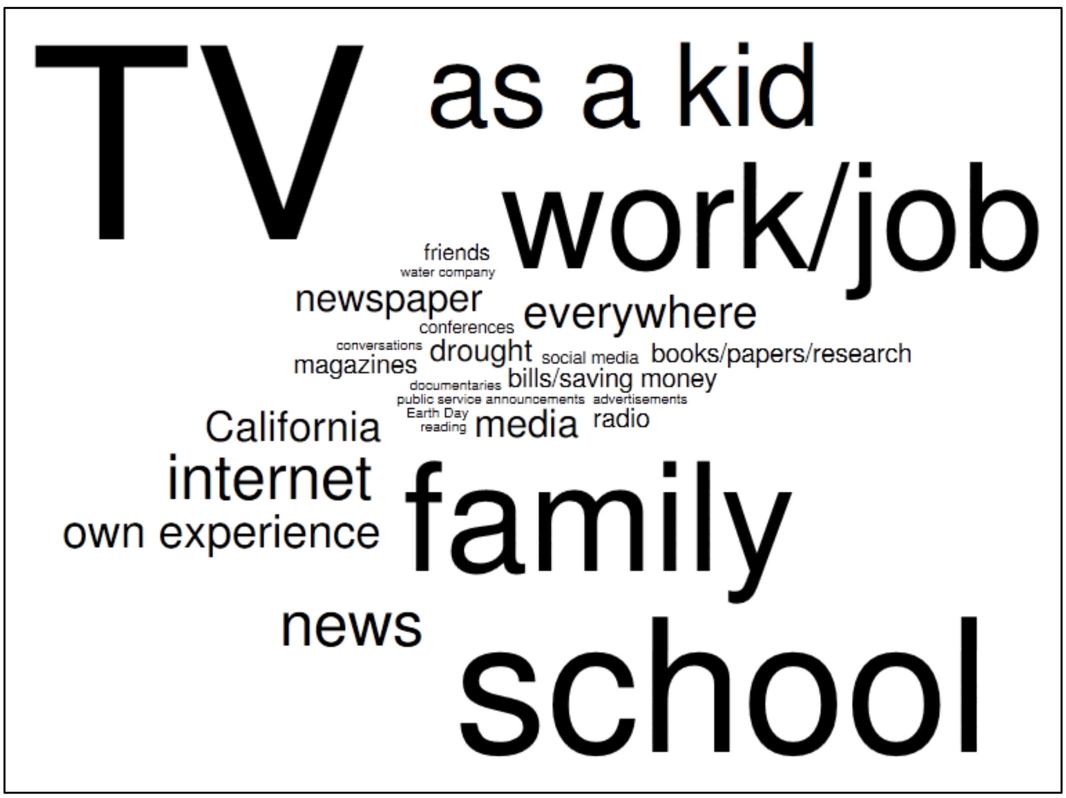

Figure 2. Survey Question 3 – word cloud on how using less water has been learned.

Table B-3. Survey Question 4.

	Are you ever given restrictions on water usage? (length of showers, amount of drinking water, etc.)
Yes	20.5%
No	79.5%

Survey Question 4 "If so, please describe" comments:

- Attempt to limit water use to save money
- Try to use less water during daily activities, e.g., showering, dishwashing; self or family imposed restrictions for conservation purposes, with some explicit home limits, e.g., 5 min. showers, 64 oz of water per day, or only certain times to water plants; limits on outside watering, washing cars
- During deployment/on a ship
- When staying/living in a region with a drought, e.g., CA
- At campsites
- During a hot/dry season
- When at water restricted installations, e.g., Fort Hood
- In housing community/by a home owners' association
- Overseas or living abroad - time or quantity limits
- Living in a shared hot-water apartment complex
- During water pipe construction

Table B-4. Survey Question 5.

At CERL, how often do you:	Mean response	Standard deviation
Use a shower	1.62	1.150
Use a toilet/urinal	4.95	0.228
Use a kitchen/cafeteria sink	3.56	1.288
Use a bathroom (not kitchen) sink for washing your hands	4.79	0.696
Use a bathroom (not kitchen) sink for brushing your teeth	1.91	1.242
Use a bathroom (not kitchen) sink for disposing coffee/drinks	1.55	0.862
Use a bathroom (not kitchen) sink for any other purpose (if so, specify)	1.40	0.755
Use a water fountain	4.20	1.092
Use water in a lab	1.69	1.286
Use water for any other purpose (if so, specify)	1.82	1.175
1 – never, 2 – rarely, 3 – a few times a month, 4 – a few times a week, 5 – daily		

Question 5 "If so, please specify" comments:

Bathroom sink other uses:

- Washing silverware, dishes
- Spitting, rinsing mouth
- Shaving, rinsing face
- Washing contacts
- Washing fruit
- Washing small/misc. items
- Cleaning mud off shoes
- Getting water

Water for any other purpose:

- Making coffee
- Getting ice/water from cafeteria
- Watering plants
- Cooking
- Washing dishes
- Washing/cleaning equipment
- Use in experiments
- Running humidifier (in winter)
- Test tanks for leaks
- Filling fish pond
- Sauna
- Filling automobile radiator

Table B-5. Survey Question 6, part 1.

	Have you ever noticed water being wasted at CERL?
Yes	42.9%
No	57.1%

Table B-6. Survey Question 6, part 2..

	Where is water wasted at CERL?
Frequency	**Comments**
32	Toilet sensors are overly sensitive and flush multiple times, for sometimes just a change in posture, standing next to the toilet, or even when stall is empty (seems a lot of complaints are from women's restroom users)
7	Toilet/urinal water running
5	Stuck toilet/urinal valves
5	Bathrooms
5	Cafeteria/coffee/kitchen areas
4	Faucets left on
3	Labs

	Where is water wasted at CERL?
Frequency	**Comments**
3	Cold water in some sinks - water wasted getting to hot water
3	Landscaping/irrigation running too long
2	Men's locker room taking time to warm up water
1	Locker room showers being left on
1	Sinks could turn off a little faster
1	DPW - cleaning equipment, etc.
1	Leaky lab sinks
1	No aerator on sink tap in acoustics area
1	Leaks

Table B-7. Survey Question 7.

	Do you know how to report water waste at CERL?
Yes	22.0%
No	78.0%

Majority of specified methods include contacting DPW personnel/using the DPW website/reporting to DPW via SharePoint.

Table B-8. Survey Question 8.

	Graywater is untreated wastewater from bathroom sinks, showers, or laundry machines. It is not water from kitchen sinks and dishwashers (called blackwater). Some places have localized graywater reuse systems that clean the water for non-potable uses, i.e., toilet flushing or irrigation. Have you ever heard of the term graywater before this survey?
Yes	87.2%
No	12.8%

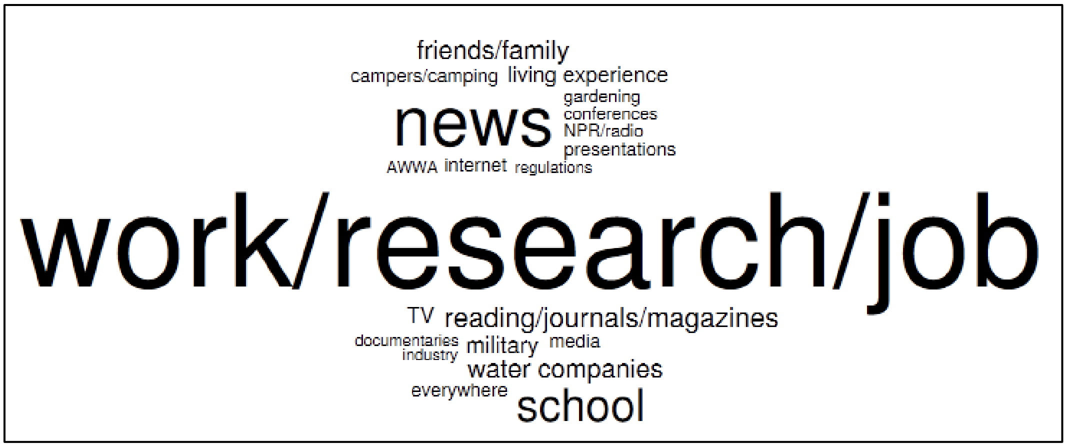

Figure 3. Survey Question 8 – word cloud on how graywater has been learned.

As would be expected, most of the CERL respondents have heard of graywater (probably because it was discussed with them before they took the survey), and a lot were probably already familiar with graywater.

Table B-9. Survey Question 9.

	Do you have a graywater or rainwater system set up at home? If so, for how long, what do you use it for, and from what sources do you get the water?
Yes	11.0%
No	89.0%

Most answers are rain barrels/roof collection for gardening and landscaping purposes. A few answers mentioned using sump water for gardening, and there was an answer for radiative dew collection.

Table B-10. Survey Question 10.

	Do you have some other type of water conservation system set up at home (e.g., smart irrigation, water-smart landscaping, or water saving appliances such as washers and dishwashers)?
Yes	49.1%
No	50.9%

Specific answers:

- Washers - water saving, variable load, HE, energy star
- Toilets - variable flush, low flow
- Dishwasher - water saving, energy star, Bosch
- Rainwater/cistern
- Runoff collection for irrigation/drip irrigation, smart irrigation, timer irrigation, not watering lawn at all
- Showers - low flow, controllable flow

Faucets - low flow, water restrictor

Table B-11. Survey Question 11.

What is your opinion of drinking water from:	Mean response	Standard deviation
Water fountains	3.85	0.95
Unfiltered kitchen/cafeteria faucets	3.16	1.01
Unfiltered bathroom faucets	2.66	1.16
Water bottles	3.85	1.01
Filtered faucets	4.27	0.69
1 – will not drink, 2 – low quality, 3 – tolerable, 4 – high quality, 5 – most preferred		

Most people think filtered faucets are best, with water bottles and fountains equally ranked next, with cafeteria sinks as tolerable and bathroom faucets closer to low quality.

Table B-12. Survey Questions 12 and 13.

How often do you think about how much energy/water is used during daily activities at CERL?	Mean response	Standard deviation
Energy use	2.63	1.09
Water use	2.23	1.02
1 – never, 2 – some of the time, 3 – half of the time, 4 – most of the time, 5 – always		

Thinking about energy use is a mix between some of the time and half the time, whereas thinking about water is just a little over some of the time.

Table B-13. Survey Question 14.

Rate the importance of the following on the way you perform daily tasks:	Mean response	Standard deviation
Effectiveness (getting the best results)	4.73	0.53
Efficiency (saving time)	4.32	0.82
Standing operating procedures (requirements)	3.87	1.05
Resource conservation (saving energy, water, etc.)	3.55	1.07
Safety (reducing risk)	4.23	1.10
1 – not important, 3 – somewhat important, 5 – very important		

Most answers are between somewhat important and very important.

Table B-14. Survey Question 15.

	Are you aware that the Army has water reduction goals?
Yes	67.1%
No	32.9%

Table B-15. Survey Question 16.

	Before this survey, did you know that CERL is trying to reduce its water use?
Yes	69.5%
No	30.5%

Table B-16. Survey Question 17.

	Are you aware of the planned modifications to the water system at CERL?
Yes	32.9%
No	67.1%

Most people are aware of the goal to reduce water use, but most are unaware of the retrofits to CERL.

Table B-17. Survey Question 18.

	If you answered "Yes" to Question 15 or 16, have you changed your habits to help meet water reduction goals?
Yes	17.1%
No	82.9%

Some people who said "no" mentioned that they already use a minimal amount of water, and a few others remarked that they were not sure what they could do to help. For the people who said yes, a few of the comments were:

- Being more water conscious
- Making sure the lab faucet is shut properly
- Installed a rainwater catchment for lab needs, which saves 1200 gallons over the summer
- Reduction in time letting the faucet run

Table B-18. Survey Question 19.

	Would you be interested in setting your home up with a rainwater or graywater reuse system?
Yes	64.1%
No	28.2%
Maybe/unsure write-ins	7.8%

Comments from people who answered "yes":

- Avoids future water wars and reduces cost
- Could be good for watering plants
- Water conservation
- Lightens load on community cleaning systems and could get return on investment
- Efficiency, sustainability
- Good for gardening
- Good for flushing toilets

- Reduces water bill
- Right thing to do
- Rainwater yes, graywater no for various reasons (e.g., cost, complexity, safety)
- Rainwater could be used to wash vehicles and tools/equipment

Comments from people who answered “no”:

- Already have rainwater collection
- Not graywater - seen the results of improper treatment and application of it
- Live in an apartment
- No time to set up
- Not enough use to justify cost
- Do not use much water so not worth time and effort
- Do not have much use for non-potable water except for flushing
- Already very conservative
- Old house, replumbing too expensive
- Plenty of water in Illinois
- Difficult to set up
- Possibility of system malfunction

Comments from people who wrote in “maybe/unsure”:

- Need to be better educated on pros and cons, what’s involved, how much it would cost and money it could save
- One factor is appearance
- Graywater might not be allowed for Urbana residents

Table B-19. Survey Question 20.

	If a graywater system for your home bathroom sink was available and easily accessible, would you use it for watering plants?
Yes	75.8%
No	20.5%
Maybe/unsure write-ins	3.7%

Table B-20. Survey Question 21.

	If a graywater system for your home laundry was available and easily accessible, would you use it for watering plants?
Yes	70.0%
No	23.1%
Maybe/unsure write-ins	6.9%

Comments from people who answered “yes”:

- As long as simple/easy to use, available, inexpensive, accessible, not too visible, not messy
- Why not? Plants do not need potable water
- But not food plants

- Cuts costs
- Useful for drought periods, won't harm groundwater or plants
- Easy and effective way to save water
- Gardens and flowers need lots of water
- Conserving water is important
- Help avoid future water wars
- It is the right thing to do
- Less treatment of waste water

Comments from people who answered "no":

- Already have rainwater collection
- Because of clogged/slow drain
- No plants to water
- Graywater in household cannot be kept biologically clean due to the need to care for elderly household members and pets
- Harmful stuff if not filtered/soapy water would be harmful to plants
- Don't use enough water to justify
- Don't water plants/rely on rain
- Localized graywater sources have a potential to increase health/environmental risks

Comments from people who wrote in "maybe/unsure":

- Depends on cost, ease of use
- (For laundry question) As long as laundry soap/chemicals do not cause any problems

Some responses seemed to indicate that people thought that untreated graywater would be used. It looks like some people were confused on whether graywater that's been recycled or pure graywater would be used.

Table B-21. Survey Question 22.

Frequency	Reuse of graywater is not desirable for toilet water because:
20	It can contain germs
23	The water can smell
8	It won't save much water
100	N/A – graywater is safe for toilet flushing
12	The water can be cloudy
24	Extra maintenance will be needed
8	Other

"Other" reasons:

- Improper treatment and residue
- It cannot be safely cleaned- I would only use it for washing outside the home, lawns or landscapes
- Might affect flap valve

- Toilet and bathroom sink are automatic anyways! And water qty is controlled *unhygienic*
- Toilet tank water can be used for emergency drinking water
- Biohazards, other risks from sink water, especially public sinks. Water will have to be supplemented
- If you're using handwashing water there won't be enough
- Pets drink from toilets. Toilet tanks are a potential water source etc.

Some responses seemed to indicate that people thought that untreated graywater would be used – it looks like some people were confused on whether graywater that's been recycled or pure graywater would be used.

Table B-22. Survey Question 23.

	If a graywater system for your home bathroom sink was available and easily accessible, would you use it for toilet water?
Yes	81.6%
No	18.4%

Some comments:

- "Depends on how it looks, if it looks like a normal bathroom then it's ok"
- Several responses were along the lines of don't know/maybe/need more info

Table B-23. Survey Question 24.

	If a graywater system for your home laundry was available and easily accessible, would you use it for toilet water?
Yes	84.1%
No	15.9%

Some comments:

- "Depends on how it looks, if it looks like a normal bathroom then it's ok"
- Several responses were along the lines of don't know/maybe/need more info

Table B-24. Survey Question 25.

	If a graywater system for bathroom sinks at CERL was available, would you object to using it for toilet water?
Yes	10.2%
No	89.8%

Some comments:

- "Yes, provided there are no health hazards"
- Several responses were along the lines of don't know/maybe/need more info
- Some people also may have been confused with the "object to" part and instead put the opposite answer to what they meant

Table B-25. Survey Question 26.

	Would you be interested in learning more about graywater from bathroom sinks being used for toilet water?
Yes	61.2%
No	38.8%

Comments:

- the results of your research will be of interest
- the quality of water
- required resources, maintenance, etc.
- put out documentation in breakroom or post where we can read it online
- need to have ideas for containment and pumping
- hold an info session or send detailed email about it
- at CERL yes, at home no
- a flyer on how it works
- just build the infrastructure. We'll use it. :)
- if it is the most cost effective way to meet our goals then do it
- I think I understand how it works already well enough
- I consider it unhygienic; at home we use flush the toilet after we have used it twice (if it's used to pee only)
- do it - I'm supportive
- as long as it doesn't smell worse than a bathroom usually smells, no big deal to me
- like the idea of specifically targeting handwashing water for the toilet, presumably all contained in the bathroom

Table B-26. Survey Question 27.

Frequency	How would you like to learn more about reducing water use? (check all that apply)
76	Posters and signs
53	Online tutorials
43	Handbooks and pamphlets
35	Classroom lectures/seminars
48	Hands-on demonstrations
9	Other

"Other" comments:

- passive techniques
- behavior modification
- brownbag lunch
- hand puppets
- something fast
- emails

- short internet articles
- web, general.

Table B-27. Survey Question 28.

Gender	
Male	56.7%
Female	43.3%

Table B-28. Survey Question 29.

Which building is your lab/office located? (check all that apply)	
Bldg. 1	36.0%
Bldg. 2	42.0%
Bldg. 3	22.0%

Table B-29. Survey Question 30.

What is your age?	
18-24	10.9%
25-34	18.4%
35-44	18.4%
45-54	23.8%
55-64	23.8%
65+	4.8%

Table B-30. Survey Question 31.

How many years have you worked at CERL?	
Under 2	16.4%
2 to 5	23.7%
6 to 10	12.5%
10 or more	47.4%

Survey Question 32 – any other suggestions or comments about reducing water use:

- 1) use bath towels more than once 2) don't wash clothes until dirty 3) reduce flushes, when possible 4) don't use dishwasher
- audit of DPW and laboratories to determine where we have leaks & over-use from old technologies & equip.
- Before implementing any form of graywater reuse at CERL you need to set up a review group including
  - the Illinois State Water Survey
  - Northern Illinois Water
  - Local chapter of AWWA - Chicago or Springfield
  - UIUC Environmental Engineering Dept.

- better shower heads would be an easy fix to save a bit of water in the locker rooms
- consider making us aware of the sources of our water, i.e., not an infinite resource from a pipe, but the Mahomet aquifer, and it discharges to treatment plant, then Boneyard or wherever
- do we use water on bldg exteriors @ CERL?
- Do you have any readily available research on the aquifer from which C-U and surrounding towns obtains its water?
- I appreciate your sensitivity towards my feelings about infrastructure. And if there is a way to increase energy & water efficiency while providing safe water and electricity: just do it.
- I doubt the cost effectiveness of any projects to reuse water. My guess is any major project would cost more than what a year of water costs.
- I have observed over the years that the public sinks here at CERL have been used for more than hand washing. Liquids are disposed of in the sinks such as coffee, tea, etc. Bio-hazards have been found in the sinks many times, such as blood and vomit. It would take an effective treatment system to make the sink water safe for use in other plumbing fixtures. In addition, at least in the men's restroom, the observed use of the sinks would not produce enough water to supply the urinals and toilets. Supplemental water would be necessary
- I just wonder if water is really being wasted here and if this project is going to save enough to justify its cost. At the same time, I understand the research value of the project
- I see water constrained regions- CA, GA, etc., but here in IL, I don't really want to worry about it. I don't waste, but also don't try too hard to reduce
- if it is an accepted practice & cost effective, then put it to use here. It will become the new normal
- In-fill building is supposed to have a new fish pad [?] and some landscaping. Suggest rain water to be used to fill & water them
- make it as easy to do as possible
- maybe consider using waterless urinals
- metrics? Where is water used @ CERL? Where too much? What is the water balance on the aquifer? How does CERL compare?
- most people will not care about conservation at work simply because they are not responsible for the cost. It is the "not my problem" philosophy
- no plant
- put low flow shower heads in locker rooms
- put the signs about reducing water use where people used to be at
- rain water
- rainwater storage
- See note below and don't be offended. I think what your doing is good just not in all circumstances. The moral to the graywater story is "sh*t happens" when you have a house of pets and old folks so it's best not to use graywater
- Sometimes I would like to wash my hands with hot water after using the bathroom. This takes running the sinks at CERL about 3 times before the water is hot enough. Is it possible to designate one of the sinks as a "hot water" sink that would be set at a higher temperature than the other sinks in the bathroom to prevent wasting water while the water temperature gets hot enough?
- tell us how!
- the toilets flush before I'm finished sometimes. They seem nearsighted and I end up flushing twice

- we could use water conserving toilets - e.g., up for liquid waste down for solid. Also- remove the auto sensors- if you move even a little it will flush and waste water
- we have all these new roofs going on are we doing anything to capture rainwater
- yes - immediately available hot H2O at bathroom and kitchen sinks
- yes! Try fixing the sensors in the bathroom toilets :)
- educate user
- keep up the good work and pushing for awareness

Appendix C: Pre-Retrofit Faucet, Shower, and Toilet Water Use Amounts

Table C-1 below lists the flow rates for the water fixtures at CERL for both pre- and post-retrofit. Anything that was not retrofit, e.g., toilets, urinals, and some faucets, do not have post-retrofit water use values.

Table C-1. Pre- and post-retrofit flow rate values for CERL water fixtures.

	Room	Type	Number	Pre-retrofit	Post-retrofit	Comments
Bldg. 1	Men's room - room 1118	Faucet	1	1	0.5	
			2	1	0.5	
			3	1.3	0.5	
		Toilet	Avg.	2	—	
		Urinal	Avg.	0.125	—	
	Women's room - room 1115	Faucet	1	1.3	0.5	
			2	1.2	0.5	
		Toilet	Avg.	5.1	—	
	Men's locker room - room 1145	Faucet	1	1.4	0.5	
			2	1.1	0.4	
		Shower	1	1.6	1.6	
			2	3.1	2	
			3	2.7	2.1	
			4	1.9	1.5	
		Toilet	Avg.	1.7	—	
		Urinal	Avg.	0.4	—	
	Kitchen - room 1119	Faucet	1	0.7	—	*The measured flow rate was for a reasonable flow - not fully turned on
		Hand-held	1	0.5	—	
Bldg. 2	Men's room - room 2111	Faucet	1	1.4	0.4	
			2	1.2	0.5	
			3	1.3	0.4	
		Toilet	Avg.	3.4	—	
		Urinal	Avg.	0.2	—	
	Women's room - room 2108	Faucet	1	1.3	0.4	
			2	1.5	0.4	
		Toilet	Avg.	1.9	—	
	Women's locker room -	Faucet	1	1.2	0.5	
			2	1.3	0.5	
		Shower	1	2.6	2.6	*Not sure if these retrofit or not

	Room	Type	Number	Pre-retrofit	Post-retrofit	Comments
	room 2163		2	1.7	2.7	*Not sure if these retrofit or not
			3	2.8	2.2	*Not sure if these retrofit or not
			4	1.9	2.2	*Not sure if these retrofit or not
			5	1.5	1.6	*Not sure if these retrofit or not
		Toilet	Avg.	5.3	—	
	Kitchen - room 2011	Faucet	1	1.5	—	*The measured flow rate was for a reasonable flow - not fully turned on
	Kitchen area - room 2169	Faucet	1	0.7	—	*The measured flow rate was for a reasonable flow - not fully turned on
		Hand-held	1	1.1	—	
Bldg. 3	Men's room - room 3005	Faucet	1	1.2	—	*Not retrofit
			2	1.4	—	*Not retrofit
			3	1.2	—	*Not retrofit
		Toilet	Avg.	3.6	—	
		Urinal	Avg.	0.6	—	
	Women's room - room 3004	Faucet	1	1.3	0.5	
			2	1.2	0.5	
			3	1.1	0.5	
		Toilet	Avg.	4.1	—	
	Kitchen area near north exit	Faucet	1	1.2	—	*The measured flow rate was for a reasonable flow - not fully turned on

Appendix D: CERL Water Model

D.1 Assumptions

Table D-1 lists information on CERL population statistics and assumed daily occupancy. The occupancy fractions were estimated from the overall CERL daily occupancy estimate of 67% discussed in 5.2.1.2 as well as from people counts of the men's restroom, discussed in Appendix F. These fractions were multiplied by the individual building's male and female populations to get the estimated numbers of males and females present each day.

Table D-1. CERL population and occupancy assumptions.

	Male	Female	Occupancy fraction (amt. here on given day)	Avg. males actually present per day	Avg. females actually present per day	Total population actually present per day
Bldg. 1	71	53	0.7	50	37	87
Bldg. 2	92	47	0.63	58	30	88
Bldg. 3	39	29	0.85	33	25	58
Total population in Bldgs. 1-3:						232

It should be noted that no distinction was made between the types of employees present at CERL. For example, CERL has a small population of student employees (~40) that are contracted through the local University of Illinois at Urbana-Champaign. These contractors work a schedule of 10-20 hours a week and therefore are not as present at CERL as federal employees.

To approximate bathroom and kitchen water use, individual daily statistics were estimated. Table D-2 lists these assumptions. A person was estimated to use a toilet/urinal four times a day, with males using a urinal three times out of the four (Blokker 2011). 16 seconds of hand washing (Blokker 2011) was assumed to occur after each of the four toilet/urinal uses, though it is likely that some people use sinks for less time, if at all. Regarding kitchen sink uses, results from the CERL Water Attitudes and Practices Survey indicated that an individual's average use is between a few times per month and a few times per week. It was thus estimated that a person would use the cafeteria sink twice in a 5-day work week for 16 seconds each time. Daily showers for both genders were also estimated based off of feedback from the aforementioned survey, with an estimated 8 minutes per shower (USEPA 2015). There are also five water fountains in the three buildings. From (Sebastian 2011), it was estimated that a person drinks 2.7 cups of tap water per day, with a third of that occurring away from home.

Table D-2. Estimated daily use statistics.

Type of assumption	Frequency
Male's daily toilet uses	1 use per day per male
Male's daily urinal uses	3 uses per day per male
Male's daily hand washes	4 uses per day per male
Female's daily toilet uses	4 uses per day per female
Female's daily hand washes	4 uses per day per female

Type of assumption	Frequency
Person's daily cafeteria sink uses	0.4 uses per day per person
Total number of daily male showers	12 total male showers per day
Total number of daily female showers	3 total female showers per day
Avg. shower duration (min)	8 min per shower
Avg. hand wash duration (s)	16 seconds per hand wash
Avg. cafeteria sink duration (s)	16 seconds per use
Avg. tap water drunk per day (cups)	2.7 cups per day per person
Fraction of tap water drunk away from home	0.33

D.2 Measured flow rates

Faucet flow rates (pre-retrofit) and toilet/urinal flush amounts were measured and are summarized in Appendix C.

D.3 Building results

A description of the three buildings with their respective estimated water users is presented below. For some users, e.g., certain labs, water is used every day, weekends included. Since most of CERL's water consumption occurs during the weekdays, non-workday water uses were averaged into work day uses. For example, if a device uses 10 gallons per day, 7 days a week, it was estimated that it would use 10*7/5 = 14 gallons per work day. Keeping a consistent denominator allowed for adding up the total average daily water consumption.

D.3.1 Bldg. 1

Regarding water-using rooms, Bldg. 1 has a men's restroom, a women's restroom, a men's locker room, a small kitchen area, a bathroom in a DPW area, two water fountains, and over a dozen lab areas. Water use in Bldg. 1 can vary depending on what experiments are running. Each water user is described below in Table D-3.

Table D-3. Bldg. 1 water users.

Room description	GPD
Men's room – Has two toilets, three urinals, and three faucets. Pre-retrofit, an average faucet flow rate of 1.1 GPM was measured, and the average toilet and urinal water use was estimated at 1.5 gallons per flush (GPF). Since there is a men's locker room in Bldg. 1, it was assumed that only 80% of Bldg. 1's male population use this restroom, and the other 20% use the locker room as a primary bathroom.	205
Women's room – Has two toilets and two faucets. Pre-retrofit, an average faucet flow rate of 1.25 GPM was measured, and the average toilet use was estimated at 3 GPF.	958

Room description	GPD
Men's locker room – Has two toilets, one urinal, two faucets, and five showers. One shower did not appear to be working, as it was primarily being used as a storage area. Pre-retrofit, an average faucet flow rate of 1.25 GPM was measured, the average toilet water use was estimated at 2 GPF, the average urinal water use was estimated at 1.5 GPF, and the average shower flow rate was measured at 2.325 GPM.	279
Kitchen – Has a faucet and a coffee machine. Pre-retrofit, the faucet was measured at 0.7 GPM for a reasonable flow for hand washing. The coffee machine was estimated to hold 2 liters of coffee (0.53 gallons) and be refilled approximately 14 times a day.	14
DPW restroom – The DPW staff have a bathroom located on the north end of Bldg. 1. This bathroom was unknown to exist at the time of the audit, however data for this bathroom has been collected already (Miller 2014). This DPW area consists of a faucet with a flow rate of 1 GPM and a toilet with a water flow rate of 2 GPF. It was estimated that this bathroom has approximately four uses per day. This bathroom was not retrofit.	9
Water fountains – There are two water fountains in Bldg. 1 with an average flow rate (of faucet operation, not button operation) of 1.2 GPM.	5
Labs – The lab descriptions are explained in the next table.	554
Total	2023

There are over a dozen labs at CERL, each with varying degrees of water use, depending on the experiments being run. The sinks in these labs were not retrofit. Table D-4 shows a breakdown of these labs and their estimated water uses.

Table D-4. Bldg. 1 lab water users.

Lab description	GPD
CERL lab eye/face wash stations and safety showers – There are a total of 15 eyewash stations and 13 safety shower stations in the various labs at CERL. CERL staff tests the eyewash stations on a weekly basis (estimated at 15 gallons of water use total), and UIUC personnel test the eyewash stations and safety showers every 3 months (estimated at 6 gallons per eyewash and 17.5 gallons per safety shower). This computes to water use of 317.5 gallons every 3 months, or 7.9 GPD on average.	8
Paint Lab – Has two sinks: one that is used for non-lab purposes (e.g., washing dishes or hands) and another in the formulation room that is used very infrequently. The average use of these sinks is 1.6 GPD.	2
Accelerated Weathering Lab – Has a salt fog chamber and an accelerated weathering tester, which have a combined water use of 1.7 GPD.	2
Immersion Tanks – Paint Lab experiments are also set up in immersion tanks near room 1175. These immersion tanks run continuously 24/7 with a flow rate of 33 GPD, or 46.2 GPD for each average work day.	46
Microfab Lab – Has sink used infrequently for washing hands for an average use of 0.2 GPD	0
Advanced Materials Lab – Has a sink which is used infrequently for washing hands and glassware, for an average use of 1.2 GPD.	1

Lab description	GPD
Advanced Analytical Instrument Lab – Has a sink that is used for washing hands, for an average use of 2.1 GPD.	2
Air Pollution Lab – Has three sinks. One sink is used for experiments and washing glassware at an average 35.1 GPD. A second sink is used for mostly washing hands, for an average use of 3.3 GPD. The third sink is mostly used for experiments for an average of 44.1 GPD.	82
Materials Fabrication and Weathering Lab – Currently does not have any water demand. However, the lab space is being remodeled and may have some water use in the future.	0
Nanomaterials and Sustainable Systems Lab – Has two sinks used primarily for lab uses with a total average amount of 18.5 GPD.	18
Soils Lab – Has two sinks and a glassware washer. On average, water for experiments amounts to 0.5 GPD, and the glassware washer uses 0.6 GPD.	1
Synthetic Bio Lab – Has two sinks, a water purifier, glassware washer, and ice maker. The sinks are mostly for handwashing at an average total use of 3 GPD. The purifier, washer, and ice maker amount to 1.3, 7.0, and 0.6 GPD respectively.	12
Environmental Chem. Lab – Has a sink for mostly handwashing, a water purifier, and a glassware washer with water uses of 1.5, 1.3, and 4.6 GPD respectively.	7
Chem. Bio Lab – Has four sinks that use an average 7 GPD for mostly washing lab equipment, and a water purifier that uses 0.1 GPD.	7
Sustainable Infrastructure Systems Lab – Has a sink and a spigot, where the sink is mostly used for washing dishes at 2 GPD, and the spigot is used to periodically fill a 175 gallon water tank for lab purposes, for an average of 17.5 GPD.	20
Bio Lab – Has four sinks, two autoclaves for sterilization of equipment, and a water purifier. One sink is used for dishwashing at 10 GPD, two sinks are used primarily for handwashing at 10 GPD total, and the fourth sink is used rarely for handwashing at 0.2 GPD. Regarding the autoclaves, one uses approximately 238.5 GPD, and the other is a backup that is almost never used. The water purifier uses approximately 1 GPD.	260
Materials Prep Lab – Has sanding stations/polishing wheels that use a trickle of water. These are used on a monthly basis for approximately 0.2 GPD on average.	0
Scanning electron microscope (SEM) – Uses cooling water at 2.6 GPM. Use shown to be ~34 hrs. over past 3 months (not including times water left on), for an average use of ~85 GPD.	85
Total	554

D.3.2 Bldg. 2

Regarding water-using rooms, Bldg. 2 has a men's restroom, a women's restroom, a women's locker room, a kitchen, a smaller kitchen area, two water fountains, and a high bay area. Water use in Bldg. 2 is approximately constant, with exception to a few times a month when the high bay area can use tremendous amounts of water. Each water user is described below in Table D-5.

Table D-5. Bldg. 2 lab water users.

Room Description	
Men's room – Has two toilets, three urinals, and three faucets. Pre-retrofit, an average faucet flow rate of 1.3 GPM was measured, the average toilet water use was estimated at 2 GPF, and the average urinal water use was estimated at 1 GPF.	470
Women's room – Has two toilets and two faucets. Pre-retrofit, an average faucet flow rate of 1.4 GPM was measured, and the average toilet use was estimated at 2 GPF. Since there is a women's locker room in Bldg. 2, it was assumed that only 80% of Bldg. 2's female population use this restroom, and the other 20% use the locker room as a primary bathroom.	251
Women's locker room – Has two toilets, two faucets, and five showers. Pre-retrofit, an average faucet flow rate of 1.25 GPM was measured, the average toilet water use was estimated at 3.5 GPF, and the average shower flow rate was measured at 2.1 GPM.	209
Kitchen – Has a faucet, coffee machine, and ice machine. Pre-retrofit, the faucet was measured at 1.5 GPM for a reasonable flow for hand washing. Because a smaller kitchen area exists in Bldg. 2, it was estimated that 90% of Bldg. 2's population use the main kitchen, and the other 10% use the smaller one. Regarding the coffee machine, it was assumed that coffee drinkers at CERL use the Bldg. 1 coffee machine instead. The ice machine was estimated to make 180 lbs of ice per day, or 21.6 gallons.	34
Smaller kitchen area – Pre-retrofit, the smaller kitchen area has a sink that was measured at 1.7 GPM, with a total use of 2.2 GPD.	2
Water fountains – There are two water fountains in Bldg. 2 with an average flow rate (of faucet operation, not button operation) of 1.2 GPM.	5
High bay – The high bay holds a hydraulic pump that can use approximately 50 gallons per minute for cooling purposes (Miller 2014). Since this is a large amount of water that is used infrequently, it was not included in the Bldg. 2 average calculation. There is also a concrete construction project in the high bay, which uses approx. 125 GPD on average for concrete making.	125
Total	1096

D.3.3 Bldg. 3

Regarding water-using rooms, Bldg. 3 has a men's restroom, a women's restroom, a kitchen area, and a water fountain. Water use in Bldg. 3 is mostly dependent on building population and is thus approximately constant as there are no lab areas. Each water user is described below in Table D-6.

Table D-6. Bldg. 3 water users.

Room description	GPD
Men's room – Has two toilets, two urinals, and three faucets. Pre-retrofit, an average faucet flow rate of 1.0 GPM was measured, the average toilet water use was estimated at 2 GPF, and the average urinal water use was estimated at 1.5 GPF.	283

Room description	GPD
Women's room – Has four toilets and three faucets. Pre-retrofit, an average faucet flow rate of 1.2 GPM was measured, and the average toilet use was estimated at 2 GPF.	505
Kitchen area– Has a faucet with a pre-retrofit flow rate of 1.2 GPM.	7
Water fountains – There is one water fountain in Bldg. 3 with an average flow rate (of faucet operation, not button operation) of 1.6 GPM.	3
Total	799

Appendix E: CERL Water Use Box and Whisker Plots

Box and whisker plots were also generated for the three buildings and Bldg. 3 men's restroom for the period from 6/1/15 through 10/25/16, showing the relative water use for each day of the week (Figures 4 through 7). Friday data includes any weekend water use. Also, red squares were added to the graphs to show the average value.

For Bldgs. 1 and 2, water use can vary depending on what labs are using water. For Bldg. 3 and its men's restroom, water use is more predictable, where the average water use is lowest on Fridays and Mondays, which corresponds to some CERL employees who frequently take Mondays or Fridays off. Again, due to inaccuracies involving meter sizes, this data is mostly representative of relatively high flow rate uses, such as toilet flushing, lab uses, and sometimes showers.

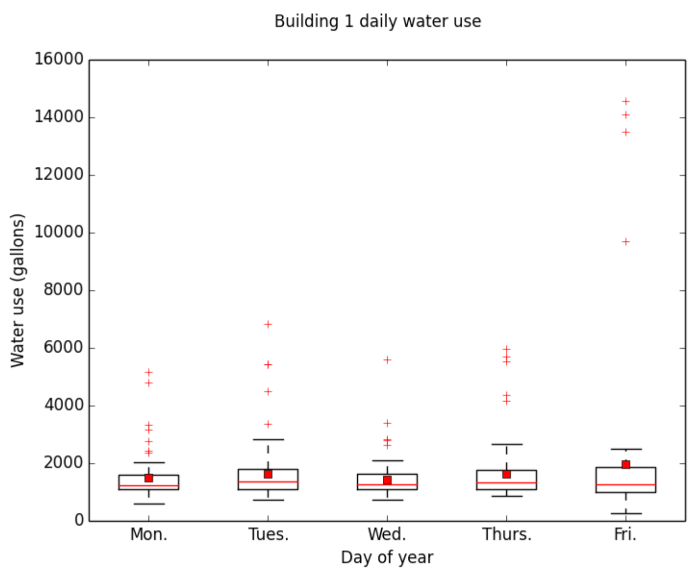

Figure 4. Bldg. 1 daily water use box and whisker plot.

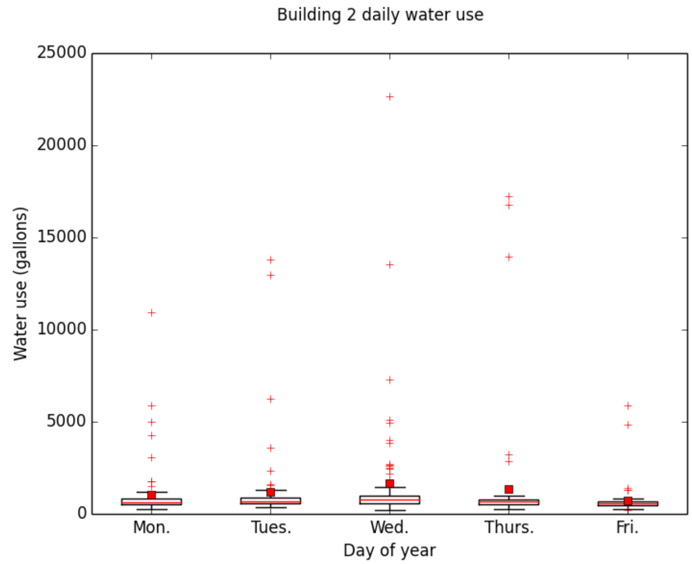

Figure 5. Bldg. 2 daily water use box and whisker plot.

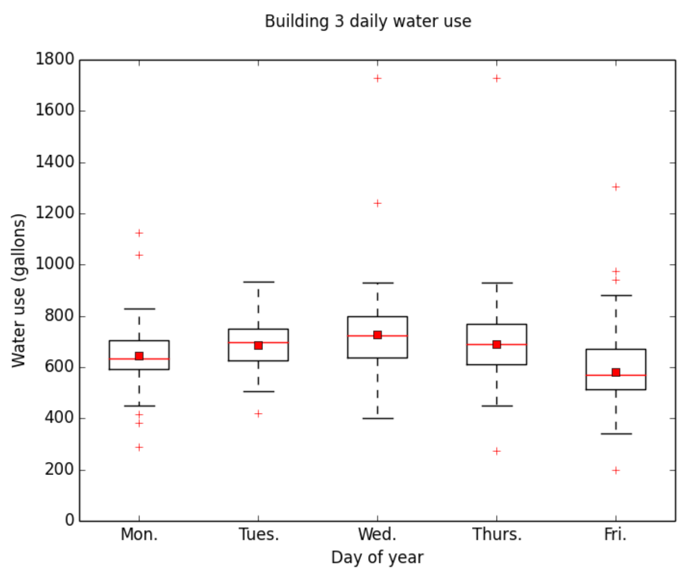

Figure 6. Bldg. 3 daily water use box and whisker plot.

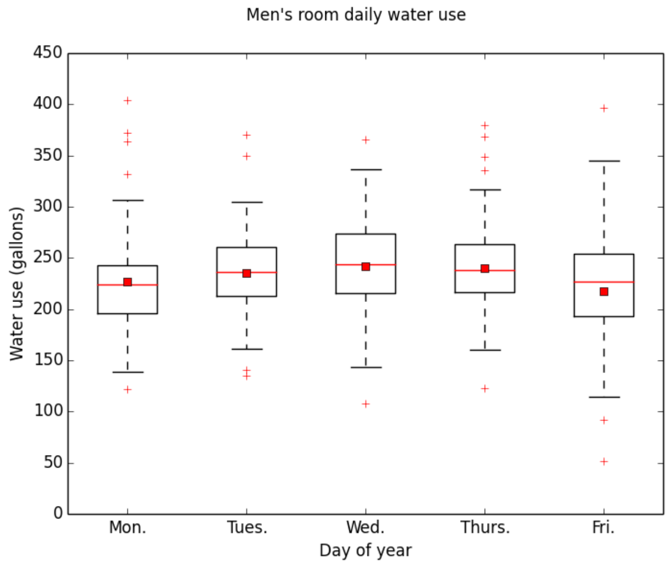

Figure 7. Bldg. 3 men's restroom daily water use box and whisker plot.

Appendix F: CERL Men's Restroom People Counting

There are various types of people counters commercially available, including some that use cameras, infrared (IR) devices, or magnets. Camera people counters can't be used in a bathroom, therefore devices using infrared technology and magnets were selected. Additionally, it is likely that camera people counters are more complicated and expensive, making them less attractive compared to other options. Regarding the people counters used in this study, it was unknown whether the infrared people counter or the magnet people counter would be more accurate, so both were tested.

The infrared device of choice, the EPC-IRD1 Electronic Pedestrian Counter made by Inter-Dimensional Technologies, Inc., was chosen because it is an effective and relatively low cost (~$174) option. It functions by emitting an IR beam so that when a person passes through it, the IR beam is reflected off of the person and is read by the device's receiver sensor (Inter-Dimensional Technologies, Inc. 2011). The default range of the sensor is effective to a little over a foot, and it can be increased by another 10 inches at the cost of some battery life. Also, the IRD1 emits an IR beam at 2 times per second, however this frequency can be increased at the cost of battery life. For longer distances (e.g., for a very wide door), a separate device can be purchased to function purely as a long-range IR beam generator, and the IRD1 would function only as a receiver. A person walking through the beam would break the beam and cause the IRD1 to increase count. For the purposes of this study, however, the ~22-in. extended range of the IRD1 alone was satisfactory. Placement of the sensor was important, as the beam had to pass through everyone entering the bathroom, and it also had to not be triggered by the bathroom door opening. Another consideration was that if the IR beam hit a metal wall, the beam would be reflected back into the sensor, giving false counts. The bathroom wall was not metal, however for metal walls, a less reflective covering can be placed over the metal part. Additionally, the IRD1 has to be placed away from sunlight in an area where stray IR beams do not impact it.

The magnetic people counter used was the EPC-MAG1 Electronic Pedestrian Counter, also made by Inter-Dimensional Technologies, Inc. This device is also relatively low cost (~$99) and easy to set up. The MAG1 consists of a main body that is wired to a sensor that is placed along the top doorframe. On the door immediately across from the sensor, a separate magnet is installed so that whenever the door is opened, the magnet moves out of detection range of the sensor. When the door closes again, the sensor detects the magnet, and the count is increased by one (Inter-Dimensional Technologies, Inc. 2007). The MAG1 can also be configured to ignore a door bouncing when it shuts. The potential downside of this sensor is that if someone holds the door for someone or the door does not close fully before someone else enters, the MAG1 would only count one person.

The setup of the people counters in the men's bathroom is shown below in Figure 8. Opposite of the door is a privacy wall (not shown in the picture) which forces everyone entering and exiting to pass by the IRD1 detector. The setup of an IRD1 would likely be more challenging in a bathroom with an open layout, as the counter would need to be placed in a location that would register everyone walking by. This might necessitate the use of a MAG1 instead, though this could undercount if a significant amount of people use the bathroom and the door is not able to always fully close behind a user.

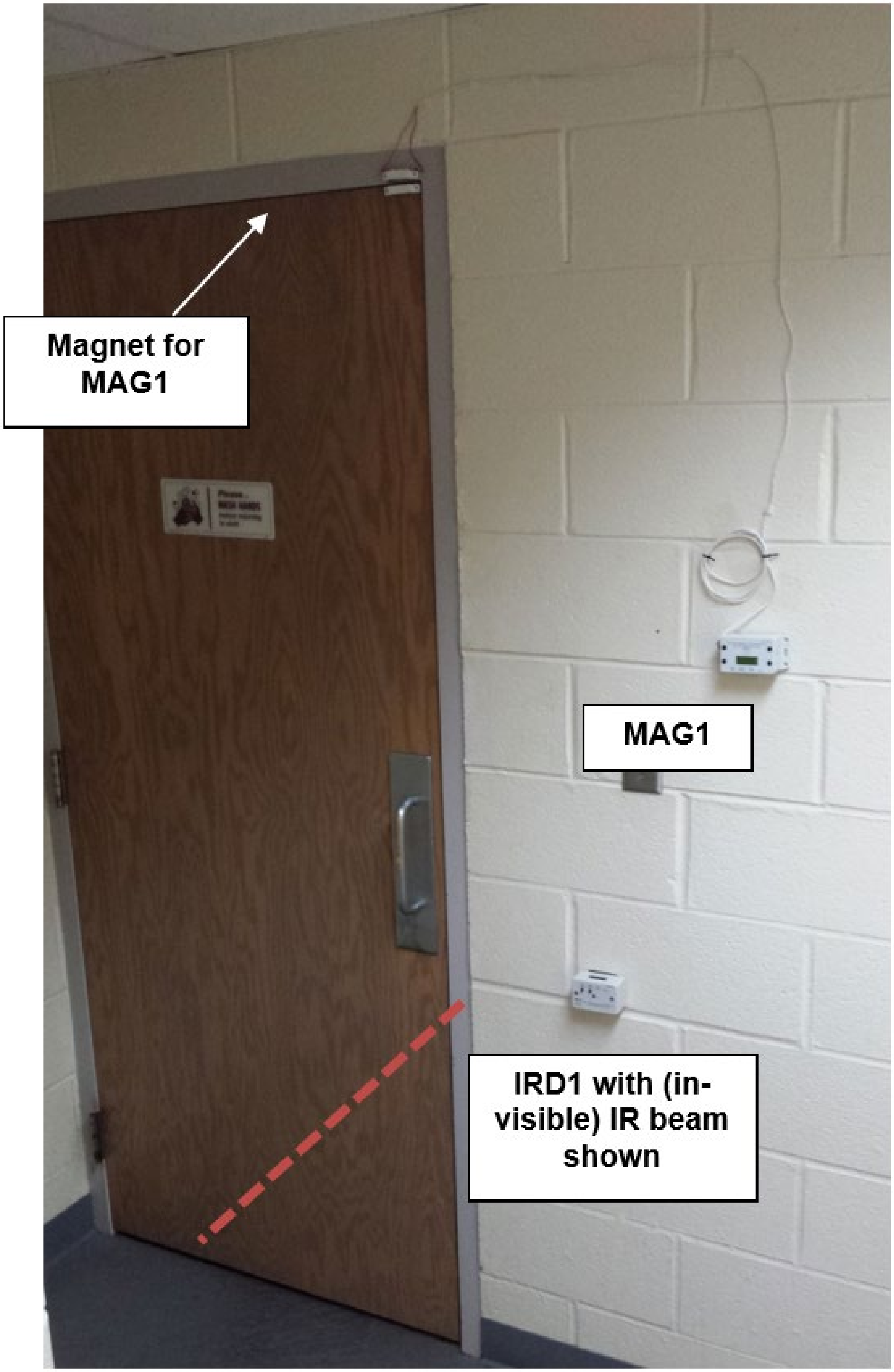

Figure 8. IRD1 and MAG1 placement.

Both detectors keep a running total of the number of counts. Though there is no way for the counters to track the counts over time, it might be possible for a user to customize the people counters to interface with a microcontroller to do this, such as an Arduino or a Raspberry Pi. For this project, the people counts were monitored daily (workdays only) at the beginning of the day (~7-8 AM). The daily values are computed by taking the count difference between two consecutive workdays and dividing by 2, since a person enters and exits the room. Any other factors are also taken into consideration, such as the person recording the counts entering and exiting the bathroom. If the resulting daily value was a decimal (corresponding to an odd people count number), it was rounded up. For the MAG1, this corresponds to the door not fully closing behind someone as another person enters. For the IRD1, this corresponds to possibly two people walking by the IRD1 before the IRD1 resets, only registering one person. Figure 9 shows the resulting daily traffic.

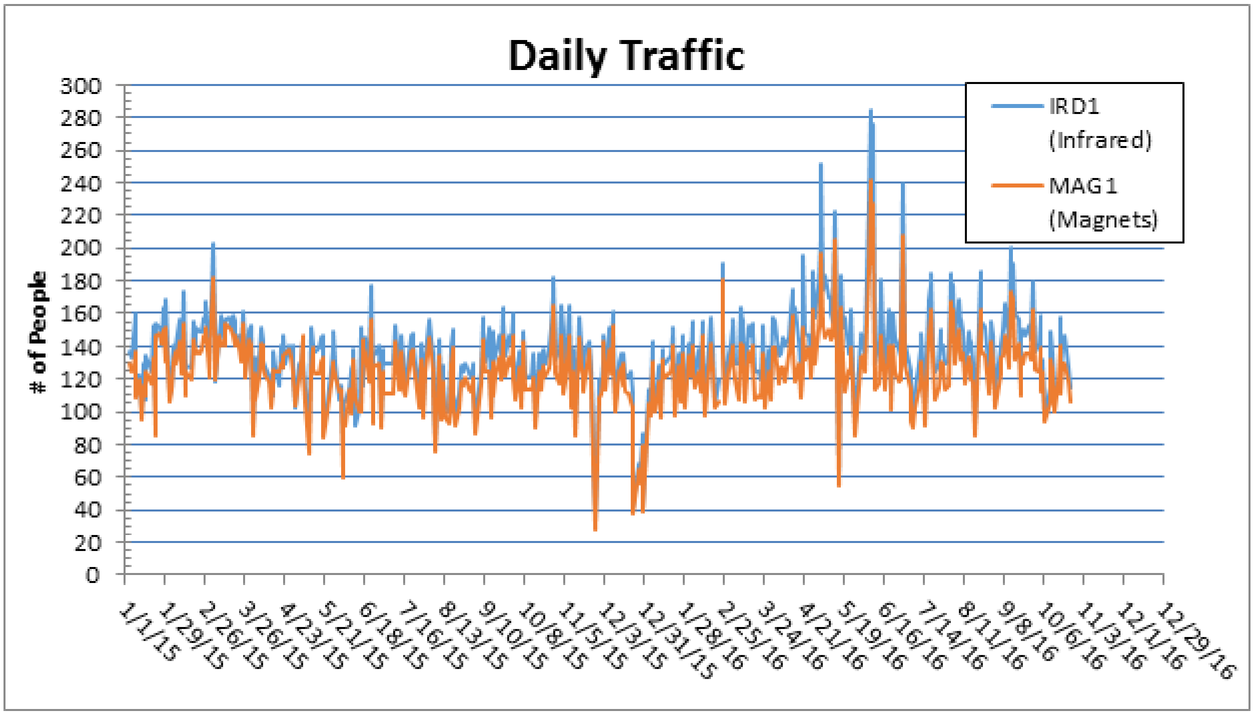

Figure 9. People counts for both people counters.

From the figure, it is apparent that the IRD1 generally has more counts per day than the MAG1. This is due to the bathroom door not completely closing when someone else walks in or leaves the bathroom. Thus, the IRD1 readings give more accurate values of the actual number of people. In general, the accuracy of the people counter depends on the type of room – if the door is able to close quickly and there is no place to set an IRD1 to capture everyone passing a certain point, the MAG1 would be more suitable.

Statistics on the people counters are provided below in Table F-1. The maximum value was observed when visitors from Fort Leonard Wood attended an all-day meeting with CERL members in the main conference room of Bldg. 3. The least number of people occurred during holiday periods.

Table F-1. People counter statistics.

	IRD1	MAG1
Mean:	138.08	125.70
Std. dev:	27.07	22.83
Min:	35	28
Max:	284	242
Mode:	130	125
Median:	138	126

Appendix G: Men's Restroom Retrofit and Graywater System Model

For the post-retrofit case, the following conditions were assumed:

- Existing high GPF toilets are replaced with 1.28 GPF toilets;
- The flush valves for the toilets are sensor-operated and sometimes flush too often ("ghost flushing") – the post-retrofit case assumes this is fixed;
- Existing urinals are replaced with waterless urinals;
- The faucets are installed with 0.5 GPM aerators; and
- A graywater recuse system is installed that recycles 80% of the faucet water.

This results in a daily water use of 62.9 gal, or 22.2% of the original bathroom water use. This drops an average visit's water use from 2.1 gal to 0.5 gal. Per year, this saves 57,560 gal of water, which translates to a money savings of $295 for the current Champaign, IL rate of $0.5130 per hundred gallons; energy savings have not been incorporated into this value. Details on the values used in these modeled cases are provided below in Tables G-1 and G-2.

Table G-1. Pre-retrofit water use of Bldg. 3 men's restroom.

Parameter	Value	Notes
Avg. daily Bldg. 3 male population	33.15	From CERL model; this matches well with actual avg. of 138 bathroom users using restroom at 4 times a day
Avg. toilet flush GPF	3.0	From estimated toilet flush amounts
Avg. urinal flush GPF	0.6	From estimated urinal flush amounts
# toilet uses per day per person	1	From water model
# urinal uses per day per person	3	From water model
Extra toilet (not urinal) flush factor	1.8	Calculated to match water model's water use with actual metered amount; some % of this is due to ghost flushing; also, note that urinals are never flushed more than once
Total toilet use (gal)	179.0	=(avg. daily pop.)*(uses per day)*(avg. GPF)*(extra flush factor)
Total urinal use (gal)	59.7	=(avg. daily pop.)*(uses per day)*(avg. GPF)
Total flush water (gal)	238.7	Actual daily metered amount for flushes was 236 gal
Average faucet flow rate GPM	1.27	Measured
# uses per day	4	From water model
Avg. hand wash duration (sec)	16	From water model
Total faucet use (gal)	44.8	=(avg. daily pop.)*(uses per day)*(avg. hand wash duration)*(avg. faucet flow rate) Actual daily metered amount for sinks was 42.7 gal

Parameter	Value	Notes
Total restroom daily water use (gal)	283.5	=(total flush water)+(total faucet use)

Table G-2. Predicted post-retrofit water use of Bldg. 3 men's restroom.

Parameter	Value	Notes
Avg. daily Bldg. 3 male population	33.15	From CERL model; this matches well with actual avg. of 138 bathroom users using restroom at 4 times a day
Avg. toilet flush GPF	1.28	Low flow toilets use 1.28 GPF
Avg. urinal flush GPF	0.0	Waterless urinal
# toilet uses per day per person	1	From water model
# urinal uses per day per person	3	From water model
Extra toilet (not urinal) flush factor	1.4	Eliminated ghost flushing
Total toilet use (gal)	59.4	=(avg. daily pop.)*(uses per day)*(avg. GPF)*(extra flush factor)
Total urinal use (gal)	0.0	=(avg. daily pop.)*(uses per day)*(avg. GPF)
Total flush water (gal)	59.4	
Average faucet flow rate GPM	0.50	Retrofit GPM
# uses per day	4	From water model
Avg. hand wash duration (sec)	16	From water model
Total faucet use (gal)	17.7	=(avg. daily pop.)*(uses per day)*(avg. hand wash duration)*(avg. faucet flow rate)
Reclamation %	80%	Needs better estimate (I guessed 80%)
Recycled water for flushing	14.1	=(total faucet use)*(reclamation %)
Total restroom daily water use (gal)	62.9	=(total flush water)+(total faucet use)-(recycled water)

Appendix H: Facility Personnel Feedback Survey

MCRD graywater system survey – November 2016

1) Rate your satisfaction with the MCRD graywater systems on a scale of 1-5, with 1 being very unsatisfied and 5 being very satisfied.

1 2 3 4 5

If you are unsatisfied, why? (e.g., mechanical issues, systems require too much maintenance/repairs, not pleased with performance, aesthetics, etc.)

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2) Rate your understanding of the MCRD graywater systems (i.e., how they work, how to fix them, etc.) on a scale of 1-5, with 1 being no understanding and 5 being excellent understanding.

1 2 3 4 5

3) List any issues you've had with the graywater systems, e.g., O&M issues, manufacturer issues, etc.

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4) Rate the ease to perform maintenance/repairs on the MCRD graywater systems on a scale of 1-5, with 1 being very difficult and 5 being very easy.

1 2 3 4 5

5) How often have the systems required maintenance/repairs, and what type of work has been done (replacing parts, fixing broken parts, etc.)?

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6) Are maintenance/repair issues usually something that you or someone on-base can address, or do you need to contact someone outside (and if so, who)?

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7) For the systems that are offline, approx. how long did they last before getting turned off?

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8) Approx. how often are filters cleaned or changed?

____

9) Rate the performance of the MCRD graywater systems on a scale of 1-5, with 1 being poor and 5 being excellent.

1 2 3 4 5

Explanation (if any):

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10) Has a drop in water use been noticed with the graywater systems (presumably for Bldg. 573 since this is the only working system)?

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11) Do you consider the graywater systems to be cost-effective (considering water savings, energy costs, filter costs, maintenance costs, overall system costs, etc.)?

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12) Have you received comments from others on base about the graywater systems? If so, what has been said?

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13) Does the irrigation system add-on ever get used? And if so, is it effective?

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14) Do you think the systems' documentation is adequate for your needs? If not, what is lacking?

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15) Rate how satisfied you are with the graywater system data collection on a scale of 1-5, with 1 being very unsatisfied and 5 being very satisfied.

1 2 3 4 5

If you are unsatisfied, why? (e.g., are there capabilities you think should be included, is there data that's missing, etc.)

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16) Rate how satisfied you are with the graywater system controls on a scale of 1-5, with 1 being very unsatisfied and 5 being very satisfied.

1 2 3 4 5

If you are unsatisfied, why? (e.g., are there additional controls or capabilities that should be included, etc.)

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17) Do you have any "lessons learned" regarding the graywater systems, or other comments you would like to share?

18) What recommendations would you have for others interested in a graywater recycling system?

19) Would you recommend graywater systems to other installations?