RESIDENTIAL GRAYWATER REUSE:
The Good, The Bad, The Healthy

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RESIDENTIAL GRAYWATER REUSE:
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INTRODUCTION

In arid regions of the U.S., water conservation and reuse are issues that receive a great deal of public attention. The search for ways to responsibly use and reuse water is vital to the sustainability of the water supply and thus the future of these areas. Wastewater treatment and reuse is one of the best water conservation options available to communities located in arid areas. Many large scale reuse efforts have been developed, such as the watering of golf courses with treated municipal effluent or the use of effluent for groundwater recharge (Asano, 1998). But the potential for wastewater reuse is not limited to large-scale projects supplied by community wastewater treatment facilities. It is also available to individual homeowners. Graywater recycling offers a way in which people can save and reuse the wastewater generated in their own home.

To add to the understanding of and clarify the issues surrounding the safe and effective use of household graywater, in 1998 the Water Conservation Alliance of Southern Arizona began an in depth study of residential graywater reuse in the greater Tucson area. The study, supported by the Arizona Department of Water Resources, the Arizona Department of Environmental Quality, the Pima County Department of Environmental Quality, looked at two separate aspects of graywater usage in the area: 1) the number of households currently using some portion of the graywater they generate and 2) the water quality of the residential graywater being generated and how that water quality affects the soil that is irrigated with that water. What follows are the results of this study.

SUMMARY OF FINDINGS:

GRAYWATER REUSE SURVEY: DATA & EVALUATION OF RESULTS

Mailings and Response Rates

Surveys were mailed to owner-occupied single family residences (SFRs) in the service areas of six water providers (Avra Water Co-op, Flowing Wells Irrigation District, Green Valley Water, Town of Marana, Metro Water Improvement District, Town of Oro Valley, Ray Water Company, and Tucson Water.) Residents of two additional service areas, Green Valley and Avra Valley, also were mailed surveys, despite the dearth of SFRs. In Green Valley, surveys were mailed to owner-occupied townhomes and condos. In Avra Valley, surveys were mailed to the owners of residential parcels which had improvements valued at more than $20,000. This approach was necessitated by Pima County's classification of manufactured homes as something other than permanent structures, as nearly all these are lots with manufactured homes and only a few are traditionally constructed residences.

Recipients were identified from the October 1999 Pima County ARCVIEW data base. All SFR properties within service area boundaries where the owner and the occupant were identical were identified and recipients randomly drawn from those pools. This sampling methodology resulted in each home owner within a service area having an equal chance of receiving a questionnaire. Between service areas, chances of receiving a survey varied considerably. For example, a much smaller percentage of home owners in Tucson Water's service area received surveys than in the Marana service area. For this reason, some results presented in this report are weighted so that some tentative conclusions can be drawn regarding graywater reuse throughout Pima County. (The County is used as a proxy for the Tucson Active Management Area.)

Survey mailings and response rates are summarized in Table 1. Just under 2,000 surveys were mailed, with some 600 usable responses returned. Response rates vary from 11 percent in Ray Water to 46 percent in Green Valley. These differences between service areas are likely due to different socio-demographic characteristics. For example, this type of survey is more likely to be returned by retirees.

Table 1:
MAILING & RESPONSES BY PROVIDER

PROVIDER	Mailed	Returned	% Returned
Avra Co-op	144	32	22.2
Flowing Wells	339	76	22.4
Green Valley	295	135	45.8
Marana	223	61	27.4
Metro	331	110	33.2
Oro Valley	173	59	34.1
Ray	170	19	11.2
Tucson Water	308	89	28.9
TOTAL	**1,983**	**581**	**29.3**

The overall response rate, including incomplete surveys, is around 33 percent. This is quite high for a fairly long mail-out survey with no follow-up phone calls or postcards.

Reuse of Graywater

Survey recipients were asked if they reuse any graywater. Responses to that question are summarized in Table 2.

A total of 49 respondents, or 8.4 percent of all respondents, indicated they reuse some of their graywater. Reuse rates by service areas vary considerably, from less than 2 percent to 25 percent. Some of the variability is probably due to the relatively small numbers involved. Nevertheless, some of the differences are statistically significant.

Service areas break down into three groups. Green Valley, Metro, and Oro Valley all show less than 4 percent reusing graywater. Differences between these reuse rates are not statistically significant; however, differences in rates between these three service areas and the other four service areas are statistically significant, suggesting that they may share characteristics that are reflected in little graywater reuse. These are all relatively affluent areas with relatively new, high-value housing. Relatively few homes are on septic tanks.

By contrast, Flowing Wells, Marana, Ray, and Tucson Water all show much higher graywater reuse rates of between 13 and 16 percent. Differences among the graywater reuse rates of survey respondents in these four service areas are statistically insignificant. Three of these service areas are characterized by relatively low incomes and older, lower-value housing; Tucson Water serves a wide range of neighborhood types, but contains considerably older neighborhoods and low income areas as well. Septic tanks are somewhat more frequent in these service areas.

A startling 25 percent of Avra Co-op respondents report some graywater reuse. Because of the relatively few surveys mailed to the Avra Co-op service area, one cannot be confident that the reuse rate is significantly higher than in some other service areas. For example, the difference between Avra Co-op’s reuse rate and the reuse rate in Ray Water is not statistically significant. Nevertheless, surveys were sent to Avra Co-op customers because of certain systematic differences in housing. The dwelling units are overwhelmingly manufactured housing and virtually all Avra Co-op customers are on septic tanks. Income levels tend to be fairly low, as well.

Table 2:
GRAYWATER REUSE BY PROVIDER

PROVIDER	Respondents	Reusing GW	% Reuse	Weight	Wt. % Reuse
Avra Co-op	32	8	25.0	0.02	0.50
Flowing Wells	76	10	13.2	0.03	0.40
Green Valley	135	2	1.5	0.03	0.04
Marana	61	9	14.8	0.01	0.15
Metro	110	2	1.8	0.07	0.13
Oro Valley	59	2	3.4	0.05	0.17
Ray	19	3	15.8	0.02	0.32
Tucson Water	89	13	14.6	0.77	11.24
TOTAL	**581**	**49**	**8.4**	**1.00**	**13.0**

All this suggests factors that may increase the likelihood of graywater reuse:

S older homes
S lower value homes
S manufactured housing
S lower income levels
S septic tanks

These factors appear consistent with assumptions about what motivates some people to reuse graywater. Motivations presumably include:

- environmental sensitivity
- water conservation ethic
- desire to reduce one’s water bill
- desire to reduce one’s sewer bill or prolong the life of a septic system

The survey was conducted in such a way that it is possible to extract respondents’ street addresses from survey forms. Street addresses can then be used to extract housing age and value from Pima County records and water demand levels and sewer system connections from water providers and Pima County Wastewater. Such analysis is not part of this study or report, but will be undertaken in the future.

Estimating TAMA-wide Reuse

To better estimate Tucson AMA-wide graywater reuse, a weighted average is calculated. Each service area's graywater reuse rate is multiplied by an approximation of its share of owner-occupied single family residences within Pima County (See Table 3, last two columns). The result is graywater reuse at an estimated 13 percent of owner-occupied SFRs and manufactured homes in Pima County. This corresponds roughly to between 20,000 and 30,000 households, or 40,000 to 80,000 persons.

This suggests the enormity of the public policy issue that graywater reuse represents. If graywater reuse often causes public health problems, then a very large number of people are at risk. If, on the other hand, the great majority of graywater reuse situations pose little if any health risk, then the lost opportunities for greater water conservation are enormous.

Household Size and Composition

Another apparent difference between the service areas where graywater reuse is rare and those where it is more prevalent is household demographics. Households in Green Valley, Oro Valley, and Metro Water are, on average, smaller and older than households in the other five service areas. Fortunately, we have direct evidence on this issue from the survey.

Respondents were asked how many people lived in their household. They also were asked to indicate how many of these people fell into various age brackets. (Unfortunately, some respondents mis-read this follow-up question. For example, several checked the 0-4 bracket, apparently indicating that there were between 0 and 4 persons in the household, rather than writing how many persons in the household were between the ages of 0 and 4.)

There was no strong a priori belief concerning the impact of household size and ages on graywater reuse. On the one hand, the more people in a household, the more graywater is generated thereby increasing potential water conservation and utility bill savings. On the other hand, graywater reuse requires some time and effort. Heads of households with multiple children might not have the time or energy to devote to constructing and maintaining a graywater system.

Data for respondents' household size as a function of service area and whether the household reuses graywater is summarized in Table 3.

Table 3:
HOUSEHOLD SIZE
by service area and graywater reuse

PROVIDER	Graywater Reusers	Non-GW Reusers	All Respondents
Avra Co-op	2.78	2.09	2.29
Flowing Wells	2.38	2.37	2.37
Green Valley*	1.50	1.81	1.80
Marana	3.00	2.74	2.78
Metro*	3.00	2.46	2.46
Oro Valley*	1.00	2.31	2.26
Ray*	3.67	3.54	3.56
Tucson Water	2.75	2.50	2.54
All Respondents	**2.67**	**2.31**	**2.34**

* too few graywater reusers for differences to be relevant

The data support the view that households with more residents, and therefore more graywater on average, are somewhat more likely to reuse some graywater. Differences in household sizes between graywater reusers and others within service areas are generally not significant because of the small number of cases involved. However, the differences for all respondents is significant, although not terribly large.

Sources of Graywater

Those respondents reporting graywater reuse were asked from which sources they put graywater to use. Responses are summarized in Table 4.

The most frequently tapped source of graywater by far is clothes washers, accounting for 66 percent of all graywater sources. Next are bathroom tubs/showers (15 percent) and kitchen sinks (10 percent). Bathroom sinks account for only 5 percent of graywater sources, and "other" accounts for the remaining 4 percent. The relatively small numbers of graywater reusers does not allow any conclusions to be drawn about types and numbers of graywater sources by service areas.

The great majority of graywater reusers tap a single source, with a minority tapping two or three sources. On average, reusers tap 1.2 sources of graywater.

Table 4:
Graywater SOURCES

Graywater Source	Avra	FW	GV	Marana	Metro	OV	Ray	TW	TOTAL
clothes washer	8	8	1	9	2	0	3	10	41
bath 1 sink	0	1	0	0	0	0	0	0	1
bath 2 sink	0	0	0	0	0	0	0	0	0
bath 1 tub/sh	3	1	0	1	0	0	0	1	6
bath 2 tub/sh	1	0	0	0	0	0	0	1	2
kitchen sink	0	1	1	2	0	2	0	1	7
other	0	0	0	0	0	0	0	1	1
Total Sources	12	11	2	12	2	2	3	14	58
GW Reusers	8	10	2	9	2	2	3	13	49
Avg # of sources	1.5	1.1	1.0	1.3	1.0	1.0	1.0	1.1	1.2

Age of Graywater Systems

Respondents were asked to report the age of their graywater systems. About 20 percent of those who reported reusing graywater did not report an age for the system. This could be due in part to some respondents not considering themselves to have a “system”; for example, many apparently simply direct washing machine drainage water onto vegetation via a hose. Others may have bought homes that already had graywater systems. For those 80 percent who did report an age, it ranged from a few months to 30 years.

Responses are summarized as mean (average) age and median (typical) age in Table 5. The average or mean age of all systems is 9.2 years. The typical, or median age of all systems is 7.5 years. Comparisons across service areas are not meaningful because of the small numbers involved.

Table 5:
MEAN AND MEDIAN AGE OF Graywater SYSTEMS
for respondents reporting an age

PROVIDER	number of systems	mean age (years)	median age (years)
Avra Co-op	7	6.3	4
Flowing Wells	8	9.0	9
Green Valley	0	n/a	n/a
Marana	8	13.5	11
Metro	2	5	5
Oro Valley	1	6	6
Ray	3	10.3	15
Tucson Water	11	8.8	7
TOTAL	**40**	**9.2**	**7.5**

Storage of Graywater

Only two respondents reported storing any graywater. Both reported aboveground storage, with capacities of 20 and 165 gallons.

Treatment of Graywater

Five respondents, or approximately 10 percent of graywater reusers, reported they treat their graywater. Two filter it, one uses bleach in the clothes washer, and one uses no-phosphate detergent. One did not describe the method of treatment.

Application of Graywater

Respondents were asked how they apply graywater to its various uses. Responses are summarized in Table 6 below.

Graywater reusers resort to an average of 1.3 methods to apply graywater. The most common method is surface application (34 percent), followed by garden hose (20 percent) and by bucket (15 percent). Other application methods reported include below ground (11 percent), soaker hose (8 percent), bubbler (3 percent) and "other" (9 percent). In this latter category were large, fixed pipes, trench, and bucket-like containers.

No one reported using a drip system to apply graywater to vegetation. Also, there is some suspicion that the "below ground" response was given by some persons who apply water to the surface, but then it sinks "below ground."

Table 6:
HOW IS Graywater APPLIED?

APPLICATION	Avra	FW	GV	Marana	Metro	OV	Ray	TW	TOTAL
to the surface	2	5	1	5	1	1	2	5	22
below ground	4	1	0	0	0	0	1	1	7
drip system	0	0	0	0	0	0	0	0	0
by bucket	0	4	2	0	0	2	0	2	10
garden hose	1	3	0	3	1	0	0	5	13
soaker hose	0	2	0	2	1	0	0	0	5
bubblers	1	1	0	0	0	0	0	0	2
other means	0	1	0	1	0	0	1	3	6
TOTAL	**8**	**17**	**3**	**11**	**3**	**3**	**4**	**16**	**65**

Uses of Graywater

How respondents use graywater is summarized in Table 7. Graywater reusers indicate an average of nearly two uses each. Irrigation of shade or ornamental trees is by far the most common, accounting for 32 percent of all reported uses. This is followed by irrigation of shrubs (19 percent) and grass (14 percent). These three uses account for two-thirds of all graywater uses.

Relatively few graywater reusers apply it to potential food sources, with 9 percent reporting irrigation of fruit/nut trees and 4 percent irrigating vegetable/herb gardens.

Table 7:
WHERE IS Graywater USED?

USE	Avra	FW	GV	Marana	Metro	OV	Ray	TW	TOTAL
grass	1	4	0	4	1	0	2	1	**13**
shrubs	3	5	0	2	1	0	1	6	**18**
potted plants	0	2	1	0	0	1	0	2	**6**
wildflowers	1	1	0	0	0	0	0	2	**4**
compost	0	0	0	0	0	0	0	0	**0**
shade/ornam trees	7	7	0	6	0	0	1	9	**30**
fruit/nut trees	1	1	1	0	0	0	1	4	**8**
veg/herb gardens	0	1	0	0	0	0	0	3	**4**
annual/bedding plants	0	0	2	0	0	2	0	1	**5**
other	0	0	0	2	0	0	0	3	**5**
TOTAL	13	21	4	14	2	3	5	31	**93**

Why Graywater is Not Reused

Over 90 percent of respondents indicated they do not reuse any graywater. Reasons offered for this are reported in Table 8. Responses varied considerably, with about 1.7 reasons offered per respondent.

The top reason offered for not reusing graywater is “don't know how.” Another common reason is “need info./assistance.” This suggests that if the legal barriers were lowered and public education and incentives offered, graywater reuse might increase considerably.

Several of the reasons offered are similar, by design. The 13 specific reasons can be grouped into five categories. For example, “don’t know how” and “need info./assistance” both indicated the respondent needs help. These two categories account for 30 percent of all reasons given.

Similarly, “isn’t worth the trouble”, “not enough time” and “not worth the cost” all indicate a similar lack of motivation. These three reasons account for 20 percent of all responses. “Water not near use” and “no use for water” indicate reuse is not practical, and account for 19 percent of responses. “Not sure safe/sanitary” and “water is salty/chemicals” suggests health or environmental concerns. These account for 15 percent. Legal, permitting, and permitting issues account for 7 percent of responses, and “other” accounts for the remaining 10 percent

Table 8:
WHY NOT USING Graywater?

REASON	Avra	FW	GV	Marana	Metro	OV	Ray	TW	TOTAL
may need inspection	2	0	2	1	1	0	0	3	**9**
may be illegal	3	9	1	6	8	3	1	5	**36**
isn't worth trouble	0	3	14	2	5	7	1	9	**41**
not sure safe/sanitary	0	11	17	7	18	10	6	19	**88**
water is salty/chems	2	6	9	5	8	3	0	9	**42**
not enough time	3	6	3	2	8	3	1	9	**35**
don't know how	6	11	33	21	42	18	8	27	**166**
not worth the cost	4	13	22	7	17	10	4	18	**95**
need info./assistance	6	12	13	13	18	12	4	13	**91**
may need a permit	2	2	2	1	4	0	0	3	**14**
water not near use	1	7	26	7	15	4	0	7	**67**
no use for the water	4	12	43	5	11	9	1	9	**94**
tried permit, gave up	0	0	2	0	0	0	0	1	**3**
other	6	12	24	10	13	16	1	7	**89**
TOTAL	39	104	211	87	168	95	27	139	870

Survey Summary

It appears that 20,000 to 30,000 households in Pima County might currently be reusing graywater. These households contain 50,000 to 80,000 persons. Graywater reuse is a major issue in terms of the number of persons involved.

It appears that graywater reuse is more common in older homes and lower-income areas. Residents of manufactured homes may be particularly likely to reuse graywater because of the greater access to wastewater plumbing. Septic system preservation may be a factor in some graywater reuse.

Whether most of these systems are being operated in a safe and sanitary manner is not known. However, the survey results also suggest that if graywater reuse is determined to not be a public health issue, and if permitting requirements are relaxed, graywater reuse might increase substantially. Whether and how ADWR and municipal water providers should encourage graywater reuse are issues that should be addressed.

SUMMARY OF FINDINGS:

WATER QUALITY- ANALYSIS

The summary of the study findings is reflected in both our fact sheet, which is contained in this report (see page 36), and the draft rules from ADEQ titled Reclaimed Water General Permit: Graywater Irrigation (see page 38) published April 17, 2000.

* On a continuum from highest to lowest risk by source of graywater:
    Kitchen sink
    Washing machines
    Tub/showers
    Bath sinks

* Risk factors include but are not limited to:
    washing diapers
    household pets
    feral animals and birds
    wet dry irrigation cycles
    organic matter in the irrigated soil

Description of Project Methodology & Selection Criteria

The criteria for site selection included:

Storage of graywater
Septic system
Graywater filtration
Graywater disinfectant
Water sources:
  Clothes washer
  Kitchen sink
  Bath sink
  Bath tub/shower
  Other

Vectors:
  Children
  Pets
  Washing diapers
Graywater application:
  Surface (spray, drip, flood, furrow)
  Subsurface
  Food crops
  Fruit trees
  Turf

Site selection was made after development of the site and criteria matrix. This enabled the group to select the most representative set of sites. The grant request called for a total of ten sites to be selected. Ultimately eleven sites were chosen, based upon a consensus that chances were high that one site would be lost during the course of the study.

Data collection was done in accordance with ADEQ’s Quality Assurance Project Plan (QAPP) and the Field Manual for Water Quality Sampling, published by ADEQ and the UA Water Resources Research Center. The only variance from the guidelines, which has been agreed to by ADEQ, PCDEQ and UA, was the measurement of electrical conductivity and pH in the UA laboratory rather than in the field.

All eleven study sites were visited and detailed information about each household and their systems were gathered and compiled. (Please see Attachment #2 for complete site characteristics)

Graywater is defined as all wastewater generated in the household, excluding toilet wastes (Gerba *et al.*, 1995). It can come from the sinks, showers, tubs, and washing machine of a home. It has been reused for purposes such as landscape irrigation and toilet flushing. But little data is available about the chemical and microbial quality of this water. Studies of graywater from a single family home have shown the presence of total and fecal coliforms and heterotrophic plate count (HPC) bacteria (Karpiscak *et al.*, 1987; Gerba *et al.*, 1995). If graywater reuse is truly to be a viable option for residential water conservation, then concerns about its safety need to be addressed, especially those related to the potential for transmission of disease. Graywater may be used by homeowners to irrigate both ornamental and food plants, and there is epidemiological evidence that the use of wastewater, particularly for the irrigation of food crops, has resulted in disease transmission when undisinfected effluent was used (Crook, 1985).

In order to assess the risks involved in the reuse of graywater, more information about the quality of this water and the factors that influence it is needed. Therefore, a yearlong study of eleven Tucson, Arizona households that recycle graywater was undertaken. Graywater, graywater-irrigated soil, and potable water irrigated soil were analyzed for fecal coliforms, fecal streptococci, and *Escherichia coli*. Fecal coliform bacteria were included because they are indicator organisms commonly used in water quality monitoring (APHA, 1999) and reuse standards (Maier *et. al*, 2000). *Escherichia coli* was selected because it is thought to be the most specific indicator of true fecal contamination (Gleeson and Gray, 1997). Fecal streptococci and coliphages have been selected because they have been suggested as indicators for some of the more environmentally resistant pathogens, such as enteric viruses (Maier *et. al*, 2000). Participating homes were chosen for the presence and absence of children and animals, methods of graywater storage, and household sources of captured graywater. Together, these site characteristics and the bacterial data gathered were to provide information about which factors in and around a home influence the quality of recycled household graywater before and after application to soil.

Materials and Methods

Water samples were collected from available graywater in 1L sterile plastic bottles. Soil samples were collected from yard sites irrigated by graywater or potable water. Samples were placed in sterile plastic tubes or bags using an ethanol-disinfected spatula. Samples were transported on ice to the laboratory, where they were held at 4˚C until processing. Samples were processed within 8 hours of receipt in the laboratory.

Soil moisture was measured by drying 10g portions of soil at 100˚C for 24 hours. Moisture content was calculated as described in the *Environmental Microbiology Laboratory Manual* (Pepper, Gerba, and Brendecke, 1995).

Fecal coliforms

Fecal coliforms in water were quantitated using spread plate and membrane filtration techniques on mFC agar (Difco, Detroit, MI). Volumes of up to 10 mL were assayed.

Fecal coliforms in soil were processed according to a modified protocol for the elution of bacteria from soils (Zuberer, 1994). 10g portions of soil were mixed with glass beads and 95 mL of 0.1% peptone. Bottles were shaken on a rotary shaker for 20 minutes to elute the organisms from the soil particles. The eluent was analyzed for fecal coliforms using the spread plate technique. Plates were incubated inverted at 44.5±5˚C for 24 hours. Blue or blue-white colonies were counted under a magnifier with light source. Random presumptive colonies were selected and aseptically transferred to EC broth with MUG (Difco, Detroit, MI). Broth tubes were incubated at 44.5±5˚C for 24 hours. Tubes were examined for growth and fluorescence. Growth indicated the presence of fecal coliforms. Fluorescence under ultraviolet light indicated the presence of *E. coli*. EC with MUG tubes were compared to a positive control using *E. coli* ATCC# 15597.

Escherichia coli

E. coli was quantitated using the Simplateâ system for total coliforms and *E. coli* (IDEXX, Westbrook, ME). Water and soil samples of up to 1 mL were processed according to the manufacturer's instructions. After incubation at 37˚C for 24 hours, plate wells showing a purple color were positive for total coliforms, and purple wells fluorescing under UV light were positive for *E. coli*. Numbers of *E. coli* were calculated according to the most probable number method using a table provided by the manufacturer, and results were expressed as MPN per 100 mL of water or gram of dry soil.

Fecal Streptococci

Fecal streptococci in water were analyzed using the spread plate and membrane filtration techniques on KF streptococcus agar (Difco, Detroit, MI). Volumes of up to 10 mL were analyzed. Eluent from soil was obtained as described above and analyzed using the spread plate technique. Plates were incubated inverted at 41.5˚C for 48 hours. Light to dark pink colonies were counted under a magnifier with light source. Random presumptive colonies were selected and transferred to brain heart infusion agar (Difco, Detroit, MI). They were confirmed according to the protocol outlined in the *Standard Methods for the Examination of Water and Wastewater* (APHA, 1999), using brain heart infusion and bile esculin azide media (Difco, Detroit, MI). All confirmation tests were compared to positive controls using the fecal streptococcus *Enterococcus faecalis* and negative controls using *Pseudomonas aeruginosa*.

Coliphages

Coliphages in soil and water were analyzed using the double layer agar technique (Adams, 1959). Samples were held at 4˚C for 24 hours before processing. TSA bottom agar was used. MEndo (Difco, Detroit, MI) top agar was used to suppress overgrowth of Gram positive organisms in the top agar layer. The host used was *E. coli* ATCC# 15597. 3 mL volumes of water and soil eluent were assayed. Plates were incubated inverted at 37˚C for 24 hours. Plaques were counted under a magnifier with light source.

Protozoan parasites

Water samples were examined for *Giardia* and *Cryptosporidium* according to a modified Information Collection Rule protocol (See appendix A). Volumes of 1 L were examined. Parasites were detected using indirect immunofluorescent antibody staining and examination under an ultraviolet microscope.

Statistical Analysis

Statistical analysis was performed using analysis of variance (ANOVA) (Sokal and Rohlf, 1995) with SYSTAT Version 9 software (SPSS Inc., 1999). The level of significance was defined as 95% (a=0.05). Therefore, *p* values less than 0.05 generated by ANOVA are considered to be statistically significant.

Table 9:
QUALITY OF GRAYWATER AND YARD SOIL FOR HOUSEHOLDS WITH AND WITHOUT CHILDREN 0-12 YEARS
(Average of all sites)

	Organisms	With children	Without children
Water	Fecal Coliforms	4.99E+03	4.25E+03
	E. coli	6.10E+01	1.01E+01
Graywater irrigated soil	Fecal Coliforms	1.26E+03	3.24E+01
Background soil	Fecal Coliforms	8.99E+00	4.07E+00

Table 10:
QUALITY OF GRAYWATER AND YARD SOIL FOR HOUSEHOLDS INCLUDING AND EXCLUDING KITCHEN SINK GRAYWATER
(Average of all sites)

	Organisms	Including	Excluding
Water	Fecal Coliforms	8.84E+04	8.22E+02
	E. coli	9.48E+01	8.33E+00
Graywater irrigated soil	Fecal Coliforms	1.56E+03	2.69E+01
Background soil	Fecal Coliforms	2.61E+00	8.25E+00

Table 11:
QUALITY OF GRAYWATER AND YARD SOIL FOR HOUSEHOLDS WITH IN-GROUND AND ABOVEGROUND TANKS
(Average of all sites)

	Organisms	In ground	Above Ground
Water	Fecal Coliforms	1.82E+04	6.43E+02
	E. coli	2.95E+02	3.15E+00
Graywater irrigated soil	Fecal Coliforms	7.85E+00	4.57E+02
Background soil	Fecal Coliforms	N/A	N/A

Table 12:
QUALITY OF GRAYWATER AND YARD SOIL FOR HOUSEHOLDS WITH AND WITHOUT ANIMALS (Average of all sites)

	Organisms	With	Without
Water	Fecal Coliforms	2.12E+03	3.34E+04
	E. coli	3.55E+01	1.05E+01
Graywater irrigated soil	Fecal Coliforms	1.72E+02	1.88E+02
Background soil	Fecal Coliforms	5.88E+00	4.38E+00

Table 13:
PROTOZOAN PARASITES

Site	*Giardia*	*Cryptosporidium*
1	None detected	None detected
5	None detected	None detected
7	None detected	None detected
10	None detected	None detected
13	None detected	None detected
19	None detected	None detected

Table 14:
POTABLE WATER IRRIGATED SOIL SAMPLES FROM HOUSEHOLDS WITH NO GRAYWATER IRRIGATION- SITE CHARACTERISTICS

Sample Code	Date Taken	Site	Characteristics
C-1	1/7/00	Yard	dogs, horses, drip irrigation, no kids
C-2	1/10/00	Yard	dog, sprinkler irrigation, no kids
C-3	1/9/00	Garden (flowers)	dogs, cats, hose irrigation, no kids
C-4	1/9/00	Yard, under citrus tree	dog, hose irrigation, no kids
C-5	1/10/00	Yard	dog, cats, hose irrigation, no kids
C-6	1/9/00	Yard	cats, hose irrigation, kids
C-7	1/10/00	Garden (vegetable)	no pets, hose irrigation, no kids
C-8	1/10/00	large potted plant	cats, hose irrigation, no kids

Table 15:
POTABLE WATER IRRIGATED SOIL SAMPLES FOR CONTROL

Site Code	Fecal Coliforms (CFU/g dry soil)	Fecal Streptococci (CFU/g dry soil)
C-1	0	0
C-2	0	0
C-3	0	0
C-4	0	0
C-5	0	0
C-6	0	0
C-7	0	0
C-8	0	5.88´10^{3}

Table 16:
P-VALUES FROM ANALYSIS OF VARIANCE FOR FECAL COLIFORMS IN GRAYWATER

Factor	P value
Quarter*	4.13´10^{-12}
Animals (presence or absence)	6.23´10^{-12}
Storage (in ground or above ground)	4.82´10^{-12}
Source (including or excluding kitchen sink)	8.89´10^{-12}
Children (Presence or absence)	6.88´10^{-12}
Animals and Quarter (2 factor interaction)	4.76´10^{-12}
Source and animals (2 factor interaction)	6.53´10^{-12}
Sources and Quarter (2 factor interaction)	4.02´10^{-12}
Children and Quarter (2 factor interaction)	4.21´10^{-12}

*****for purposes of statistical analysis, the year was divided into four quarters beginning in January

Table 17:
P-VALUES FROM ANALYSIS OF VARIANCE
FOR FECAL COLIFORMS IN SOIL

Factor	P value
Quarter*	4.17×10^{-12}
Irrigation (graywater or potable water)	8.82×10^{-12}
Storage (in ground or above ground)	1.20×10^{-11}
Animals (presence or absence)	1.12×10^{-11}
Source (including or excluding kitchen sink)	5.84×10^{-12}
Children (Presence or absence)	7.28×10^{-12}
Animals and Quarter (2 factor interaction)	3.99×10^{-12}
Storage and Quarter (2 factor interaction)	4.89×10^{-12}
Sources and Quarter (2 factor interaction)	3.69×10^{-12}
Children and Quarter (2 factor interaction)	5.03×10^{-12}
Storage and Animals (2 factor interaction)	8.23×10^{-12}

Discussion Graywater Quality

Fecal coliforms

Fecal coliforms were consistently detected in all samples from all sampling sites (Figures 1&2). Seasonal variation can be seen in fecal coliform levels (Figure 1). Levels seem to peak in April, then decline in May-June, and then rise again in August-September. When the year is separated into quarters, statistical analysis (Table 16) shows significant difference in levels over time ($\mu=0.05$, $p=4.13\times10^{-12}$). Highest overall fecal coliform levels were found at Site 14 (Figure 2), a site with graywater coming exclusively from the kitchen sink. This site had no pets, no children, and no storage, suggesting that the kitchen sink may represent a significant source of contamination, with levels surpassing that of graywater from all other combined household sources, as shown by the lower levels of fecal coliform bacteria present in graywater from other sites. Sites 1, 6, 17, and 18 had the next highest fecal coliform levels, with levels in graywater from these houses being roughly equal. Sites 1, 6, and 17 all included kitchen sink water in their graywater, again indicating the kitchen sink may represent a significant contamination source. Sites 1, 17 and 18 used in ground storage, possibly providing an environment conducive to bacterial growth. The lowest levels of fecal coliforms in graywater were found at site 19, a site utilizing washing machine water exclusively.

Levels of fecal coliforms were roughly equal in houses with and without children under 12 (Figure 9, Table 9). Again, a higher level is seen in house 14, a site with graywater coming exclusively from the kitchen sink. However, statistical analysis (Table 16) indicated that there is a significant difference in fecal coliform levels in houses with and without children ($\mu=0.05$, $p=6.88\times10^{-12}$). Therefore, the presence of children may make a small difference in graywater fecal coliform load.

Fecal coliform levels were higher in households including the kitchen sink in their graywater than in houses excluding the kitchen sink (Figure 7, Table 10). However, Site 18 stands out (Figure 7). With no children and only one household pet (cat), the reasons for this higher level of fecal coliform contamination are unclear. Statistical analysis (Table 16) shows a significant difference in fecal coliform levels with the presence or absence of kitchen sink water ($\mu=0.05$, $p=8.89\times10^{-12}$). The higher levels of contamination in graywater including the kitchen sink again points to the kitchen sink water as a contamination source, possibly due to the introduction of large amounts of organic matter, providing nutrient sources for organisms present. Washing of meat and poultry products in the sink may also introduce organisms into the graywater supply.

Fecal coliform levels in graywater also are higher in households using in ground storage tanks than in households using above ground tanks (Figure 8, Table 11). Statistical analysis (Table 16) indicates that storage does make a significant difference in fecal coliform levels (μ=0.05, p=4.82´10^{-12}). The higher levels in sites with in ground storage may indicate that storage tanks may provide a favorable environment for bacterial growth while shielding organisms from sunlight, which can inactivate them.

Fecal coliform levels were slightly higher in houses without animals than in those with animals (Figure 10, Table 12). House 14, a house without any animals, had higher fecal coliform levels than some houses with animals. Statistical analysis (Table 16) indicates that animals do make a significant difference in fecal coliform levels (μ=0.05, p=6.23´10^{-12}). The impact of the presence of animals on fecal coliform levels, though significant, may be small.

One of the interesting points that statistical analysis brings to light (Figure 8) is interaction between factors that influence graywater quality. Based on the site characteristics and samples collected, it is possible to analyze two way interactions- that is, to see if two factors interact to produce a significant difference in fecal coliform levels. In this study, it is possible to do this for quarter (time) and animals, source and animals, quarter and source, and quarter and children. Analysis of variance showed that all of these two-way interactions produce a significant difference in fecal coliform levels. Therefore, presence or absence of animals, presence or absence of kitchen sink water, presence or absence of children, and storage method all impact the way that fecal coliform levels vary over time. This suggests that what may be happening here with the factors that influence graywater quality is an additive or synergistic effect. Rather then being viewed in isolation, the interaction of these factors and their impact on graywater quality must be considered.

Escherichia coli

E. coli in water was quantitated using the Simplateâ system, a most probable number method for total coliform bacteria and *E. coli*. If all wells in a Simplateâ are positive for *E. coli*, then the MPN of organisms is greater than the maximum number that can be detected by the plate- a limitation of the method.

E. coli was sampled on a total of 10 dates in August through December. *E. coli* was detected on all dates except one in mid-October (Figure 5). *E. coli* was highest in September, with levels declining sharply until mid October and then beginning to rise again in November and December. *E. coli* levels reached another peak in mid December.

E. coli was detected in graywater from 6 of 10 sites (Figure 6). Sites 10, 13, 14, and 19 had no detectable *E. coli*, while site 17 had the highest levels.

These results disagree with the results for *E. coli* using ECMUG broth, a presence/absence test for

E. coli. Samples positive for *E. coli* as a percentage of all samples taken can be seen in Figures 3 and 4. These samples, taken from March through December, show a seasonal variation in number of samples testing positive for the presence of *E. coli* (Figure 3). Here, samples with *E. coli* seem to decline from March to August, then rise again until September, when there is a sharp decline. Samples *with E. coli* then rise sharply again in mid September, then decline until mid November, then rise again. The midyear decline may be due to inactivation by the typically high summer temperatures.

E. coli was detected in samples from all sites. Site 17 was the only site with 100% of samples positive for *E. coli* (Figure 4). This is a site with kitchen sink water, a child under the age of 5, and in ground storage. Sites 7 and 14 had the next highest percentage of positive samples, 60%. Site 14 used exclusively kitchen sink water, while site 7 used washing machine and bath water. Contrary to the Simplateâ results, which detected no *E. coli* in graywater from sites 10, 13, 14, and 19 (Figure 4), ECMUG testing showed the presence of *E. coli* in graywater from these sites, ranging from 25 to 60% of total samples (Figure 6). The Simplates also indicated that no *E. coli* was present in any samples on 10/18 (Figure 3), whereas approximately 80% of samples taken on that date were positive for *E. coli* using ECMUG (Figure 4). These differences are probably due to variation between two methods for the detection of *E. coli*.

From results of quantitation of *E. coli* by the Simplate method, it is difficult to tell how the presence or absence of kitchen sink water influences the levels of *E. coli* in graywater (Figure 11, Table 10). Levels of *E. coli* when all sites are averaged differ by one order of magnitude. While the highest *E. coli* level was found in house 17, which included kitchen sink water, the method detected no *E. coli* in house 14, a site using exclusively kitchen sink graywater. *E. coli* at site 7, without kitchen sink water, was higher than house 1, using kitchen sink water. It may be that while the kitchen sink introduces fecal bacteria into graywater, it does not necessarily introduce higher levels of *E. coli* than would be there in the absence of kitchen sink water. This is reinforced by the ECMUG results (Figure 4). The highest percentage of samples positive for *E. coli* was found at site 17. However, the other sites using kitchen sink graywater, 1, 6, and 14, did not have consistently higher percentages of samples positive for *E. coli* than sites that did not use kitchen sink graywater.

Levels of *E. coli* were higher in houses using in ground storage (Figure 13, Table 11). The somewhat higher levels in other sites with in ground storage may indicate that storage tanks may provide a favorable environment for bacterial growth while shielding organisms from sunlight, which can inactivate them.

The impact of children in a household on *E. coli* levels in graywater is questionable (Figure 13, Table 10). Averaged across all sites, levels of *E. coli* in houses with and without children were roughly equal (Table 9). The highest level of *E. coli* was found in house 17, a house with children. However, *E. coli* in houses 1, 2, and 7, houses without children, were higher than in house 5, a house with children. House 5 *E. coli* levels were also equal to house 18, a house with children. There were houses both with and without children in which no *E. coli* was detected. Therefore, the presence of children younger than 12 in a household may not increase the load of *E. coli* in graywater. This is confirmed by the ECMUG results. Again, house 17 had the highest number of samples positive for

E. coli (Figure 4). However, households without children did not have consistently lower numbers of samples positive for *E. coli* than did houses 5 and 10, the other households with children. In some cases, houses without children had equal or greater numbers of samples positive for *E. coli* when compared with houses with children.

As with children, the impact of animals on the levels of *E. coli* in household graywater is questionable (Figure 14, Table 12). Averaged across all sites, levels of E. coli in houses with and without animals were roughly equal (Table 12). The highest levels of *E. coli* were found in houses 17 and 7, houses with animals. However, houses with and without animals had undetectable levels of *E. coli*. Houses 5 and 18, with animals, had *E. coli* equal to house 2, without animals. House 1, without animals, had higher *E. coli* than houses 5 and 18. Therefore, the presence of animals in a household may not increase the load of *E. coli* in graywater.

Fecal Streptococci

Fecal streptococci were detected in graywater from all sites (Figure 27), with sites 14, 17, and 19 having the highest levels. Like the fecal coliforms, the fecal streptococci indicate that fecal contamination is making its way into household graywater.

Protozoan Parasites

Of those samples that could be examined by IFA staining, all were negative for protozoan parasites (Table 13). This is consistent with the fact that there was no evidence (based on self-reported illnesses of residents) that anyone in the households might be shedding protozoan parasites.

Coliphages

There was only one occurrence of coliphages in graywater, occurring in August at site 5. This indicates that it was only a random occurrence, and coliphages are not usually present in this graywater.

Irrigated Soil Quality

Fecal coliforms

Fecal coliforms were detected in most samples of graywater irrigated soil (Figure 15). Seasonal variation can be seen in fecal coliform levels in graywater irrigated soil (Figure 15). Levels are highly variable from month to month. Peaks seem to occur in June and August-September. When the year is separated into quarters, statistical analysis (Table 17) shows significant difference in levels over time ($\mu=0.05$, $p=4.17$´10^{-12}). Fecal coliforms were detected in potable water irrigated (background) soil in fewer months of the year. In most samples, fecal coliform levels in potable water irrigated soil were lower than in graywater irrigated soil, although a few times they were slightly higher. Fecal coliforms in potable water irrigated soil seem to have a differing pattern of seasonal variation, with peaks in January and August and sharp reductions in April-June.

Fecal coliforms were detected at various times in graywater irrigated soil from all sites (Figure 16). Highest overall fecal coliform levels were found at sites 6K, 6W, 10 and 14. Sites 6K and 14, with the highest levels of soil contamination, are irrigated with graywater coming exclusively from the kitchen sink. Site 14 has no pets, no children, and no storage, suggesting that the kitchen sink may represent a significant source of contamination, with contamination from the water being introduced into the soil, as shown by the lower levels of fecal coliform bacteria present in graywater from other sites. However, houses 1 and 17, also using kitchen sink graywater, have lower levels of fecal coliforms in soil than 6K and 14. Therefore, the contamination at sites 6K and 14 is probably not entirely due to the kitchen sink, but may have other contributing factors. 6W and 10 are irrigated with washing machine water, suggesting that the washing machine can still serve as a source of fecal contamination.

Levels of fecal coliforms in background soil were lower than levels in graywater irrigated soil for most sites (Figure 16). For some sites, fecal coliforms were at undetectable levels in background soil. Statistical analysis (Table 17) shows that type of water used for irrigation makes a significant difference in soil fecal coliform levels (μ=0.05, p=8.82´10^{-12}). This shows that graywater irrigation does introduce fecal coliform contamination into the soil at levels above what is normally present.

Levels of fecal coliforms in graywater irrigated soil were higher in houses with children under 12 than in houses without (Figure 25, Table 9). Statistical analysis (Table 17) indicated a significant difference in soil fecal coliform levels because of the presence or absence of children (μ=0.05, p=7.28´10^{-12}). Analysis showed that children had a statistically significant impact on fecal coliform levels in graywater (Table 16), and this effect appears to carry over into the soil.

Across all sites, fecal coliform levels were highest in graywater irrigated soil at sites including the kitchen sink in their graywater (Table 10). Fecal coliform levels were highest in graywater irrigated soil at two sites including the kitchen sink in their graywater, 6K and 14 (Figure 21). Statistical analysis (Table 17) showed a significant difference in fecal coliform levels in graywater with and without the kitchen sink (μ=0.05, p=5.84´10^{-12}). The higher levels if contamination in graywater irrigated soil including the kitchen sink again points to the kitchen sink water as a contamination source. However, this may not always be the case, since sites 1 and 17, also users of kitchen sink water, have lower levels of fecal coliforms in graywater irrigated soil than some households without kitchen sink water.

Fecal coliform levels in graywater irrigated soil are higher in households using above ground storage tanks than in households using in ground tanks (Figure 22, Table 11). Statistical analysis (Table 17) shows that storage makes a significant difference in fecal coliform levels (μ=0.05, p=1.20´10^{-11}). This differs from the trend seen in the graywater, where levels in water sampled from in ground tanks were slightly higher (Figure 8). It may be that over time, the use of an above ground surge tank creates an environment similar to a continuous laboratory culture, with nutrients always being introduced to support growth of bacteria which are then washed out onto the soil. Bacteria in this state are not subject to the growth and die off kinetics that would probably be seen in a closed environment such as a storage tank.

Fecal coliform levels in graywater irrigated soil were similar in houses with animals (Figure 23, Table 12). This trend also occurs in the background soil (Figure 24). However, statistical analysis shows a significant difference in soil with and without animals (μ=0.05, p=1.12´10^{-11}), so it is possible that the impact of animals, thought significant, is still small.

As with the graywater data, statistical methods can be used to analyze two way interactions. That is, to see if two factors interact to produce a significant difference in fecal coliform levels. With the soil data, it is possible to do this for quarter (time) and animals, storage and quarter, quarter and source, quarter and children, and storage and animals. Analysis of variance showed that all of these two-way interactions produce a significant difference in fecal coliform levels in soil (Table 17). Again, this suggests that what may be happening here with the factors that influence graywater quality is an additive or synergistic effect. Rather then being viewed in isolation, the interaction of these factors and their impact on graywater quality must be considered.

Escherichia coli

The presence or absence of *E. coli* in soil was analyzed using ECMUG. *E. coli* was sampled on a total of 10 dates in August through December . *E. coli* was not detected in graywater irrigated soil on dates in April, May, June, November, and December (Figure 17). The number of samples testing positive for *E. coli* was highest in august through November. Background soil *E. coli* did not follow the same trend (Figure 18). The number of samples positive for *E. coli* peaked in March, but no *E. coli* was detected in background soil from April through June. This indicates that irrigation with graywater does introduce *E. coli* into the soil that would not otherwise be present.

E. coli was detected in 12 of 13 graywater irrigated soil sites (Figure 19). Site 1 had no detectable *E. coli*, while sites 6T/S, 6K, 6W and 14 had the highest percentages of samples positive for *E. coli*.

E. coli was detected in 7 of 12 background soil sites (Figure 20). Sites 1, 5, 6, 18, and 30 had no detectable *E. coli*, while sites 5, 13, and 14 had the highest percentages of samples positive for *E. coli*. Again, this indicates that irrigation with graywater does introduce *E. coli* into the soil that would not otherwise be present.

Fecal Streptococci

Fecal streptococci were detected in most samples of graywater irrigated and background soil (Figure 28). For most sites, fecal streptococci levels were higher in graywater irrigated than in background soil. Fecal streptococci do seem to be present even in potable water irrigated soil. However, the differences in levels between the two soils suggest that graywater irrigation introduces additional fecal streptococci into the soil.

Coliphages

There were two occurrences of coliphages in soil, one in graywater irrigated and one in background soil. One was at background site 2 in December, and one was at Site 6K in September. These occurrences were not correlated with any coliphages in the graywater at these sites, and thus appear to be random.

Soil Controls

Eight soil samples were collected in January from Tucson, Arizona residential yard sites irrigated with potable water (Table 6). They were analyzed for fecal coliforms and fecal streptococci. No fecal coliforms were detected in any of the soils (Table 7). There was fecal streptococci detected in soil at one of the sites. These controls indicate that low or undetectable levels of these organisms that are normally present in potable water irrigated soil.

SUMMARY OF FINDINGS:

WATER QUALITY/SOIL QUALITY RISK ASSESSMENT

There is an absence of epidemiological data regarding the risks of gastrointestinal illness and the use of recycled household graywater for home irrigation purposes. Therefore, it is desirable to use a formal risk assessment framework to estimate the risks involved in the use of household graywater for irrigation. Quantitative risk assessment for microorganisms has been used for drinking water and reclaimed wastewater (Haas *et. al*, 1999). Since graywater is a form of wastewater, it is reasonable to apply a similar risk assessment methodology for the use of household graywater.
The risks involved in exposure to household graywater come from the enteric pathogens that could be present in the water. This research has shown that fecal indicators (fecal coliforms and streptococci) are present in graywater. This indicates that fecal contamination has made its way into graywater, which raises the possibility of human enteric pathogens, such as *Salmonella* and *Shigella*, as well as pathogenic enteric viruses, may have also made their way into the graywater supply.

It is known from this research that one very important human fecal indicator, *Escherichia coli,* has made its way into the graywater and graywater irrigated soil of several of the households participating in the study. *E. coli* is of significance because it is the only coliform exclusively fecal in origin (Gleeson and Gray, 1997). While not all strains are human pathogens (many are harmless mutalists in the human intestinal tract), the presence of *E. coli* suggests that pathogenic strains, if shed by members of the household, could end up in the graywater supply and also in the soil irrigated with it.

In order to estimate the risk of infection, a beta Poisson model was used:

$$P=1-(1+(N/b))^{-a}$$

Where P is the probability of infection, N is the exposure, and a and b are values defined by the dose response curves specific to individual organisms (Rose).

For the purposes of this analysis, the main source of risk was assumed to be the ingestion of graywater irrigated soil by children playing in yards. Values for the average amount of soil ingested by a child during this activity are available (Haas, *et. al*, 1999). For a child under 6, the reported value is 200 mg/day, for a child over six, 100mg/day. Therefore, a single exposure for a child under 6 would be 200 mg, and for a child over 6 it would be 100 mg.
In estimating exposure for this model, there are two key elements: the amount of soil ingested and the number of microorganisms present in that amount of soil. With the data

gathered in this study, there are different ways of estimating the amount of organisms ingested in a single exposure. One way is by using levels of fecal coliforms in soil. This can be modeled

based on key assumptions:
1. That all fecal coliforms detected are *E. coli*
2. That they are all pathogenic strains

Using these assumptions, which constitute a worst- case scenario, exposure was calculated with numbers of fecal coliforms detected per gram of dry soil. Risk can be assessed household by household, using alpha and beta values for *Escherichia coli* of a=0.1705 and b=1.61´10^6 (Pepper, Gerba, and Brusseau, 1996).

Table 18:
FECAL COLIFORMS IN SOIL
BY SITE

Site	Geometric Mean
	(CFU/g dry soil)
1	3.52E+01
2	9.31E+00
5	9.15E+01
6T/S	5.65E+02
6K	2.27E+06
6W	6.90E+03
7	1.32E+01
10	2.13E+03
13	3.58E+01
14	2.04E+04
17	2.28E+00
18	3.56E+00
19	3.32E+0

Table 19:
RISK OF INFECTION
FROM A ONE TIME EXPOSURE*

Site	Child Under 6	Child over 6
1	7.46E-07	3.73E-07
2	1.97E-07	9.86E-08
5	1.94E-06	9.69E-07
6T/S	1.20E-05	5.98E-06
6K	4.15E-02	2.22E-02
6W	1.46E-04	7.31E-05
7	2.80E-07	1.40E-07
10	4.51E-05	2.26E-05

13	7.58E-07	3.79E-07
14	4.31E-04	2.16E-04
17	4.83E-08	2.41E-08
18	7.54E-08	3.77E-08
19	7.03E-08	3.52E-08

Yearly exposure risk can be calculated by multiplying the risk for a single exposure by the number of exposures in a single year. Assuming exposure 350 days in a single year (Pepper, Gerba, and Brusseau, 1996), the risks become:

Table 20: RISK FOR 1 YEAR

	Child Under 6	Child over 6
Site	Year of exposure	Year of exposure
1	2.61E-04	1.30E-04
2	6.90E-05	3.45E-05
5	6.78E-04	3.39E-04
6T/S	4.19E-03	2.09E-03
6K	1.45E+01	7.78E+00
6W	5.11E-02	2.56E-02
7	9.79E-05	4.89E-05
10	1.58E-02	7.89E-03
13	2.65E-04	1.33E-04
14	1.51E-01	7.56E-02
17	1.69E-05	8.45E-06
18	2.64E-05	1.32E-05
19	2.46E-05	1.23E-05

What do these estimates say about the level of risk? In the case of drinking water treatment, the U.S. Environmental Protection Agency recommends that treatment processes be designed so that a person is not subjected to a risk of infection of more than 1 per 10,000 per year (Pepper, Gerba, and Brusseau, 1996). If we set a threshold of acceptable risk of 1 in 10,000, it can be seen from Table 5 that some of these households are above the level of acceptable risks to varying degrees. Houses 1, 5, 6, 10, 13, and 14 all have risks of infection greater than 1 in 10,000 per year. In the cases of houses 6, 10, and 14, the risk is greatest. Looking at the characteristics of these households can give some idea as to the source of these risks. Sites 1, 6K, and 14 use kitchen sink graywater, indicating that the inclusion of kitchen sink water raises the risk of infection to unacceptable levels. Sites 5, 6, and 10 have children under the age of 5, which may contribute to fecal coliform levels. House 13 has neither children nor kitchen sink water, so the reasons for the elevated level of risk in this household are unclear. However, the general trend in these risk estimates is that risk is highest, surpassing the 1 in 10,000 per year threshold, in houses having small children and using kitchen sink graywater.

However, this analysis probably overestimates risk, since not all fecal coliforms are pathogenic, children are unlikely to play in exactly the same areas every day, and pathogens are not always present. Prevalence of enteric pathogens in humans ranges from about 1 to 5% in the United States (Haas, *et. al*, 1999). Thus, it is unlikely that any given pathogen would be present more than 5% of the time. In addition, not all infections result in disease. Finally, once applied to soil, pathogens will eventually die off, especially during the hot, dry summers in this region. This can be seen in studies with polioviruses and rotaviruses, which showed that these viruses do not persist more than 40 hours in secondary treated effluent applied to lawn grass during wintertime climate conditions in Pima County (Badawy, 1986). While bacterial pathogen risks may be overestimated, since protozoan parasites and enteric viruses have a higher infectivity, risks of infections from these pathogens might be underestimated (Haas, *et. al,* 1999).

CONCLUSIONS

Graywater Quality

Fecal coliforms

- Fecal coliforms were consistently detected in all samples from all sampling sites. The concentrations exhibit seasonal variation.

- Fecal coliform levels were significantly higher in households including the kitchen sink in their graywater than in houses excluding the kitchen sink, indicating that it is a major contamination source.

- Fecal coliform levels in graywater were also significantly higher in households with children, those with animals, and those using in ground storage tanks.

Escherichia coli

- *E. coli* was detected in samples from all sites.

- Levels of *E. coli* were higher in houses using in ground storage.

- Levels of *E. coli* were higher in houses using kitchen sink graywater

- The impact of children, animals, and storage in a household on *E. coli* levels in graywater appears to be small.

Protozoan Parasites

- Although samples were limited, no protozoan parasites were detected.

Coliphages

- There was only one occurrence of coliphages in graywater. This indicates that it was a random occurrence, and coliphages are not usually present in graywater. This suggests that coliphages are not a good indicator of graywater quality.

Irrigated Soil Quality

Fecal coliforms

- Fecal coliforms were detected in most samples of graywater irrigated soil, and exhibit seasonal variation.

- Levels of fecal coliforms in graywater irrigated soil were significantly higher than levels in background soil for most sites. Graywater irrigation does introduce fecal coliform contamination into the soil at levels above what is normally present.

- Fecal coliform levels were significantly higher in graywater irrigated soil at sites including the kitchen sink in their graywater.

- Levels of fecal coliforms in graywater irrigated soil differed significantly in houses with children under 12, those with animals, and those using above ground storage tanks. The impact, while significant, is small.

Escherichia coli

- *E. coli* and fecal streptococci were detected more frequently in graywater irrigated soil than in potable water irrigated soil. This indicates that irrigation with graywater does introduce *E. coli* and other organisms into the soil that would not otherwise be present.

Coliphages

- There were two occurrences of coliphages in soil, one in graywater irrigated and one in background soil. These occurrences were not correlated with any coliphages in the graywater at these sites, and thus appear to be random, again suggesting that coliphages are not a good indicator of soil quality after graywater application.

Recommendations Based on Risk

This analysis supports a recommendation that kitchen sink water should be excluded from graywater used for irrigation purposes, since it carries what is potentially the greatest risk of exposure to enteric pathogens (though not necessarily enteric viruses or protozoa). Some small additional risk may result from the presence of children, animals, and underground storage. For this reason, residents should be strongly encouraged to take into consideration the makeup of their particular household and the methods of irrigation (i.e., avoiding irrigation of entire lawns) before deciding how to recycle their graywater.

References

1. Adams, M.H. (1959). Coliphages. Interscience Publisher, Inc, N.Y.

2. American Public Health Association (1995). Standard Methods for the Examination of Water and Wastewater, 19th ed., Washington, D.C.

3. Asano, Takashi. (1998). Wastewater Reclamation, Recycling, and Reuse: An Introduction. *In*: Wastewater Reclamation and Reuse. Takashi Asano, (ed), Technomic Publishing, Lancaster, Pennsylvania, pp 40.

4. Badawy, A.S. (1986). Development of a method for recovery of rotaviruses from vegetables and its application for rotavirus survival on crops. Ph.D dissertation. University of Arizona, Tucson, Arizona.

5. Crook, James (1985). Health and Regulatory Considerations. *In*: Irrigation With Reclaimed Municipal Wastewater – A Guidance Manual. J. Stuart Pettygrove, and Takashi Asano (eds.), Lewis Publishers, Chelsea, MI, pp. 10-14.

6. Gerba, Charles, T. Straub, J. B. Rose, M. Karpiscak, K. Foster, and R. Brittain (1995). Water Quality Study of Graywater Treatment Systems. Water Resources Bulletin, **31**:109-116.

7. Gleeson, Cara, and Nick Gray (1997). The Coliform Index and Waterborne Disease. E and FN Spon, London.

8. Haas, Charles, J. Rose and C.P. Gerba. (1995). Quantitative Microbial Risk Assessment. John Wiley and Sons, New York.

9. Karpiscak, Martin, *et al*. (1987). Casa del Agua: Progress Report on Phase 2.

10. Karpiscak, Martin, Kennith Foster, K. James DeCook, Charles Gerba, and Richard Brittain. (1986). Casa del Agua: Progress Report on Phase 2.

11. Maier, Raina, C.P. Gerba and I. Pepper. (2000). Environmental Micobiology.

12. Pepper, Ian, C.P. Gerba and J. Brendecke. (1995). Environmental microbiology: A laboratory manual. Academic Press, San Diego.

13. Pepper, Ian, C.P. Gerba and M. Brusseau. (1996). Pollution Science. Academic Press, San Diego.

14. Rose, Joan. The Application of a Risk Assessment Model for Pathogenic Microorganisms in Sludge: A Case History of Risk from Sludge Treated Playing Fields (unpublished).

15. Sokal, R., and F. Rohlf. (1995). Biometry, 3rd ed. W.H. Freeman, N.Y.

16. Zuberer, D. 1994. Recovery and Enumeration of Viable Bacteria. p. 199-144. *In* J.M. Bigham (ed.) Methods of Soil Analysis. Part 2. Soil Science Society of America, Madison, Wisconsin.

ARIZONA DEPARTMENT of ENVIRONMENTAL QUALITY
RESIDENTIAL GRAYWATER REUSE RULES
effective JANUARY 2001

TITLE 18. ENVIRONMENTAL QUALITY
CHAPTER 9. DEPARTMENT OF ENVIRONMENTAL QUALITY
WATER POLLUTION CONTROL

ARTICLE 7.
DIRECT REUSE OF RECLAIMED WATER

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R18-9-701. Definitions

Unless provided otherwise, the definitions provided in A.R.S. § 49-201, A.A.C. R18-9-101, A.A.C. R18-9-601, A.A.C. R18-11-301, and the following terms apply to this Article:

4. “Gray water” means wastewater collected separately from a sewage flow that originates from a clothes washer, bathtub, shower, and sink, but does not include wastewater from a kitchen sink, dishwasher, or toilet.

6. “Irrigation” means the beneficial use of water or reclaimed water, or

both, for growing crops, turf, or silviculture, or for landscaping.

R18-9-711. Type 1 Reclaimed Water General Permit for Gray Water

A. A Type 1 Reclaimed Water General Permit allows private residential direct reuse of gray water for a flow of less than 400 gallons per day if all the following conditions are met:
   1. Human contact with gray water and soil irrigated by gray water is avoided;
   2. Gray water originating from the residence is used and contained within the property boundary for household gardening, composting, lawn watering, or landscape irrigation;
   3. Surface application of gray water is not used for irrigation of food plants, except for citrus and nut trees;
   4. The gray water does not contain hazardous chemicals derived from activities such as cleaning car parts, washing greasy or oily rags, or disposing of waste solutions from home photo labs or similar hobbyist or home occupational activities;
   5. The application of gray water is managed to minimize standing water on the surface;
   6. The gray water system is constructed so that if blockage, plugging, or backup of the system occurs, gray water can be directed into the sewage collection system or on-site wastewater treatment and disposal system, as applicable. The gray water system may include a means of filtration to reduce plugging and extend system lifetime;
   7. Any gray water storage tank is covered to restrict access and to eliminate habitat for mosquitoes or other vectors;
   8. The gray water system is sited outside of a floodway;
   9. The gray water system is operated to maintain a minimum vertical separation distance of at least 5 feet from the point of gray water application to the top of the seasonally high groundwater table;
   10. For residences using an on-site wastewater treatment facility for black water treatment and disposal, the use of a gray water system does not change the design, capacity, or reserve area requirements for the on-site wastewater treatment facility at the residence, and ensures that the facility can handle the combined black water and gray water flow if the gray water system fails or is not fully used;
   11. Any pressure piping used in a gray water system that may be susceptible to cross connection with a potable water system clearly indicates that the piping does not carry potable water;
   12. Gray water applied by surface irrigation does not contain water used to wash diapers or similarly soiled or infectious garments unless the gray water is disinfected before irrigation; and
   13. Surface irrigation by gray water is only by flood or drip irrigation.

B. Prohibitions. The following are prohibited:
   1. Gray water use for purposes other than irrigation, and
   2. Spray irrigation.

C. Towns, cities, or counties may further limit the use of gray water described in this Section by rule or ordinance.

R18-9-719. Type 3 Reclaimed Water General Permit for Gray Water

A. A Type 3 Reclaimed Water General Permit allows a gray water irrigation system if:
   1. The general permit described in R18-9-711 does not apply,
   2. The flow is not more than 3000 gallons per day, and
   3. The gray water system satisfies the notification, design, and installation requirements specified in subsection (C).

B. A person shall file a Notice of Intent to Operate a Gray Water Irrigation System with the Department at least 90 days before the date the proposed activity will start. The Notice of Intent to Operate shall include:
   1. The name, address and telephone number of the applicant;
   2. The social security number of the applicant, if the applicant is an individual;
   3. A legal description of the direct reuse site, including latitude and longitude coordinates;
   4. The design plans for the gray water irrigation system;
   5. A signature on the Notice of Intent to Operate certifying that the applicant agrees to comply with the requirements of this Article and the terms of this Reclaimed Water General Permit; and
   6. The applicable permit fee specified under 18 A.A.C. 14.

C. The following technical requirements apply to the design and installation of a gray water irrigation system allowed under this Reclaimed Water General Permit:
   1. Design of the gray water irrigation system shall meet the on-site wastewater treatment facility requirements under R18-9-A312(C), (D)(1), (D)(2), (E)(1), (G), and R18-9-E302(C)(1), except the septic tank specified in R18-9-E302(C)(1) is not required if pretreatment of gray water is not necessary for the intended application;
   2. Design of the dispersal trenches for the gray water irrigation system shall meet the on-site wastewater treatment facility requirements for shallow trenches specified in R18-9-E302(C)(2);
   3. The depth of the gray water dispersal trenches shall be appropriate for the intended irrigation use but not more than 5 feet below the finished grade of the native soil; and
   4. The void space volume of the aggregate fill in the gray water dispersal trench below the bottom of the distribution pipe shall have enough capacity to contain two days of gray water at the design flow.

D. The Department may review design plans and details and accept a gray water irrigation system that differs from the requirements specified in subsection (C) if the system provides equivalent performance and protection of human health and water quality.