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Long-Term Study on Landscape Irrigation Using Household Graywater – Experimental Study

INTERIM REPORT

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LONG-TERM STUDY ON LANDSCAPE IRRIGATION USING HOUSEHOLD GRAYWATER - EXPERIMENTAL STUDY

INTERIM REPORT

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Background

As water supply becomes more limited throughout the world, there is a growing interest for innovative approaches to water resources sustainability. One approach that is gaining popularity is household graywater reuse for residential landscape irrigation. Graywater irrigation systems offer many benefits, however the use of such systems has not become widespread due to concerns about safety issues. While some states have begun to legalize and regulate the practice of graywater reuse for residential landscape, little guidance based on scientific data has been provided for the safe operation of graywater irrigation systems. Limited scientific data is available on the fate of graywater chemical and microbiological constituents and the effect of these constituents on plant health after graywater is applied for irrigation. The objective of this research project is to elucidate information on the fate and occurrence of graywater constituents and their potential impacts on soil quality, groundwater quality, and plant and human health as a result of its application for residential landscape irrigation.

Phase 1 of the project, a literature review and synthesis, was completed in March 2006 and is available from WERF. The final report contains a comprehensive synthesis of the current state of the knowledge on graywater reuse for landscape irrigation at the household level. The report also identifies information gaps for future research, a number of which are being addressed through Phase 2.

Phase 2 began in May 2008 and includes a series of experimental studies. The Phase 2 experimental studies are being conducted in three parts: existing household systems, new household systems, and greenhouse studies.

First, soil samples were collected from several household sites that used graywater for irrigation for more than five years and compared with analogous soil and landscaping that had been irrigated with potable water. The second part of the study targets new applications of graywater to several selected sites; the sites may be new construction, or retrofits to newer homes that already have landscaping in place. These sites are being operated in a controlled manner for one to two years to determine the dynamics of changes to soil and plant health that might occur due to graywater irrigation and the risk to human health in new systems. In addition to the field studies, a greenhouse experiment is being conducted. The goal of the greenhouse studies is to evaluate, in a scientifically controlled environment, the toxicity potential of graywater irrigation to annual bedding plants and turfgrasses and to examine the impact of graywater irrigation on groundwater quality by conducting leachate analysis.

This interim report presents data collected to date from the first of the three parts of the experimental studies – existing household sites. The results are from 18 months of data collection on four households with graywater irrigation systems in place for more than five years. Rather than waiting to release this data at the end of the project in 2012, this interim report makes this information available in order to help fill the current research gap in a timely manner. However, interpretation of results may change as more data becomes available as the project progresses through spring of 2012. Therefore, it is important to note that conclusive recommendations on graywater irrigation cannot be made at this time.

Introduction

Data has been collected on plant health and soil quality from four homes that have had graywater irrigation systems in place from five years to 31 years at the time of sampling (Table 1). Homes included in the study are located in Bisbee, AZ, Escondido, CA, Fort Collins, CO, and Dallas, TX. These locations represent very different climatic and geographic conditions. The graywater systems at these homes varied from very simplistic to more complex with some treatment built into the system (Figures 1 through 4). For each site, a sample area was selected where graywater was applied for irrigation and a control area was also sampled with similar vegetation that had been irrigated with freshwater.

Table 1. Summary of Graywater Systems at Households Sampled to Date.

Location	Duration of Graywater Irrigation	Souce(s) of Graywater	System Description	Irrigation Method	Irrigation Frequency
Bisbee, AZ	6 years	Laundry, shower, handwash	Storage	Bucket	Manual application as needed
Escondido, CA	10 years	Laundry, shower, handwash	Storage, slow sand filter, pump	Submerged Drip	Daily
Fort Collins, CO	5 years	Laundry, shower, handwash	Storage, course filter, pump	Hose Application	Manual application as needed
Dallas, TX	31 years	Laundry	No storage, direct connect from washing machine	Hose Application	With operation of washing machine

Figure 1. Graywater System in Arizona Where Graywater is Collected in Buckets and Manually Applied to Plant Root Zones.

Figure 2. Graywater System in California Including a Sand Filtration Unit.

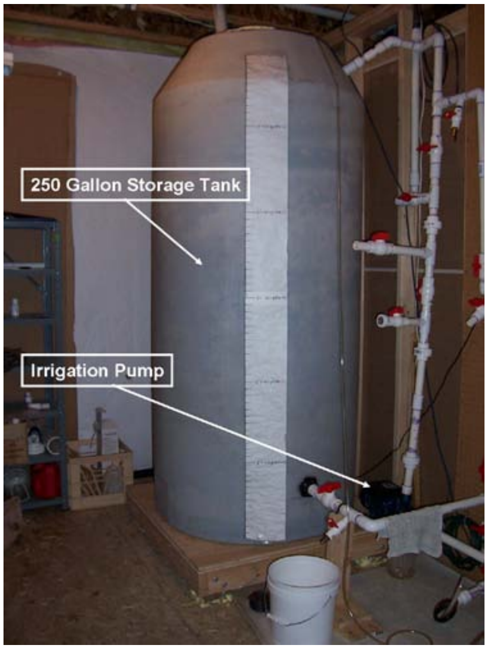

Figure 3. Graywater Storage Tank and Supply to Outdoor Irrigation in Colorado.

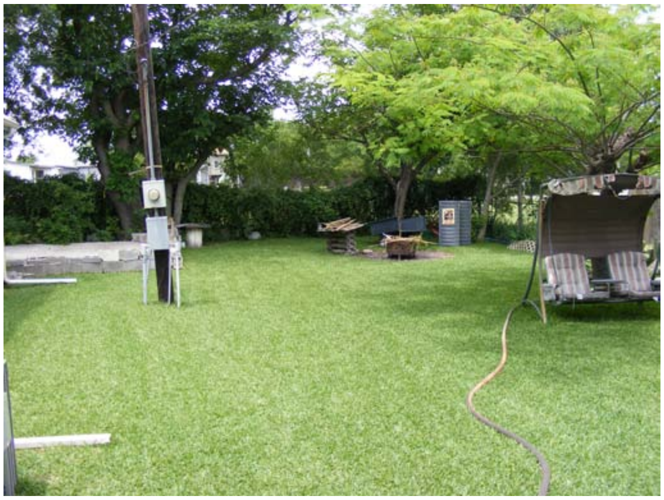

Figure 4. Direct Supply of Laundry Water to Lawn Through Hose (Texas Household).

Summary of Plant Sensitivity to Graywater Irrigation

Plants were evaluated for the following criteria: crown density, dieback, foliage color, foliar burn, foliar necrosis, leaf size, insect and disease presence, and overall quality. For evergreen conifers, the researchers also collected data on the number of years of needle retention and year-to-year growth increments. Based upon the overall evaluation, plants were classified for their relative tolerance levels to the use of graywater irrigation. Plants that exhibited some improvements or no changes under graywater irrigation were placed in very tolerant category. Plants that appeared healthy with only slight change in 1-2 evaluation criteria were placed in moderate tolerant category. Plants that exhibited small degree of decline were placed in moderate sensitive category whereas plants that exhibited significant decline were ranked as sensitive to graywater irrigation.

Our evaluations suggested that:

a. Juniper (*Juniperus spp*), Euonymus (*Euonymus spp.*), Rose of Sharon (*Hisbiscus syriacus)*, Chrysanthemum (*Chrysanthemum spp*.), and St. Augustine grass *(Stenotaphrum secundatum)* to be very tolerant to graywater irrigation (Figure 5).

b. The following plants exhibited moderate tolerance to graywater irrigation: California Valeriana (*Valeriana californica*) and Plum tree (*Prunus spp*.).

c. The following plants are moderately sensitive to graywater irrigation: Mugo pine *(Pinus mugho*) and Bearded iris *(Iris germanica*).

d. Landscape plants that are sensitive to graywater irrigation included: Scotch pine *(Pinus sylvestris)*, Hass avocado *(Persea americana* 'Hass'), and Lemon tree *(Citrus limonium*) (Figure 6).

No consistent trends were found regarding the influence of irrigation water source and individual leaf mineral content. The nature of the plant sensitivity is likely complex. Nevertheless one concern about the long-term use of graywater for landscape irrigation is the potential for salinity problems. The relationship between landscape plant salinity tolerance and their graywater response was assessed by comparing individuals plant salinity tolerance reported in the literature with the observations in this study. The regression coefficient (R^2) value of 0.36 suggest that the variance of landscape plant response to graywater cannot solely be attributed to plant response to salinity, in this case, salinity tolerance.

Figure 5. St. Augustine Grass (Upper Panel), Rose of Sharon (Middle Panel), and Euonymus Under Freshwater Irrigation (Left Panel) and Graywater Irrigation (Right Panel). These Plants Exhibited Some Improvements or No Changes under Graywater Irrigation.

Figure 6. Hass Avocado Under 50% Freshwater + 50% Graywater Irrigation (left panel) and 100% Graywater Irrigation (Right Panel). Compared to 50% Graywater Irrigated Plant, 100% Graywater Irrigation Had Reduced Leaf Size, More Severe Wilting, and Much Reduced Fruiting.

Summary of Soil Quality

Salts

An important concern related to water reuse is the accumulation of sodium (Na) and other salts in soil, which could adversely affect soil quality and plant health. All soil samples were analyzed for Sodium Adsorption Ratio (SAR), calculated as a proportion of Na to Ca plus Mg in soil, and electrical conductivity (EC), which indicates salt concentration in soil. All soil samples collected for this study had a SAR below 5 (Figure 7) and an EC of 2 mmhos cm^{-1} or less (Figure 8). The highest SAR and EC values were observed at the California household, where soils received manure as an amendment. With an EC value of 2, the California soil irrigated with potable water is considered very slightly saline, while the graywater-irrigated California soil and soils from CO and TX are considered non-saline (EC values < 2). In general, SAR values were slightly elevated in areas irrigated with graywater compared to freshwater among the households (except Colorado), although levels were not found to be high enough to cause concern for soil quality (Figure 7). For example, with a soil EC value of 2 mmhos cm^{-1} or less (very slightly saline to non-saline), a soil would not be considered sodic (high enough in Na to harm soil quality and plant health) unless the SAR value was 13 or greater.

Excess sodium has been a known problem for reuse of reclaimed wastewater. As a comparison, SAR values in varying soil types irrigated with reclaimed wastewater have been found to range from 7.7 to 12.6 (Leal et al., 2009; Qian and Mecham, 2005) while SAR was lower than 3.5 in all samples irrigated with graywater collected for our study. Of note is that several soil types were included in our study; clay loam (Colorado soils and freshwater-irrigated Texas soil), loam (freshwater-irrigated California soil), sandy loam (graywater-irrigated California soil), and sandy clay loam (graywater-irrigated Texas soil). Other research (Gross et al., 2005) has also shown that after irrigation with graywater for three years, EC and SAR were not found to increase in native soils at levels which would affect plant health. This result has important implications in terms of the value of graywater for irrigation as compared to reclaimed wastewater. Interestingly, SAR is not necessarily higher in reclaimed wastewater compared to graywater. A review of the literature revealed that the SAR for reclaimed wastewater ranges from 3 - 11 and is typically lower than 8 while the SAR for graywater ranges from 3 - 6 (Wiel-Shafran et al., 2006; Gross et al., 2005; Finley et al., 2009).

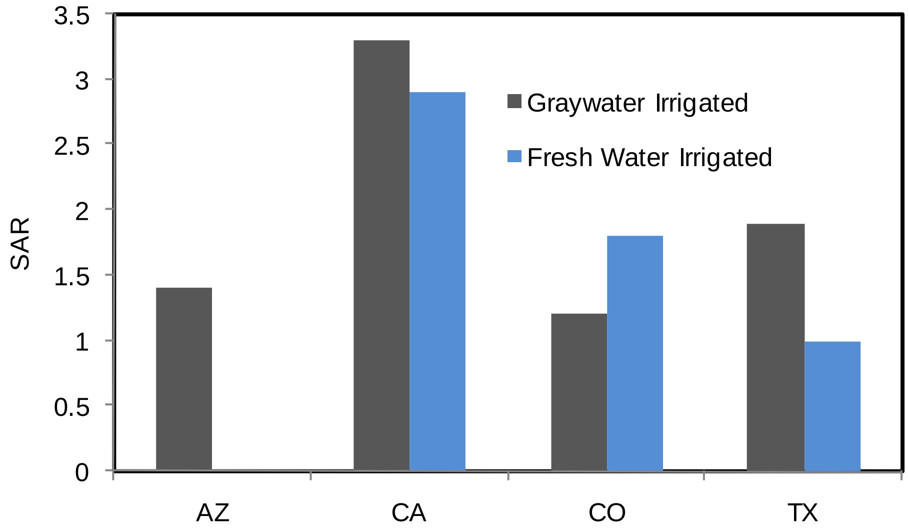

Figure 7. SAR in Soil Samples (0 – 15 cm) Collected from Households with Graywater Irrigation in Place for More Than Five Years.

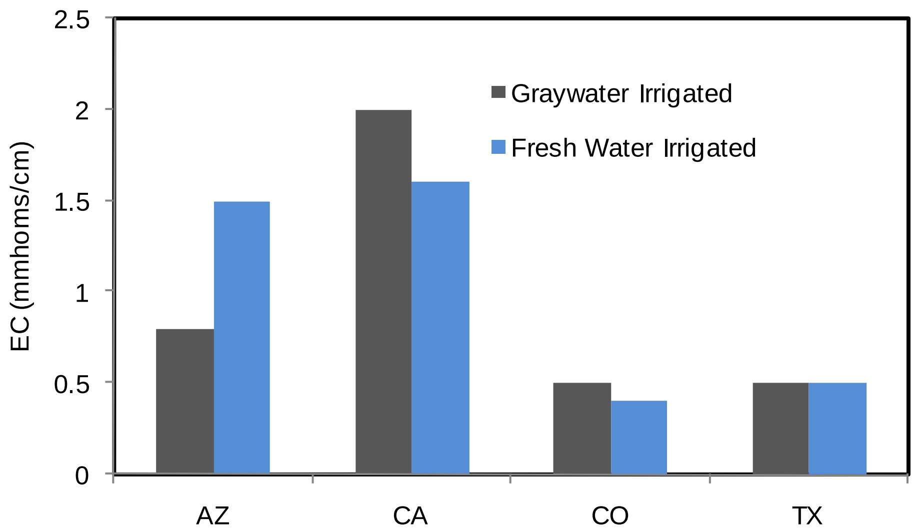

Figure 8. EC in Soil Samples (0 – 15 cm) Collected from Households with Graywater Irrigation in Place for More Than Five Years.

Surfactants

Another concern associated with the reuse of graywater is the fate of personal care product ingredients. Personal care products may migrate to groundwater or be transported in runoff after rainfall events. Surfactants, the primary ingredient in soaps and detergents, were measured in soil samples. Our analysis to this point has included linear alkyl benzene sulfonate (LAS), alkyl ethoxy sulfate (AES), and polyalcohol ethoxylate (PAE). Total surfactants were calculated by summing LAS, AES, and AE measured in soil samples (Figure 9). Surfactants were generally present at higher concentrations in graywater irrigated areas compared to areas irrigated with freshwater (Figure 9). The highest concentration of surfactants in surface soil (214 μg/kg) was measured at the household in Bisbee, AZ where very little vertical migration of water through soil was noted. The most relevant comparison for surfactants present in soils irrigated by graywater would be their presence in soils irrigated with reclaimed wastewater. Data is not available in the literature reporting surfactant concentrations in soils irrigated with reclaimed wastewater. However, data is available reporting LAS concentration in soil below tile field gravel where domestic septic effluent was dispersed. LAS was determined to be 7 mg/kg in soil 2.5 cm below the tile field gravel and was below the detection limit of 1 mg/kg at a depth of 5 cm below the tile field gravel (McAvoy et al, 1994). For our study, the highest observed concentration of LAS was 0.13 mg/kg in soil irrigated by graywater. Data is also available reporting surfactant concentration in soils amended with wastewater treatment plant biosolids. LAS concentration immediately after biosolids application was reported as high as 66 mg/kg and typically decreased to below 5 mg/kg within 12 months of application (Berna et al., 1989; Figge and Schoberl, 1989; Knaebel et al., 1990; Marcomini et al., 1989; Prats et al., 1993; Waters et al., 1989). Total surfactants were well below 66 mg/kg in soil samples collected from graywater irrigated areas, with the highest total surfactant concentration was 0.21 mg/kg. In comparison to soils receiving septic effluent or amended with biosolids, surfactants concentrations are lower in graywater irrigated soils.

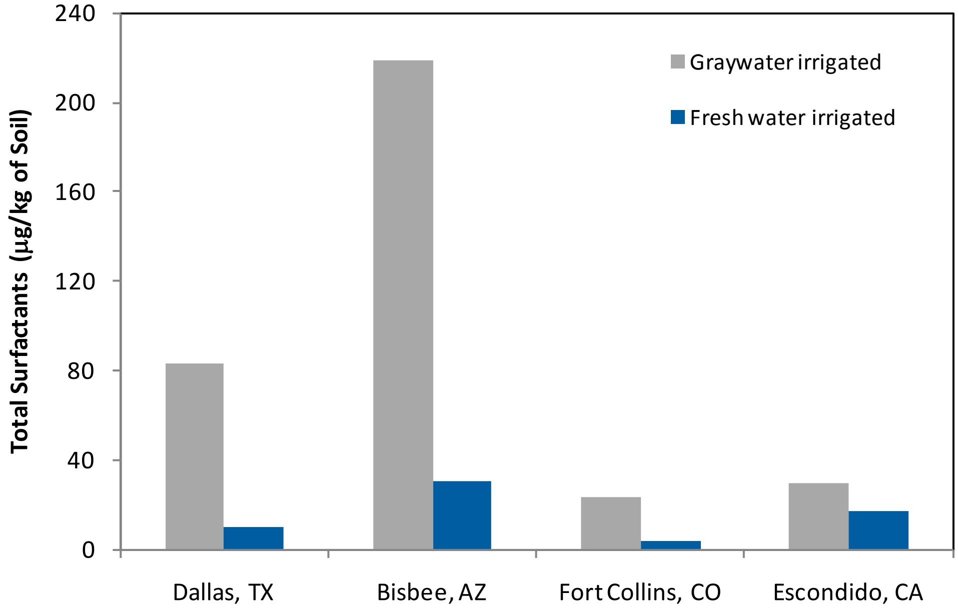

Figure 9. Surfactant (LAS, AES, and AE) in Soil Samples (0 – 15 cm) Collected from Households with Graywater Irrigation in Place for More Than Five Years.

Fecal Indicator Bacteria

Graywater contains fecal bacteria and other organisms, which could pose a risk to humans if pathogens are present in feces. The researchers therefore quantified several types of bacteria indicative of fecal contamination in soils irrigated with graywater or freshwater to determine the potential for graywater to add fecal bacteria to the environment. Measured indicator organisms included *Escherichia coli*, enterococci, and *Clostridium perfingens*. Numbers of *E. coli* were < 1 cell g^{-1} soil in soil from Arizona and California and were greater in graywater-irrigated soil only in Texas (Figure 10). Across all four households, the average number (and standard deviation) of *E. coli* was 9 cells g^{-1} soil (± 19) for freshwater-irrigated soil and 11 cells g^{-1} soil (± 16) for graywater-irrigated soil, with no statistically significant effects of graywater irrigation ($P = 0.80$; paired t-test with $\alpha = 0.05$).

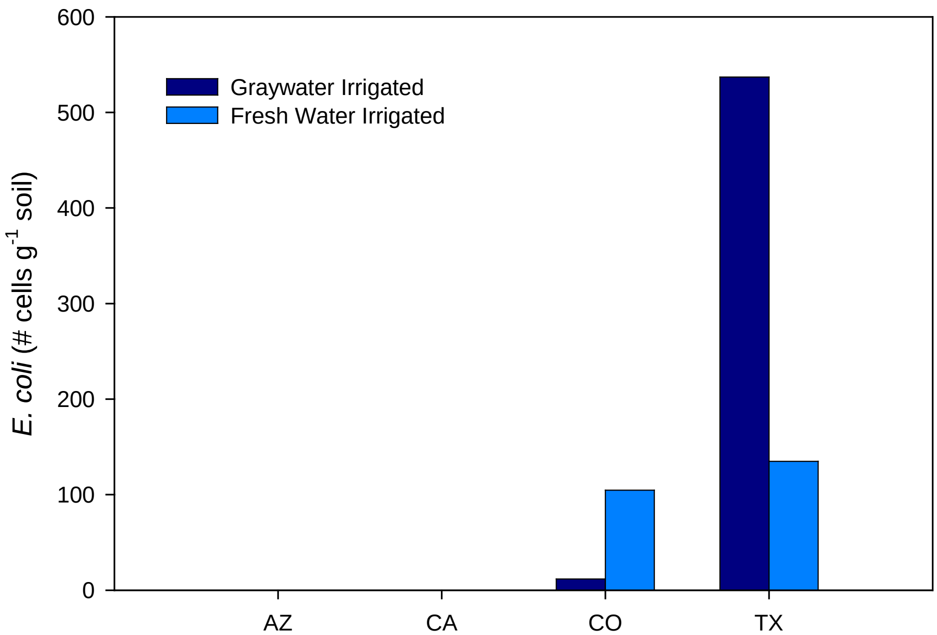

Figure 10. Numbers of *E. coli* in soil (0-15 cm) Collected from Households with Graywater Irrigation in Place for More than Five Years.

Enterococci were detected in high numbers (relative to E. *coli*) for almost all soils (Figure 11). Enterococci numbers were greater in graywater-irrigated soil in California and Texas, but the opposite trend occurred in Arizona and Colorado, where enterococci were below detection limits (<1 cell g^{-1} soil) in the graywater-irrigated soil. Across all four households, the average number (and standard deviation) of enterococci was 2,630 cells g^{-1} soil (± 20) for freshwater-irrigated soil and 480 cells g^{-1} soil (± 81) for graywater-irrigated soil, with no statistically significant effects of graywater irrigation ($P = 0.40$; paired t-test with $\alpha = 0.05$). *Clostridium perfringens* were below the limits of detection in all soils (<10 colony forming units g^{-1} soil), except for the freshwater-irrigated soil in Texas, where *C. perfringens* was quantified as 300 colony forming units g^{-1} soil.

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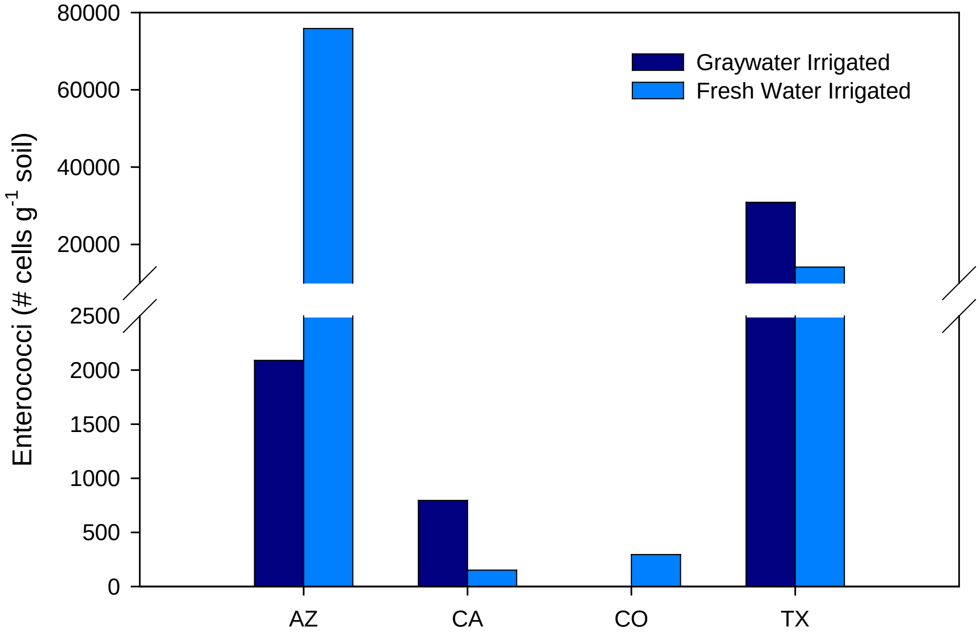

Figure 11. Numbers of Enterococci in Soil (0-15 cm) Collected from Households with Graywater Irrigation in Place for More Than Five Years. Note the Break in the Y-Axis Scale, Where Data Within the Range of 2,500 to 10,000 Cells G^{-1} Soil Are Not Shown.

Unlike for waters (marine, fresh, and drinking water), there are no regulatory standards for fecal indicator organisms in soil. However, the overall numbers (maximum of ~ 1,000 *E.coli* and ~100,000 enterococci per g soil) indicate that fecal indicator organisms at these households are probably a relatively minor component of the entire soil microbial community, as total bacteria typically range in the order of ten million to one billion cells per g soil. Overall, there were no consistent trends of graywater effects on fecal indicator organisms, likely because of highly variable conditions among households (climate, soil type, graywater composition, etc.) as well as confounding effects at individual households. For example, fecal indicator counts were likely affected by the presence of domestic animals or wildlife which defecated on the soils. This was particularly apparent at the Texas household, where free-range chickens and dogs were known to defecate on the graywater-treated area and may have contributed to the high numbers of *E. coli* and enterococci at this location. Others have found that high numbers of enterococci relative to *E. coli* may indicate wildlife as a source of fecal contamination, rather than anthropogenic sources (Fisher et al., 2000). This further supports the impact of animal influence at the TX household, and possibly the AZ and CA households as well.

Summary of Graywater Irrigation Systems

Several types of graywater irrigation systems which have been in place for more than five years were included in this study, one with submerged drip lines and three with surface application of graywater (Table 1). Much debate exists over whether graywater irrigation distribution systems should be submerged underground or if surface application of graywater is acceptable. The household in CA included in this study had submerged drip irrigation lines and adhered to CA state regulations, which require that graywater irrigation systems are buried underground. Of note is that the depth to bedrock at this site was very low, typically less than 6". Resurfacing of graywater was visually observed at the site. In cases where top soil is shallow, application of graywater below the ground surface may actually result in resurfacing of graywater compared to surface application systems. The primary concern for surface application is potential human contact with pathogens in the top layer of the soil. While indicator organism numbers were highly variable among the three households in the top 0 – 6" of soil, numbers of indicator organisms were not consistently greater in areas irrigated with graywater compared to areas irrigated with freshwater in any sites tested, including those where graywater was surface applied. It is not possible to make comparisons about risk associated with surface drip irrigation as compared to submerged application of graywater based on pathogen indicator organism numbers measured for this study. Indicator organism numbers were not consistently greater in the top 0 – 6" of soil in samples collected from sites where graywater was applied to the soil surface as compared to a site where graywater irrigation emitters were buried below the ground surface.

The results reported in this report are from 18 months of data collection on four households with graywater irrigation systems in place. Interpretation of results may change as more data becomes available as the project progresses through spring of 2012. Conclusive recommendations on graywater irrigation cannot be made at this time.

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Ohio
Akron, City of
Butler County Department of Environmental Services
Columbus, City of
Metropolitan Sewer District of Greater Cincinnati
Montgomery, County of
Northeast Ohio Regional Sewer District
Summit, County of

Oklahoma
Oklahoma City Water & Wastewater Utility Department
Tulsa, City of

Oregon
Albany, City of
Clean Water Services
Eugene, City of
Gresham, City of
Portland, City of Bureau of Environmental Services
Lake Oswego, City of
Oak Lodge Sanitary District
Water Environment Services

Pennsylvania
Hemlock Municipal Sewer Cooperative (HMSC)
Philadelphia, City of
University Area Joint Authority

South Carolina
Charleston Water System
Mount Pleasant Waterworks & Sewer Commission
Spartanburg Water

Tennessee
Cleveland Utilities
Murfreesboro Water & Sewer Department
Nashville Metro Water Services

Texas
Austin, City of
Dallas Water Utilities
Denton, City of
El Paso Water Utilities

Fort Worth, City of
Houston, City of
San Antonio Water System
Trinity River Authority

Utah

Salt Lake City Corporation

Virginia

Alexandria Sanitation Authority
Arlington, County of
Fairfax, County of
Hampton Roads Sanitation District
Hanover, County of
Henrico, County of
Hopewell Regional Wastewater Treatment Facility
Loudoun Water
Lynchburg Regional Wastewater Treatment Plant
Prince William County Service Authority
Richmond, City of
Rivanna Water & Sewer Authority

Washington

Everett, City of
King County Department of Natural Resources
Seattle Public Utilities
Sunnyside, Port of
Yakima, City of

Wisconsin

Green Bay Metro Sewerage District
Kenosha Water Utility
Madison Metropolitan Sewerage District
Milwaukee Metropolitan Sewerage District
Racine, City of
Sheboygan Regional Wastewater Treatment
Wausau Water Works

Water Services Association of Australia

ACTEW Corporation
Barwon Water
Central Highlands Water
City West Water
Coliban Water Corporation
Cradle Mountain Water
Gippsland Water
Gladstone Area Water Board
Gold Coast Water
Gosford City Council
Hunter Water Corporation
Logan Water
Melbourne Water
Moreton Bay Water
Onstream
Power & Water Corporation
Queensland Urban Utilities
SEQ Water
South Australia Water Corporation
Sunshine Coast Water
Sydney Catchment Authority
Sydney Water
Unity Water
Wannon Regional Water Corporation
Watercare Services Limited (NZ)
Water Corporation
Western Water
Yarra Valley Water

Canada

Edmonton, City of/Edmonton Waste Management Centre of Excellence
Lethbridge, City of
Regina, City of, Saskatchewan
Toronto, City of, Ontario
Winnipeg, City of, Manitoba

STORMWATER UTILITY

California

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Los Angeles, City of, Department of Public Works
Monterey, City of
San Francisco, City & County of
Santa Rosa, City of
Sunnyvale, City of

Colorado

Aurora, City of
Boulder, City of

Florida

Orlando, City of

Iowa

Cedar Rapids Wastewater Facility
Des Moines, City of

Kansas

Lenexa, City of
Overland Park, City of

Kentucky

Louisville & Jefferson County Metropolitan Sewer District

Maine

Portland Water District

North Carolina

Charlotte, City of, Stormwater Services

Pennsylvania

Philadelphia, City of

Tennessee

Chattanooga Stormwater Management

Texas

Harris County Flood Control District, Texas

Washington

Bellevue Utilities Department
Seattle Public Utilities

STATE

Connecticut Department of Environmental Protection
Kansas Department of Health & Environment
New England Interstate Water Pollution Control Commission (NEIWPCC)
Ohio Environmental Protection Agency
Ohio River Valley Sanitation Commission
Urban Drainage & Flood Control District, CO

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American Water
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