ENVIRONMENTAL FATE AND EFFECTS OF CLEANING PRODUCT INGREDIENTS IN GRAYWATER

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1.0 EXECUTIVE SUMMARY

Household graywater is reused as a means to conserve potable water and to reduce demands on wastewater treatment. Although there are numerous definitions of graywater, a common definition is wastewater generated in the household, excluding toilet wastes, and including wastewater from bathroom sinks, baths, showers, laundry facilities, and in some instances kitchens.

The number of households using graywater is unknown. Estimates of graywater reuse in California have varied from 5-40% of all households. Of those households using graywater, irrigation and direct discharge to soil are the most likely reuse scenarios. Currently, the state of California recommends a graywater system design for irrigation consisting of filtration and below surface distribution. However, the most common reuse of graywater is probably the direct discharge of household laundry waste directly to soil through a garden hose and attached nylon filter. The second most likely reuse scenario for graywater is toilet flushing. Cleaning product ingredients in graywater are not mixed with domestic sewage and therefore are not exposed to the removal processes in domestic sewage treatment systems, such as sorption and biodegradation before discharge to the environment, except when reused for toilet flushing. Since the current trends in graywater reuse appear to be direct discharge to soil and below surface irrigation, the evaluation of graywater in this report focuses on fate and effects in soil.

The composition of graywater is variable and contains a mixture of cleaning product ingredients and other household waste. The concentration of cleaning product ingredients in graywater is estimated to be 2x higher than in domestic sewage.

Based on information obtained for this report, an identified priority data gap is quantitative information on the production, reuse, and discharge of graywater by regions of the United States. The following constituents of graywater also are identified as constituents of environmental interest. These constituents are microorganisms, salts, boron, hypochlorite, organics, and nutrients. Based on climatic data and soil types, 10 water resource regions have been identified as likely candidates for high graywater reuse. This position is supported by significant government activity related to graywater in these regions. Three water resource regions have been identified as potential areas of concern for increased salt and boron concentrations in soils irrigated with graywater (Rio Grande, Upper Colorado, and Lower Colorado). The primary issues and priority data needs related to graywater and the constituents of graywater are further identified and discussed in this report.

2.0 INTRODUCTION

The cleaning products industry has devoted enormous effort over the last thirty years to understand the environmental fate and effects of the ingredients contained in its cleaning products. The focus has been related to the removal of ingredients in municipal wastewater treatment and the fate of residual amounts remaining in discharges since this is the disposal method for approximately 70% of US wastewater. A second focus area of understanding has been residential septic systems. Much of the work conducted to understand the implications of household cleaning product ingredients discharged to the environment via septic systems relies on understanding the fate of these products upon discharge to the soil environment through the drainfield. The data and information compiled from research studies have relevance to graywater usage. Due to increasing regulations and the potential for increasing use of graywater, a review of the fate and effects of deaning product ingredients in graywater was undertaken.

Graywater reuse conserves potable water and reduces demands on wastewater treatment. Through graywater reuse, cleaning product ingredients can increasingly be discharged directly to soil for household irrigation without undergoing typical residential or municipal wastewater treatment. With this reuse of graywater, there is a potential for increased direct exposure to plants, animals, and potentially humans to cleaning product ingredients and their degradation intermediates.

WESTON? conducted a literature search to obtain available information on the environmental fate and effects of cleaning product ingredients in graywater. The search included relevant computer databases for articles, books and reports on the environmental fate and effects of cleaning products in graywater.

Databases searched from the KR Dialog Information System include:

Aerospace Database
Agris International
APILit
Aquatic Science & Fish Abstracts
Biosis Previews
CA Search
CAB Abstracts
Chemical Engineering & Biotechnology Abstracts
Current Biotechnology Abstracts
Current Contents Search
Derwent Biotechnology Abstracts
Dissertation Abstracts Online
Ei Compendex Plus
Embase
Energy SciTec
Environline
Environmental Bibliography
Food Science & Technology Abstracts
Health Periodicals
Life Sciences Collection
Medline
NTIS
Pascal
Pollution Abstracts
SciSearch
Toxline
Water Resources Abstracts
Waternet

Keywords used in the search include:

apparatus
aquifers
biochemical oxygen demand (BOD)
boats
boron
chelators
chemical oxygen demand (COD)
chloride
chlorine
cleaning product ingredients
coliform
cruise ships
design
detergents
EDTA
effects
equipment
exposure
fate
fecal coliform
gray water
graywater
grey water linked to bacteria
greywater
groundwater
hardware
health criteria
hypochlorite
indicator bacteria
metals
micro flora
microorganisms
nitrate
nitrite
nitrogen
oils
pathogens
phosphates
phosphorus
plumbing
risk
salinity
salt effect
salts
ships
soaps
sodium
soil
soil structure
soluble organic carbon (SOC)
surface water
surfactants
systems
total organic carbon (TOC)
total oxygen demand (TOD)
toxicity
transport
turbidity
U.S. Navy
use and reuse
vessels
viruses

Phone contacts were made to a number of individuals and organizations in an effort to obtain the most current information on graywater. See Appendix A for addresses and phone numbers of the individuals and organizations contacted.

Before reviewing the available information on the fate and effects of cleaning product ingredients in graywater**,** this report presents a framework for the evaluation of graywater. This report summarizes how graywater is defined, characterized and used. This report also describes graywater system designs, including treatment and disinfection, as well as the transport and environmental factors affecting cleaning product ingredients in graywater. This report concludes with a prioritization of data needed to be generated for a better understanding of the fate and effects of cleaning product ingredients in graywater.

3.0 FRAMEWORK FOR GRAYWATER EVALUATION

A framework for graywater evaluation is shown in Figure 1. This framework is based on the information obtained for this report. Figure 1 depicts the production and reuse of graywater by a hypothetical household. In order to evaluate the environmental fate and effects of cleaning product ingredients in graywater from a household, a number of components of the graywater system need to be considered. These components include inputs to graywater, location of the house, output of graywater from the house, treatment of graywater, distribution system used, environmental compartment into which the graywater is discharged, and the fate and effects of cleaning product ingredients in the graywater upon release to the environment. A further description of the components of the graywater system in this framework is as follows:

- ✍ **Inputs** are cleaning product ingredients used in a household and released in graywater. These cleaning product ingredients include salts, surfactants, builders, bleaching agents, and minor ingredients. Also associated with graywater are household soils, including organics contributing to BOD, microorganisms, solids, lint, and particulates.

- ✍ **House** indicates the location of the household and the impact that location may have on the volume and quality of graywater produced. Location is defined as region of the country and setting (rural, suburban or urban). The impact of location on the environmental fate and effects of the graywater is evaluated in this framework.

- ✍ **Output** is the graywater produced from the household. This output is based on factors such as the number of occupants, cleaning products usage, local water quality, and the plumbing that the graywater encounters.

- ✍ **Treatment** of graywater can consist of filtration, disinfection, and/or other forms of treatment. The absence of treatment is also considered in this framework. The choice of treatment can have a significant impact on the quality of the graywater.

- ✍ **Distribution systems** include irrigation systems and recycle for other applications such as toilet flushing. The choice of distribution system has a major impact on exposure to graywater. For example, graywater reused for toilet flushing will ultimately be discharged in domestic sewage while graywater reused for irrigation is discharged directly to soil. Potential human exposure to graywater differs based on above surface versus below surface irrigation.

- **Environmental compartment** is the environment to which the graywater is discharged or transported. Based on the available information, irrigation is currently the primary reuse application of graywater. Therefore, soil is the focal point of this framework. Factors that govern environmental concentration of cleaning product ingredients in soil are macro-factors (i.e., seasonal, regional, and climatic) and micro-factors (i.e., soil type, biodegradation and sorption).

- **Fate** is evaluated by the transport and removal of cleaning product ingredients in an environmental compartment. Processes controlling the environmental fate of cleaning product ingredients in graywater and soil include biodegradation and sorption.

- **Effects** are evaluated on the levels of cleaning product ingredients known to have no ecological toxicity to plants and animals and are compared to potential exposure in soil, water, and sediment. Effects on soil condition are also evaluated. Potential human exposure is the final component of this framework.

In Figure 1, the type of font and thickness of the arrow indicate relative magnitude. For example, under environmental compartment, transport of the constituents of graywater is expected to be greatest to soil, low to surface water, and negligible to air.

A simplified version of the graywater evaluation framework (Figure 1) is used throughout the report to facilitate reading of the text. At the start of a section, the bolded type in the graywater evaluation framework corresponds with the applicable section and links the section text to the overall evaluation of graywater.

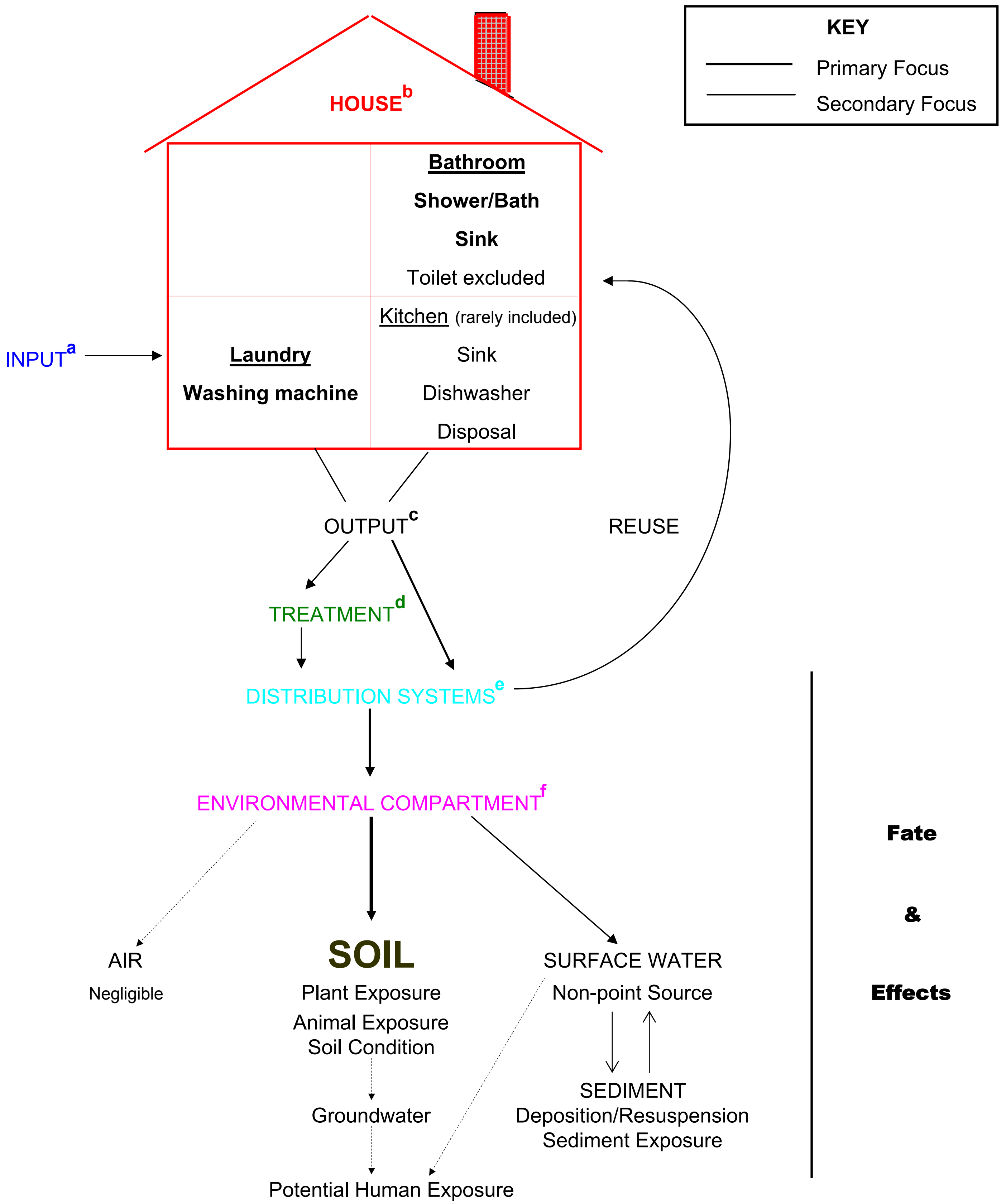


FIGURE 1: FRAMEWORK FOR GRAYWATER EVALUATION

*Footnotes refer to expanded information on the next page

4.0 DEFINITION OF GRAYWATER

There are numerous definitions of graywater. This often makes comparison of data difficult or impossible. A common definition of residential graywater is as follows:

> Graywater is defined as all wastewater generated in the household, excluding toilet wastes, and includes wastewater from bathroom sinks, baths, showers, laundry facilities, and in some instances kitchen wastewater.

This definition is useful because it defines graywater based on the wastewater source rather than the composition of waste water and it differentiates between graywater with or without kitchen waste. This definition is a modification of the frequently cited definition described in Rose *et al.*, 1991 where "Graywater is defined as all wastewater generated in the household, excluding toilet wastes, and includes wastewater from bathroom sinks, baths, showers, laundry facilities, dishwaters and, in some instances, kitchen sinks." Blackwater includes water from toilets and therefore, contains human waste (Karpiscak, 1992).

The United States Environmental Protection Agency (USEPA) and World Health Organization (WHO) use performance-based water quality criteria for reused water, including graywater. USEPA had reviewed the reused water issue and decided that the published "Guidelines for Water Reuse" (USEPA, 1992) are applicable to graywater (J. Kreissel, personal communication).

A number of states include a definition of graywater in their regulations. For a complete review of current regulations see "Issues, Perceptions, Regulations, and Legislation Associated with Cleaning Product Ingredients in Graywater" (Weston, 1996, unpublished). In the absence of a federal definition for graywater, different states use different definitions. Representative definitions of graywater are presented in Table 1.

Some definitions of graywater exclude kitchen sink and dishwasher wastewaters (California) while other definitions specifically include dishwasher wastewater (Massachusetts). Some definitions exclude garbage disposal wastes but include other kitchen waste (New Mexico). One state defines graywater by the absence of fecal material (Connecticut). It is unclear how this latter definition deals with the reported presence of fecal coliform microorganisms in graywater. Some states include a statement in the definition that exclude unhealthy, hazardous or toxic water (Texas). Two states require local health department approval in the definition (Michigan and New Jersey).

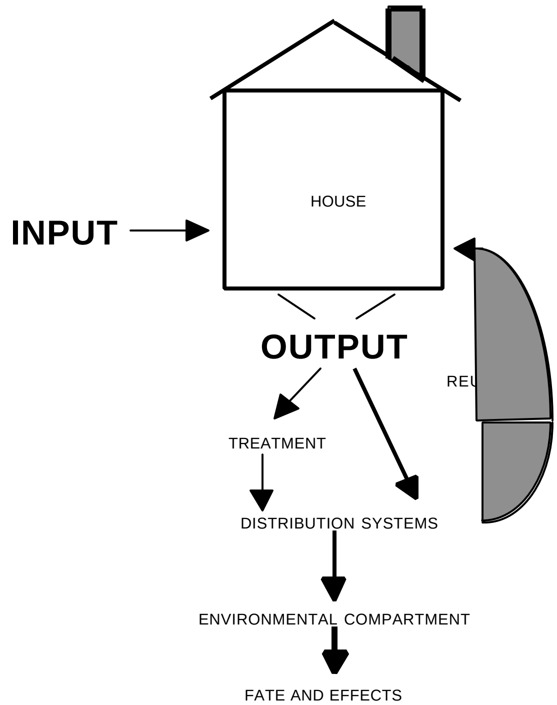
These regulatory definitions reflect the range of definitions found in the literature reviewed for this report. It is clear from the variety of definitions of graywater that there is a wide variation in the quality of graywater. As described in the characterization section of this report, the quality of graywater differs based on definition. Any data on graywater should be accompanied by a clear definition of the graywater used. When such information is available, it is included in this report.

Table 1: Representative Definitions of Graywater In State Legislation And Regulations [1]

State	Graywater Definition
California (current)	"Graywater is untreated household wastewater which has not come into contact with toilet waste. Graywater includes used water from bathtubs, showers, bathroom washbasins, and water from clothes washing machines, and laundry tubs. It shall not include wastewater from kitchen sinks, dishwashers or laundry water from soiled diapers"
Proposed revision to the definition of graywater in the California Standards	"Graywater is untreated wastewater that has not come into contact with toilet waste. Graywater includes used water from bathtubs, showers, bathroom washbasins, clothes washing machines, and laundry tubs, and other waste water that does not present a threat from contamination by unhealthy processing, manufacturing, or operating waste. It does not include wastewater from kitchen sinks or dishwashers"
Connecticut	"Domestic sewage containing no fecal material or toilet wastes."
Massachusetts	"Any putrescible wastewater discharged from domestic activities including but not limited to washing machines, sinks, showers, bathtubs, dishwashers, or other source except toilets, urinals and any drains equipped with garbage grinders."
Michigan and New Jersey	"System for the treatment and disposal of wastewater which normally does not receive human body wastes or industrial waste and is approved for use by a local health department."
New Mexico	"Water carried waste from kitchen (excluding garbage disposal) and bathroom sinks, showers, bathtubs, and washing machines."
Texas	"Wastewater from clothes washing machines, showers, bathtubs, washing hands lavatories, sinks that are not used for disposal of hazardous or toxic ingredients."
Washington	"Sewage having the consistency and strength of residential domestic type wastewater. Includes wastewater from sinks, showers, and laundry fixtures, but does not include toilet or urinal waters."

[1] Taken from Weston, Inc., Table 3 of *Issues, Perceptions, Regulations, and Legislation Associated with Cleaning Product Ingredients in Graywater"*, unpublished report to The Soap and Detergent Association, 1996.

5.0 CHARACTERIZATION OF GRAYWATER (INPUT AND OUTPUT)



Graywater from household sources has been shown to differ based on the number and age of residents as well as lifestyle and activities. For instance, residents that participate in a lot of outdoor activity, such as gardening, add more soil to the washwater waste. The quality of graywater also differs if generated from laundry or bath (Rose *et al*., 1991). The inclusion of sink wastewater also has a large impact on the quality of graywater (Novotny, 1990).

Graywater is usually measured by non-specific parameters such as biochemical oxygen demand (BOD), suspended solids, and bacteria. Some estimates of graywater characteristics from household sources are listed in Table 2. Despite graywater variations by source, some consistent observations have been reported in the literature and are summarized here. From the values in Table 2 and from the articles reviewed for this report, it is apparent that 5-day biochemical oxygen demand (BOD_5) concentrations in graywater can be higher than in household wastewater. The inclusion of garbage disposal waste greatly increases the BOD of graywater. Without garbage disposal waste, the BOD of graywater is similar to domestic wastewater. Domestic wastewater is a household wastewater including both graywater and blackwater (Laak, 1980, Novotny, 1990 and Rose *et al*., 1991). Total phosphorus in graywater has declined over the past decade (Novotny, 1990; Siegrist, 1977). However, graywater continues to contribute phosphorus in residential wastewater at concentrations of 5 to 15 mg/L (Novotny, 1990; Rose *et al.*, 1991). The majority of nitrogen in domestic wastewater is not from graywater (Novotny, 1990; Rose *et al*., 1991). Also noteworthy is the potential for higher suspended solids in graywater when in-sink garbage disposal waste is included (Novotny, 1990). Typical graywater is low in suspended solids compared to domestic wastewater.

The residential use of water typically adds about 300 mg/L of dissolved inorganic solids, although the amount added can range from approximately 150 mg/L to more than 500 mg/L (Metcalf & Eddy, Inc., 1991). A review compiled from various reports listed a range for grease in residential graywater and domestic wastewater as 60 - 150 mg/L and 50 - 150 mg/L, respectively (Laak, 1977). Grease is primarily generated in the kitchen waste of a household.

A list of representative ingredients in household detergents, cleaning products and cosmetics is included in Table 3. The table includes measured concentrations of cleaning product ingredients in raw domestic sewage and estimated concentrations in graywater.

Direct measurements of cleaning product ingredients in graywater are limited. A Japanese study reports synthetic detergents in graywater at 2.1 g/capita/day of methylene blue active substance (MBAS), 1.0 g/capita/day of linear alkyl sulfonate (LAS) and 0.07 g/capita/d of polyoxyethylene nonionic surfactant (POE-NS) (Kazuho and Ryuichi, 1988). In another study, MBAS in combined bath and laundry waste was measured in residential graywater at 22 mg/L (Hypes and Collins, 1974). Data on sodium in graywater also are limited. In one study, average values between 79 and 104 mg/L sodium were estimated for combined bath and laundry waste water (Hypes and Collins, 1974). In a more recent study, sodium in graywater was measured between 45 to 1090 mg/L with an average value of 118 mg/L (City of Los Angeles, 1992). Another author stated that each reuse cycle can increase the sodium concentration in water by more than 200 mg/L, depending on the hardness of the raw water and sodium added in use (Novotny, 1990).

Typical wastewater treatment plant influent contains boron at 1.0 mg/L (Rowe and Abdel-Magid, 1995). Boron was measured in only one of the graywater studies reviewed from this report. In that study, where participants used low boron detergent, no boron was detected in graywater storage tanks or in irrigated soil (Sheikh, 1993). Phosphate levels in graywater varied from 4 to 35 mg/L, in a study of a single family, with an average of 9.3 mg/L (Rose *et al*., 1991). These studies indicate that the composition of graywater is variable. The California Department of Water Resources plans an additional pilot study of graywater usage at six bay area sites and one Southern California site.

The presence of microorganisms in graywater is clearly documented (Rose *et al*., 1986; Rose *et al*., 1991; Gerba *et al*., 1995, Novotny, 1990). The microbial content of graywater can be high depending on the source of the water. Both total and fecal coliform concentrations are usually greater in shower and bath water than in laundry water. One exception is high fecal coliform counts in laundry water from families with cloth diaper washing. The presence of total and fecal coliforms indicate the presence of fecal contamination and the possible presence of intestinal pathogens. Also of concern is the observation that microbial populations can increase over time in graywater. Phosphate, ammonia and other nutrients are available for microbial growth in graywater. These nutrients can be present in higher concentrations in graywater than in domestic wastewater (Brandes, 1978). Therefore, even small inoculations of microorganisms from laundry or baths can cause the development of high microbial counts in graywater. Odor is also cited in graywater storage tanks, probably due to microbial activity (City of Los Angeles, 1992; Hypes and Collins, 1974; Olivieri, 1982).

Table 2: Characteristics of Graywater Compared To Domestic Wastewater

	City of Los Angeles 1992 [a]	Novotny 1990 [b] includes garbage disposal waste	Novotny 1990 [c] excludes garbage disposal waste	Rose *et al.*. 1991 [d]	Siegrist 1977 [e]	Domestic Wastewater 1990
BOD_5 (mg/L)	NA	200 - 650	125 - 380	NA	255	200 - 300 [g]
COD (mg/L)	NA	280 - 830	210 - 620	NA	N.A	680 - 800 [g]
PO_4 (mg/L)	NA	NA	NA	9.3	N.A	20 - 40 [f]
Total Phosphorus (mg/L)	NA	6 - 10	5 - 15	NA	25	2 - 20 [h]
Total Nitrogen (mg/L)	NA	1 - 8	1 - 8	1.7	17	20 - 80 [h]
Chloride (mg/L)	81	NA	NA	9.0	NA	15 - 175 [f]
Suspended Solids (mg/L)	NA	70 - 180	30 - 80	NA	155	100 - 500 [f]
pH	7.0	6.9 - 8.5	6.9 - 8.5	6.5	N.A	~ 7.0 [h]
Sodium (mg/L)	118	NA	NA	NA	NA	52 - 82 [i] (estimated)
Total Coliforms (CFU/100 mL)	$>10^5$ [j]	10^7-10^8	10^7-10^8	10^1-10^7 [k]	10^2 [l],10^3 [m]	10^9 to 10^{11} [g]
Fecal Coliforms (CFU/100 mL)	10^4 [j]	10^6-10^7	10^6-10^7	10^0-10^6 [k]	10^2 [l],10^3 [m]	10^7 to 10^9 [g]

[a] Average values calculated from raw data and not reported by the authors. Source of water varies among the eight sample sites. Graywater from three sites came from the bath, sink, laundry, and kitchen. Graywater at one site was only from the laundry and bath. Graywater from four sites was from the laundry only.

[b] Review article reporting typical range of values for graywater **including** waste from in-sink garbage disposal.

[c] Review article reporting typical range of values for graywater **excluding** waste from in-sink garbage disposal.

[d] Average value for combined graywater for one family (with a child 18 months of age) included wastewater from all sources within the house, excluding the toilet and the kitchen sink.

[e] Review article reporting average values from several studies of graywater excluding garbage disposal waste.

[f] Values from van der Leeden *et al.*,1990.

[g] Values from Novotny, 1990.

[h] Values from Water Pollution Control Federation, 1990.

[i] Estimated from median concentration in U.S. municipal water supply (12 mg/L) and input from domestic use (40 - 70 mg/L). Concentration of sodium in the water supply may vary from 1.1 to 198 mg/L (van der Leeden *et al*., 1990).

[j] Since plate counts were frequently reported as greater than the detection limit, value is artificially low.

[k] Lower counts from families without children and higher counts for families with young children.

[l] Laundry wastewater.

[m] Bath wastewater.

NA = not available

CFU = colony forming units

5.1 PRODUCTION OF GRAYWATER

Graywater in a typical household, as defined by bathroom and laundry wastewater, accounts for roughly half of the total wastewater (Table 4). Since toilet water is excluded from all definitions of graywater, the majority of graywater is generated in bathing and laundry. Water usage in the kitchen is low when compared to the bathroom or laundry. The inclusion of kitchen water in graywater does not greatly increase the volume of graywater generated (less than 25%, see Table 4). However, the inclusion of kitchen sink waste increases suspended solids and grease in graywater making operation of the graywater system more difficult (R. Kourik, personal communication). The characteristics of graywater with and without kitchen sink garbage disposal waste are presented in Table 2. The increases in BOD and suspended solids support the trend toward excluding kitchen waste from graywater production.

The California guidelines estimates graywater production in a suburban household, excluding kitchen wastewater, is 40 gallons/capita/day (California Dept. of Water Resources, 1994). This estimate appears to be consistent with the USEPA estimates of per capita water usage per day (100 gallons/capita/day versus use), with approximately 40-50% of the total wastewater consisting of graywater.

Table 3: Estimated Concentrations of Cleaning Product Ingredients in Graywater

INGREDIENTS	DOMESTIC WASTEWATER (mg/L)	
	Sewage (measured)[1,2,3]	**Graywater (estimated)[4]**
Surfactants	1 - 20	2 - 37
Anionic	3 - 8	5 - 15
Nonionic	0.2 - 2.2	0.4 - 4.1
Cationic	-	-
Amphoteric	-	-
Builders, Co-Builders		
Sodium Tripolyphosphate	-	-
Other Inorganic	-	-
Organic	3	5.5
Bleaching Agents, Activators		
Boron (Perborate)	0.1 - 0.4	0.2 - 0.7
Sodium Hypochlorite	-	-
Organic Materials	0.7 - 1.2	1.3 - 2.2
Salts (sodium, chloride, sulfate)	-	-
Minor Ingredients (generally <1%)		
Enzymes	-	-
Fragrances	-	-
Dyes	-	-
Formulation Aids	-	-
Preservatives	-	-
Anti-oxidants	-	-
Polymers	-	-
Optical Brighteners	-	-
Anti-corrosion Agents	-	-

(-) absent or not reported

[1] Rowe and Abdel-Magid,1995

[2] Trehy, *et al.*, 1996

[3] Gledhill, *et al.*,1989

[4] Estimated from raw sewage concentration and the wastewater generation reported in Table 4 of this report, excluding toilet and kitchen wastewater and assuming that cleaning products are the sole source of the constituent.

Table 4: Water Usage In A Typical Household

Usage	Percent of Total Water Used
Toilet	34.1
Kitchen	12.0
Bathroom	24.5
Laundry	23.2
Miscellaneous	6.2

From Enviro-Management & Research, Inc., 1992.

5.2 SURROGATE MEASUREMENTS OF CLEANING PRODUCT INGREDIENTS AND MICROORGANISMS IN GRAYWATER

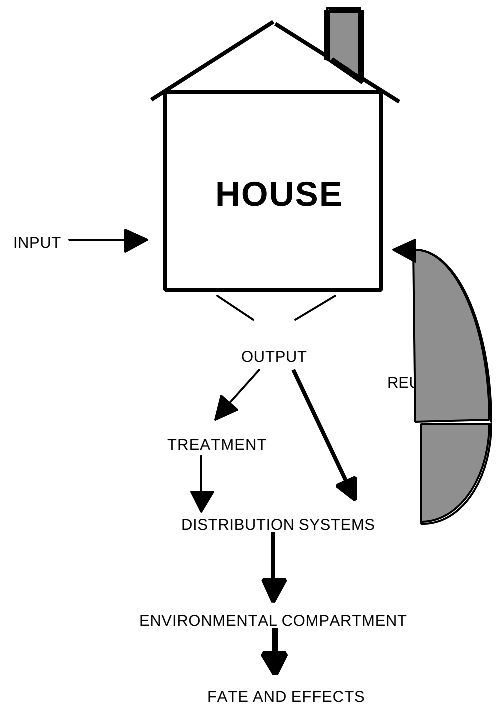
The literature contains numerous non-specific measures of graywater. These measurements include alkalinity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), conductivity, microbial plate counts, pH, suspended solids, total dissolved solids, total organic carbon (TOC), and turbidity (City of Los Angeles, 1992; Hypes and Collins, 1974). Several non-specific measurements of graywater are described that can potentially be used as surrogate measurements of cleaning product ingredients in graywater. Assumptions and data needed to extrapolate to cleaning product ingredients are discussed.

Graywater measurements should correlate with concentrations of biodegradable organic cleaning product ingredients in graywater without kitchen waste. BOD measures the oxygen utilized for the biochemical degradation of organic material (carbonaceous demand) and the oxidation of inorganic sulfides and ferrous iron. Oxidation of reduced forms of nitrogen is nitrogenous demand (APHA, 1989). Inorganic sulfides, ferrous iron and reduced forms of nitrogen should be low in graywater. Any interference from nitrogenous demand also can be inhibited by test methodology. Assuming kitchen waste is excluded from the graywater, the organic material in the graywater will mainly consist of cleaning product ingredients and material removed in the cleaning process.

Conductivity measurements should correlate with dissolved inorganic cleaning product ingredients in graywater. Conductivity is a numerical expression of the ability of an aqueous solution to carry an electric current. Solutions of most inorganic acids, bases, and salts are relatively good conductors. Conversely, molecules of organic compounds that do not dissociate in aqueous solutions conduct a current poorly, if at all (APHA, 1989). Sources of dissolved salts in graywater are cleaning product ingredients, the local water supply, the soil in laundry, and body soil. The conductivity of the water supply for the household can be used as a background value. The difference between the conductivity of the household tap water and water in the graywater surge tank should correlate with ions from salts added to the graywater in cleaning product ingredients. Similar analysis of alkalinity will correlate with the contribution of carbonates, borates and other bases from cleaning product ingredients in graywater (APHA, 1989). Another surrogate measure of inorganic cleaning product ingredients in graywater is total dissolved solids (APHA, 1989).

Although microorganisms are not introduced to graywater from cleaning product ingredients, a major issue for graywater reuse is microbial contamination. The microbial composition of graywater is usually evaluated by microbial plate count methods including enumeration of total heterotrophic bacteria, coliform bacteria, fecal coliform bacteria, and identification of specific microorganisms (APHA, 1989; City of Los Angeles, 1992; Novotny, 1990; Rose *et al*., 1991; and Siegrist, 1977). Of these tests, enumeration of fecal coliforms is a relatively simple test to evaluate the quality of graywater. Fecal coliforms are indicator organisms for the presence of fecal contamination and the possible presence of intestinal pathogens in wastewater. The fecal coliform test differentiates, by incubation temperature, between coliform bacteria of fecal origin (intestines of warm-blooded animals) and coliforms from other sources (APHA, 1989). However, local water quality regulations may require monitoring for other microorganisms (e.g., total coliform bacteria and/or *Escherichia coli*) in graywater prior to reuse.

6.0 USE OF GRAYWATER (HOUSE)



Although a broad definition of graywater includes all non-toilet wastewater, the current trend is toward excluding kitchen wastewater from reused graywater (California Dept. of Water Resources, 1994). The current trend in graywater usage also is toward subsurface irrigation of ornamental plants, lawns and fruit trees but not vegetable gardens, as recommended by California guidelines (California Dept. of Water Resources, 1994). The second most likely usage of graywater is for toilet flushing. However, the odor and color of graywater are unattractive to many people and needs to be controlled for toilet flushing applications (Anderson *et al*., 1981). A third reason to use graywater is to reduce the total wastewater flow in areas where sanitary sewage facilities are inadequate (Lehr, 1987). Some other uses for graywater include above ground irrigation, cooling towers, recirculating showers, recycling washers and aquifer recharge. With sufficient treatment, graywater also can be reused to supplement potable water and swimming pool water (Novotny, 1990). This search did not find information on the percentage of graywater used in various applications. This represents a major data gap in the information on graywater.

Quantitative information on the production, use and discharge of graywater is not available. While conducting an extensive search of the literature on graywater, various experts in the field and governmental agencies working on water resource issues were contacted by WESTON to obtain data on graywater usage throughout the United States (Appendix A-List of Contacts). Each person contacted by WESTON was asked if any information is available on the number of households using graywater, volume of graywater use, percentage of households treating graywater, or other information on the quality, treatment, use and discharge of graywater in their area. The various people contacted were unanimous in their opinion that there is very little quantitative information on graywater usage. They also mentioned that graywater is often illegally used. Therefore, collecting data on graywater usage is difficult. Even in areas where graywater use is legal, the permitting process may be difficult and avoided. For example, approximately 10 permits for graywater systems have been issued in Santa Barbara, CA since the systems were legalized in 1989. This is an area with a population of 200,000. At the same time, a 1990 limited door to door survey indicated that 40% of the residents in Santa Barbara, CA were using some sort of graywater at the height of drought conditions (Ludwig, 1995). One other estimate of residential graywater use in the San Francisco Bay area is lower, approximating 5% of the households (M. Prillwitz, personal communication). Whatever the number of households currently using graywater in California, there is a potential for the usage of graywater to increase if a proposed revision in the California Graywater Standards allowing graywater systems in multi-family dwellings, commercial, industrial, and institutional buildings is enacted (California Dept. of Water Resources, 1996).

The two estimates of 5 and 40% of the households in two areas in California using graywater are the only estimates for the United States located in this search (Ludwig, 1995; M. Prillwitz, personal communications). One other survey in Sydney, Australia found 41% of respondents made some use of graywater or sullage (the Australian word for graywater) during a recent drought (Ludwig, 1995). Of those households in California using graywater, the majority are probably discharging household laundry waste directly to soil through a garden hose and attached nylon filter (Marsha Prillwitz; Darcy Aston, personal communications). This is not a recommended method of graywater usage according to the California Graywater Guidelines.

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6.1 GRAYWATER USAGE BY REGIONS OF THE UNITED STATES

Although no quantitative information is available on graywater use by region, there is an interest in and at least limited use of graywater nationwide (Appendix A-List of Contacts). The information obtained from this search suggests that graywater usage varies by region of the country and locality. Reasons for differences in graywater use by region may include legal restrictions, public perception, water costs, and climatic conditions. Information on legal restrictions and public perception are included in "Issues, Perceptions, Regulations, and Legislation Associated With Cleaning Product Ingredients in Graywater" (Weston, 1996, unpublished). The authors of a graywater study in Barrow, Alaska suggest that areas with high water costs are more likely to use graywater and other methods to conserve water (Pollen and Smith, 1982). Information on climatic data (annual mean temperature, annual rainfall, and annual evapotranspiration) by water resource region (Figure 2 and Table 5), information on evapotranspiration rates for vegetation in the Western United States, and information on generalized soil type by regions of the United States (Appendix B) were assembled to assess the regions likely to use graywater based on water demand and to assess the impact of irrigating with graywater on soils by region (Table 5).

From Table 5, ten water resource regions are identified as likely candidates for graywater usage. These are Souris-Red-Rainy, Missouri Basin, Arkansas White-Red, Texas-Gulf, Rio Grande, Upper Colorado, Lower Colorado, Great Basin, California and Alaska. These regions were chosen because they are estimated to have less rainfall than evapotranspiration on an annual basis (Table 5). Among these regions, California has the largest population at 26,258,000 and graywater usage is legal. Therefore, California is predicted to be a region of high graywater usage. This prediction is supported by significant governmental activity in California related to graywater (California Dept. of Water Resources, 1994 and 1996; City of Los Angeles, 1992; City of Malibu, 1995; and County of Santa Barbara, 1991) and
the number of suppliers of equipment and materials for graywater systems in the state (Appendix C).

Three regions that will probably experience increases in salts and boron in soils irrigated with graywater are the Rio Grande, Upper Colorado and Lower Colorado. These regions have less rainfall than evapotranspiration on an annual basis and have Ardisols as the dominant soils type. Ardisol soils usually experience little leaching and soluble salts can accumulate (USDA, 1988). The dominant soils of California (Entifsols and Xeralfs) also have the potential to increase in salt content due to irrigation with graywater (City of Los Angeles, 1992).

These predictions are made to assist in the evaluation of graywater usage in the United States. However, the lack of quantitative information on graywater usage is a major data gap and a priority data need in the study of graywater.

Table 5: Climate and Soil Data by Water Resource Regions of the United States

Water Resource Region	Population, Thousands	Representative Location [a]	Annual Mean Temperature, °F	RF [b], Inches	ET [c], Inches	Difference Between RF and ET, Inches	Generalized Soil Types [d]
New England	12,290	Boston, MA	51.5	43.81	29.22	14.59	Spodosols
Mid-Atlantic	39,876	New York, NY	54.5	44.12	33.70	10.42	Inceptisols
South Atlantic - Gulf	32,454	Atlanta, GA	61.26	51.31	42.55	8.76	Spodosols
Great Lakes	21,319	Detroit, MI	48.6	30.68	30.01	0.67	Spodosols
Ohio	21,881	Cleveland, OH	49.6	36.81	30.73	6.08	Alfisols
Tennessee	3,846	Memphis, TN	61.8	50.41	43.77	6.64	Alfisols
Upper Mississippi	20,922	Chicago, IL	49.2	33.34	32.17	1.17	Mollisols
Lower Mississippi	7,258	New Orleans, LA	68.2	59.74	54.11	5.63	Inceptisols
Souris - Red - Rainy	**720**	**Bismark, ND**	**41.3**	**16.07**	**26.38**	**-10.31**	**Mollisols**
Missouri Basin	**10,241**	**Kansas City, MO**	**56.3**	**29.27**	**37.57**	**-8.3**	**Mollisols**
Arkansas - White - Red	**8,488**	**Oklahoma City, OK**	**59.9**	**30.89**	**45.83**	**-14.94**	**Mollisols**
Texas - Gulf	**14,627**	**Dallas, TX**	**66.0**	**32.50**	**50.88**	**-18.38**	**Vertisols**
Rio Grande	**639**	**Albuquerque, NM**	**56.2**	**8.91**	**38.1**	**-29.19**	**Ardisols**
Upper Colorado	**2,094**	**Denver, CO**	**50.3**	**14.81**	**18.93**	**-4.12**	**Ardisols**
Lower Colorado	**3,926**	**Phoenix, AZ**	**71.2**	**9.02**	**56.75**	**-47.73**	**Ardisols**
Great Basin	**1,980**	**Salt Lake, UT**	**51.7**	**15.67**	**31.18**	**-15.51**	**Mollisols**
Pacific Northwest	8,232	Seattle, WA	52.7	38.84	27.65	11.19	Inceptisols
California	**26,258**	**Los Angeles, CA**	**65.3**	**14.85**	**38.96**	**-24.11**	**Entisols, Xeralfs**
		San Francisco, CA	**56.7**	**19.33**	**33.40**	**-14.07**	**Xeralfs**
Alaska	**558**	**Fairbanks, AK**	**25.9**	**10.37**	**N/A**	**N/A**	**Inceptisols**
Hawaii	1,152	Honolulu, HI	77.0	23.47	N/A	N/A	Ultisols

[a] Metropolitan area representative of each water resource region

[b] Annual Rainfall

[c] Potential Annual Evapotranspiration

[d] Descriptions of Generalized Soil Types appear in Appendix B..

Sources: Bennett and Hazinski, 1993; van der Leeden *et al*., 1990; USGS, 1988; USDA, 1988
Water Resource Regions likely to have substantial graywater usage are in bold type

[a] INPUT

(Possible Constituents of Graywater)

Salts

- Sodium
  Chloride
  Sulfates

Surfactants

- Anionic
  Cationic
  Nonionic
  Amphoteric

Builders

- Phosphate
  Inorganic
  Organic

Bleaching agents, activators

- **Boron**
  Hypochlorite
  Organics

Minor Ingredients

- Enzymes
  Fragrances
  Dyes
  Optical Brighteners
  Formulation Aids
  Metals
  Preservatives
  Anti-oxidants
  Anti-corrosion agents
  Polymers

Associated Constituents

- Solids/Lint/Particulates
  Microorganisms

[b] HOUSE

- Location
  Region of Country
  Urban
  Rural
  Suburban

[c] OUTPUT

(Factors that May Affect Graywater Quality)

- Number of Occupants
- Age
- Activities/Cleaning Habits
- **Laundry Product Use**
- **Cleaning Product Use**
- Bathing Habits
- Local Water Quality
- Plumbing
  (House and Distribution System)

[d] TREATMENT

- No Treatment
- Filtration
- Coagulation/Filtration
- Disinfection
- Tertiary Treatment
- Carbon Filtration

[e] DISTRIBUTION SYSTEMS

- Above Ground
- **Underground**
- Recycle

[f] ENVIRONMENTAL COMPARTMENT

(Environmental Concentration Factors)

- Macro
  Seasonal
  Regional
  Climatic
- Micro
  Soil Type
  Rainfall
  pH
  Temperature
  Biodegradation
  Physical/Chemical
  Volatilization
  Sorption
  Hydrolysis

These items are included as part of the dimension of graywater. The bold items will be the primary focus of the report.

6.2 RURAL VERSUS URBAN USAGE

Graywater usage is extremely variable. A rural household of four may produce from 35 to 100 gallons per day while a suburban household of four might produce from 100 to 200 gallons per day (Warshall, 1977).

In unsewered rural and rural-suburban areas, graywater can be used to reduce the total wastewater flow (Lehr, 1987; Siegrist, 1977). For example, graywater reuse for toilet flushing or irrigation can ease hydraulic loading to conventional septic systems. However, this search did not find information on the number of households using graywater systems in rural or urban areas.

6.3 WATER QUALITY STANDARDS FOR GRAYWATER REUSE

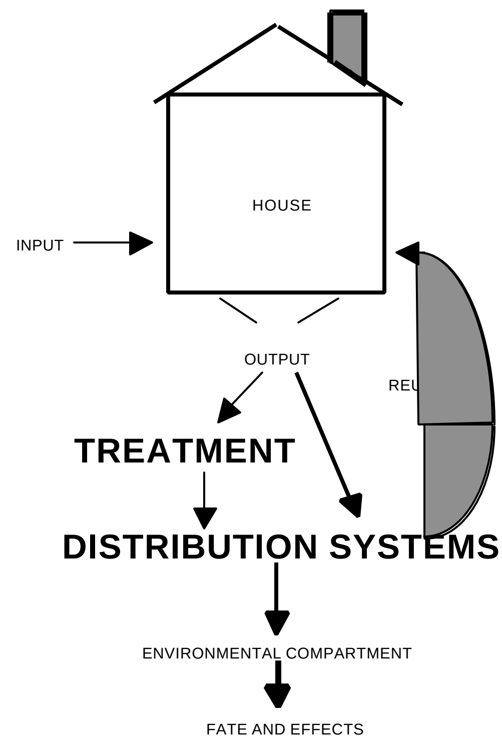
There are no nationally accepted water quality standards for graywater reuse (MWRA, 1992; Atienza and Craytor, 1995) Local public health authorities have jurisdiction over graywater system design and water quality standards. Although it is not a nationally accepted standard, the National Sanitation Foundation's Certification Standard 41 regulates the minimum water quality for recycled water. These limits are listed in Table 6 (Atienza and Craytor, 1995). Recycled water, within these limits, can **not** be used for potable water, food crops or recreational areas, but can be used for nonfood crops and ornamental plants based on USEPA Guidelines (Crook *et al*., 1994). Note: These limits are very low compared to the graywater characteristics listed in Table 2 and therefore are not very useful for graywater.

Table 6: Maximum Water-Quality Limits For Recycled Water

5 mg/L BOD
5 mg/L total suspended solids
2.2 total coliforms/100 mL
1 mg/L turbidity

(Modified from Atienza and Craytor, 1995).

7.0 GRAYWATER SYSTEMS DESIGN (TREATMENT AND DISTRIBUTION)



Graywater system design consists of many levels of technology. It ranges from the use of a garden hose to allow laundry water to drain into a backyard to dual plumbing systems with advanced treatment and water recycle. The simplest graywater systems collect the wastewater from lavatories, bathtubs, showers, and laundry facilities and then reuse the liquid with little or no treatment (Lehr, 1987). Some graywater systems are characterized by dual water supply systems (potable water to sinks, showers and laundry; nonpotable water to toilet) and dual drainage lines (graywater from showers, sinks and laundry, toilet waste). The level of wastewater treatment in this type of system can vary from minimal to enhanced (Lehr, 1987). The most advanced systems are limited only by ingenuity and economy. In most cases, the more advanced systems are not economical in a single family residence, but may have application in larger buildings.

In a "Graywater Guide" from the California Department of Water Resources (1996), the basic design of a graywater system includes a plumbing system, a surge tank, a filter, a pump, and an irrigation system. The irrigation system, either a subsurface drip system or a mini-leachfield system, is below ground. A subsurface drip system distributes the water through PVC tubing with emitters. This allows a slow (drip) release of the graywater into the soil. The emitters must meet certain criteria for size and have a demonstrated resistance to root intrusion. A pressure reducing valve, switches, and flush valves are used to control the system. A mini-leachfield distributes the water through perforated pipes into filter material of clean stone, gravel or similar material. The filter material is then covered with soil. The California graywater irrigation code further requires that irrigation be buried 9 inches below ground at spacings of 14 to 24 inches between irrigation lines depending on the soil type. Each irrigation system includes at least two irrigation zones. This allows alternate irrigation of the soil zones to prevent over saturation of soil. The California graywater standards also specify that irrigation points be neither within 5 vertical feet of the highest known seasonal groundwater nor where graywater may contaminate the groundwater or ocean.

7.1 APPLICATION RATES

In order to evaluate the environmental fate and effects of graywater, an estimate of application rates is needed. The application of graywater will vary according to the production levels in the household and the irrigation needs of the household. However, an estimate of the maximum application rate permissible by the California guidelines is 2.5 gallons/square foot/day in coarse sand or gravel using a mini-leachfield and 0.71 gallons/square foot /day in sand using sub-surface irrigation. Application rates in different soil textures are presented in Tables 7 and 8. These are maximum application rates. Actual application rates may vary based on local climatic conditions and the plants to be irrigated. Also noteworthy in Tables 7 and 8 are the wide range of application rates among the different soil textures and between the two different irrigation systems.

Table 7: Graywater Application Rates for One Family of Four by Mini-Leachfield

Soil Texture	Minimum Area [a], square feet	Maximum Application Rate [b], gallons/square foot/day
coarse sand or gravel	64	2.5
fine sand	80	2.0
sandy loam	128	1.25
sandy clay	192	0.83
clay with considerable sand or gravel	288	0.56
clay with small amount of sand or gravel	384	0.42

Applications rates are based on California Graywater Guidelines (1996) using the following equations:

[a] For minimum area of irrigation (M_A)(square feet):

$$V ? M_S ? 2 ? M_A$$

Where:

V = Estimated household graywater production rate (gallons per day)
M_S = Minimum square feet of irrigation area per 100 gallons (based on soil type)
M_A = Minimum area required for mini-leachfield (total square feet in two zones).

[b] For maximum application rate (R_{max})(gallons/square foot/day):

$$\frac{V}{M_A} ? R_{max}$$

Table 8: Application Rates for One Family of Four by Sub-Surface Drip Irrigation

Soil Texture	Minimum Area [a], square feet	Maximum Application Rate [b], gallons/square foot/day
sand	224	0.71
sandy loam	261	0.61
loam	336	0.48
clay loam	411	0.39
silty clay	597	0.27
clay	747	0.21

Applications rates based on California Graywater Guidelines (1996) using the following equations:

[a] For minimum area of irrigation (M_A)(square feet):

$$V ? M_E ? 1.17 ? 2 ? M_A$$

Where:

M_E	=	Minimum number of emitters per gallon per day, based on soil type
1.17	=	Conversion from number of emitters to square foot assuming 14 inch spacing between emitters.
M_A	=	Minimum area required for sub-surface drip irrigation (total square feet in two zones).

[b] For maximum application rate (R_{max})(gallons/square foot/day):

$$\frac{V}{M_A} ? R_{max}$$

7.2 COMMERCIALLY AVAILABLE SYSTEMS

Graywater systems can include a wide range of designs such as graywater septic tanks with sand filtration, infiltration beds, distribution to raised beds, an aerated septic tank (anti-septic tank), and constructed wetlands (Ludwig, 1994, 1995). Four systems used in the City of Los Angeles graywater pilot study are representative of commercially available systems. The four systems, the Robert Kourik system, the Agwa system, the Ted Adams system, and the WaterSave System, were primarily connected to drip irrigation. A brief description of each system is as follows.

The Robert Kourik system consists of a 55-gallon plastic surge tank, flexible tubing, sump pump, bag filter, back-flow preventer, three-way valve and fittings. This system is typically connected to the washing machine discharge line, but also can receive other household graywater (City of Los Angeles, 1992).

The Agwa System is a fully automated graywater system. It is computerized to control a three-way valve for graywater release or bypass to sewer, a pump, and an automatic backwashing sand filter system. The Agwa system connects to all household graywater sources, controls graywater irrigation, and can alternate with freshwater irrigation (Agwa Co., Burbank, Ca).

The Ted Adams system uses a plastic garbage can with a lockable lid connected to washing machine effluent. A sump pump empties the contents through PVC tubing to the irrigation system. When drip irrigation is used, a 200-micron mesh bag filter is affixed to the inlet of the tank (City of Los Angeles, 1992).

The WaterSave System is similar to the Robert Kourik system and includes two storage tanks, 200-micron mesh bag filter, pump, PVC pipes, three-way valve, and other apparatus (City of Los Angeles, 1992).

Other suppliers of commercially available graywater systems and equipment are listed in Appendix C.

7.3 COST

The cost of graywater systems vary greatly based on complexity and capabilities (City of Los Angeles, 1992). Systems that receive discharge from only the washing machine and are low-tech cost $400 to $800 with the lower cost application to homeowner installation and the higher cost with professional installation. If all sources of graywater are connected to the system, the price is $1,000 to $1,500 depending on the number of sources connected with a low-tech collection and distribution system. A fully automated system receiving graywater from all sources costs $2,500 to $5,000.

Life cycle economic comparisons indicate that the added cost of the graywater system may be defrayed by savings in water usage costs. Water costs generally range between $0.50 and $4.50 per 1000 gal although in extremely water scarce areas, costs can reach $28.00 per 1000 gal. In addition, most utilities assess a charge of between $0.20 to $1.20 per 1000 gal for treatment of the sanitary sewage discharged to the public sewers. Using average costs of $1.40 for potable water and $0.50 for sewage treatment with a 15 year life and 12 percent cost of money, the cost of a conventional plumbing system into public sewers versus a minimal graywater system with filtration and chlorination for treatment utilizing graywater simply for water closets uses (savings of 17% and 26% in water and sewage produced) versus a full-scale graywater system with tertiary sewage treatment that uses graywater for all non-potable uses (water saving of 52% and no sewage produced) is approximately the same. If water or sewage treatment costs are much higher than the norm, the cost savings associated with either graywater system increases considerably. This life cycle economic comparison is for a 250 room resort hotel with a normal usage of 117,850 gal per day, including irrigation (Lehr, 1987).

7.4 TREATMENT AND DISINFECTION

Numerous systems are used in graywater treatment including septic tanks, biological treatment units, reverse osmosis, sedimentation, filtration, disinfection, and physical/chemical treatment. However, anecdotal information indicates that most households using graywater are not using any form of treatment. The selection of a wastewater treatment process depends on the characteristics of the wastewater, the required effluent quality, and the cost of the selected treatment option. Table 9 contains reported treatment efficiencies, as percent removal of selected graywater constituents, by five treatment processes. In Table 9, the suspended solids include lint and particulates, BOD and COD includes organics and surfactants, and total dissolved solids include salts. In another study, sand filtration reduced BOD by 97%, COD by 78%, total nitrogen by 43% and fecal coliforms by 97% in graywater septic tank effluent (Boyle, 1982). In addition to those listed in Table 9, other graywater treatment systems have been evaluated. Gerba *et al.*,(1995) evaluated water quality from five graywater treatment systems consisting of:

1) Water hyacinths and sand filtration;
2) Water hyacinths, copper ion disinfection, and sand filtration;
3) Copper ion disinfection and sand filtration;
4) Copper/silver ion disinfection and sand filtration,
5) Cartridge filtration

These authors concentrated on the reduction of microorganisms in the graywater. All five systems were capable of significant reduction in fecal indicator bacteria, suspended solids and turbidity. BOD data were only collected for the first system. The BOD of the graywater was reduced from 120 mg/L to 4 mg/L. In an effort to achieve potable water quality, Hypes and Collins (1974) treated synthetic graywater with a diatomaceous earth filter coupled with either air evaporation, vapor compression, vapor diffusion, or reverse osmosis to achieve reductions in total solids from 663 mg/L to <100 mg/L and MBAS from 57 mg/L to 2 mg/L.

Table 9: Treatment Efficiencies as Percent Removal of Selected Graywater Constituents by Treatment Process

	Suspended Solids removal (%)	Biochemical Oxygen Demand removal (%)	Chemical Oxygen Demand removal (%)	Phosphate removal (%)	Nitrogen removal (%)	Total Dissolve d Solids removal (%)
Filtration	80	40	35	0	0	0
Coagulation/ Filtration	90	50	40	85	0	15
Disinfection [a]	0	20	20	0	0	0
Tertiary Treatment [b]	95	95	90	15-60	50-70	80
Carbon Filtration	0	60-80	70	0	10	5
Soil	98-100	90-99	100	87-100	40-100	0

[a] chlorination, additional removals possible with superchlorination and extended contact time.

[b] biological treatment coupled with chemical treatment, filtration and/or carbon adsorption.

Table 9 is from Lehr, 1987 and Elazar, 1972.

Possible disinfection methods are chlorination, iodine and ultraviolet irradiation (Lombardo, 1982). Because graywater may have a substantial organic and particulate content, high amounts of hypochlorite may be required for disinfection. In one study, a level of 20 mg/L free residual chlorine was required to eliminate viable coliform bacteria from unprocessed combined bath and laundry waters (Hypes and Collins, 1974). Therefore, a filtration step to remove particulates is recommended prior to disinfection. Some form of disinfection is recommended prior to reuse of graywater for toilet flushing and for stored graywater to reduce odors and the risk of pathogen transmission.

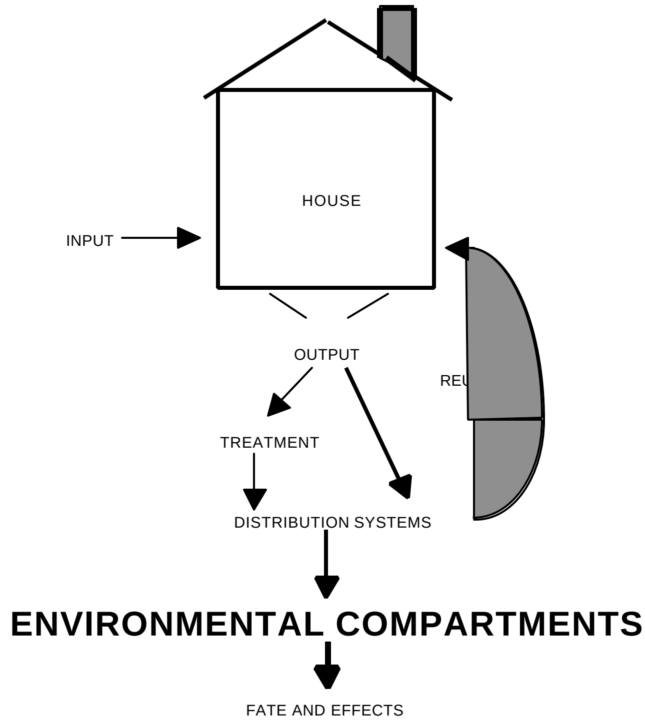
7.5 SOIL AS TREATMENT PROCESS

Infiltration of water through soil can be considered a treatment process. Soil-aquifer processes can be counted on to provide treatment benefits (NRC, 1994). In soil treatment systems, removal of organic matter from combined wastewater and graywater is reported to be 90 % (USEPA, 1978). Removal rates in soil are summarized in Table 9. Significant removals of suspended solids, BOD, COD, phosphorus and nitrogen, but not salts have been reported when wastewater is distributed on soil surfaces (Elazar, 1972). However, spatial variability of soil can influence transport and cause preferential flow of chemicals in the voids and macropores in soil. Voids can be caused by the structure of the soil or by animal activity (NRC, 1994).

High loading of graywater effluent and solids can cause clogging of emitters in the distribution system and soil. Clogging can be caused by graywater constituents (lint and particulates) collecting at the soil interface and from bacterial growth (biofilms) from nutrients in the graywater. This can lead to diminished wastewater purification in soil (NRC, 1994).

8.0 MAJOR ENVIRONMENTAL COMPARTMENTS: SOIL

8.1 TRANSPORT



The transport of cleaning product ingredients in soil following graywater application is determined by several environmental processes. The major processes that control the transport and fate of chemicals in soil and groundwater are advection, diffusion, sorption, and biodegradation. Advection is the transport of a dissolved chemical within the mass flow of water. This can occur over large distances. Diffusion is the random mixing caused by collision at the molecular scale. This occurs within very short distances where fluid motion is limited such as within pore spaces and at interfaces. Sorption describes the association of a chemical with solid phases. A substance can be adsorbed onto a two-dimensional surface or absorbed into a three-dimensional matrix. Biodegradation is the transformation of chemicals by microorganisms resulting in a change in the structure of the chemical or complete mineralization of an organic chemical to inorganic products. (Larson *et al*., 1989, Schwarzenbach *et al*., 1993). Transport of graywater constituents in soil is also dependent on the following parameters listed in Page and Pratt, 1975:

1) nature of the constituent

2) rate of application

3) management of the land surface

4) properties of the soil and the underlying sediments or geological materials,

5) depth to the saturated zone

6) amount of water in the aquifer or aquifers

7) degrees of mixing in the saturated zone

Some of the above parameters also determine sorption in soil. There are several different types of sorption reactions that may occur. These are distinguished primarily by the nature of the sorbing surface and the charge characteristics of the sorbing molecule. Sorption varies if the sorbing surface is smooth or porous and varies with charge associated with both the constituent and the sorbing surface. For example, positively charged or hydrophobic chemicals do not travel at the speed of flowing water in soil, but rather are slowed by their attraction to stationary solid sorption sites. Some positively charged species appear to be specifically sorbed strongly to certain oxide surfaces (Chang and Page, 1985). Anions are repelled from clay mineral surfaces that are negatively charged, but are attracted to positively charged broken end faces of minerals and also to free oxides in the soil. These surfaces have charges that are strongly pH dependent and attract anions most strongly under acidic conditions. Neutral organic molecules such as nonionic surfactants sorb primarily to organic matter surfaces.

Measures and parameters that can be used to evaluate the transport of cleaning product ingredients introduced to soil from graywater include K_d, residence time, retardation factor, and degradation rate constant. A measure of sorption is the solid-water distribution ratio or $K_{d.}$ This is the ratio of total chemical concentration associated with the sorbing surface and the total chemical concentration in the solution. The movement of an organic chemical in a soil also can be described by a retardation factor, which is the phenomenon of diminished transport speed of a chemical relative to the water velocity. When evaluating the transport and fate of graywater constituents in soil, the concept of residence time is useful. Residence time of a graywater constituent in soil is determined by the total amount of the chemical in the soil divided by the difference of the inputs per time minus the removal per time of the chemical in the soil of interest. Removal includes both abiotic and biotic processes that are applicable to a specific chemical. For example, biodegradation is an important environmental removal mechanism for surfactants, which can lower concentrations in soil. The overall action of chemical and biological processes on a chemical in soil can be expressed as a half-life or degradation rate constant. The length of the half-life compared to the travel time can be used as an index of the potential for the compound to survive transport in the soil. The above measures and parameters can be used to evaluate the transport of cleaning product ingredients introduced to soil from graywater.

8.2 ENVIRONMENTAL CONCENTRATION FACTORS

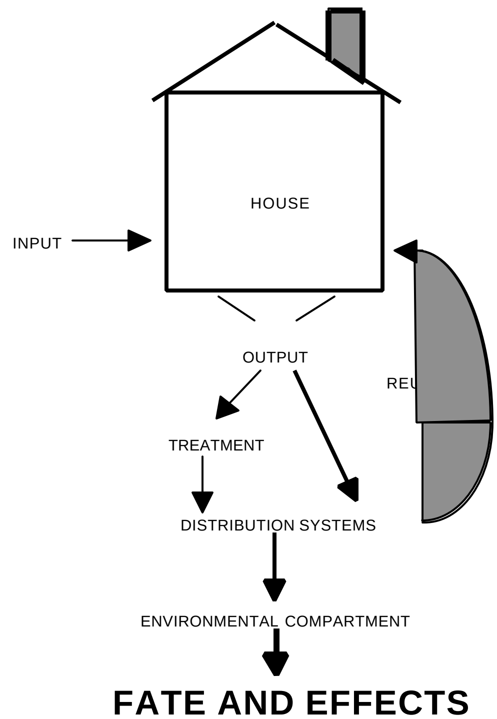
In the assessment of toxicity, the most significant factors related to exposure are the kind, duration, and frequency of exposure and the concentration of the chemical. Plants and animals can be exposed to chemicals present in water, soil, air, and food. Chemicals can enter an organism by various routes such as body surface, ingestion, and inhalation (Rand and Petrocelli, 1985). Direct human exposure to cleaning product ingredients in graywater storage and distribution systems is usually limited. Under certain situations, such as changing system filters, exposure can be elevated. Exposure routes and concentrations will differ for different uses of graywater. For example, exposure will differ with above ground versus below ground irrigation. If graywater is released directly to soil, the soil flora and fauna are exposed to the components of the graywater. The exposure will fluctuate over an extended period of time according to household water use patterns and/or irrigation requirements. The duration of the exposure will depend on the residence time of the graywater and the cleaning product ingredients in soil. The concentration of the chemical in soil will depend on the concentration added with the graywater and subsequent dilution and transport in the environment.

Factors that affect exposure to graywater can be considered on a macro and micro scale. Macro-exposure factors are on a large scale and are seasonal, regional and dimatic. Micro-exposure factors are on a smaller scale and include soil type, rainfall, pH, temperature, biodegradation, and physical/chemical properties, such as volatilization, sorption, and hydrolysis. These exposure factors govern the fate of the cleaning product ingredients in graywater. For example on a macro scale, arid regions have a greater potential for accumulation of salts and boron with graywater irrigation. This is because on a micro scale, salts are not leached from the soil by heavy rainfalls and evapotranspiration concentrates salts on the soil surface.

8.3 RISKS OF EXPOSURE

The literature is inconclusive on the risks of exposure to graywater. A risk?benefit analysis of on-site waste treatment and disposal systems ranked four systems. Graywater and septic tanks each with soil distribution systems had low risk while pit privies and composting toilets had higher risk of probable public health problems in the first year of use. The graywater system had a separate settling tank and below surface soil distribution system. The composting toilet had maintenance and monitoring problems (Olivieri, 1982). In another study, using below ground irrigation at seven sites and above ground irrigation at one site, graywater did not appear to pose a significant risk to users or to the community (City of Los Angeles, 1992). Other authors, however, express concern over the heterogeneity of graywater microbial composition and the limited information available to assess the risks associated with graywater reuse (Rose *et al.*,1991). As described in this report, potential alterations to soil condition and plant growth also need to be considered. Exposure and effects evaluations should be conducted at concentrations and application levels representative of residential graywater usage.

9.0 FATE AND EFFECTS OF GRAYWATER CONSTITUENTS OF ENVIRONMENTAL INTEREST



From the cleaning product ingredients and associated constituents in graywater that are listed in Figure 1, five constituents were identified as the focus of this report because they appear to be the constituents of greatest environmental interest related to the reuse of graywater. These constituents of graywater were chosen because they are a large part of cleaning product formulations and/or public concern exists regarding their use in some applications of graywater. Salts and organics are major constituents of cleaning products in graywater (Tables 2, 4 and 14). Public concerns about graywater exist regarding microorganisms, salts, boron, hypochlorite, pH, and the biodegradability of organics (California Dept. of Water Resources, 1994; Ludwig, 1995; Warshall, 1995; and Weston, 1996, unpublished). Furthermore, constituents of possible concern in the reuse of domestic wastewater include microorganisms, salts, boron, organics, pH, hypochlorite, nutrients, and suspended solids (Rowe and Abdel-Magid, 1995; USEPA, 1992; and Water Environment Research Foundation, 1994). The possible effects of these constituents are listed in Table 10. In regard to graywater, nutrients and suspended solids are not expected to be of concern if the system is properly sited, designed, and maintained (see sections on distribution systems and nutrients). Since the pH and alkalinity of graywater are related to soluble salts these three constituents are discussed together. Therefore, constituents of graywater focused on in this report are microorganisms, salts, boron, hypochlorite, and organics. The primary issues and priority data gaps related to the environmental fate and effects of each constituent are identified and discussed below.

Table 10: Possible Effects of Graywater Constituents

Constituent	Measured Parameter	Possible Effects
Lint, Solids, Particulates	Solids	Suspended matter can cause clogging of systems and shield microorganisms from disinfectants.
Organics	BOD, COD, TOC, and specific compounds	Biofilm formation, aesthetic problems, utilized for microbial growth, effects on plants and soil.
Nutrients	Phosphorus, Nitrogen	Phosphorus and nitrogen are essential nutrients for plant growth. Excessive plant growth and nitrate build-up are not expected in properly sited, designed, and maintained systems.
Hydrogen ion concentration/ alkaline salts	pH/alkalinity	Effects of pH and alkalinity on soil and plants.
Salts	Total Dissolved Solids, Electrical Conductivity, Specific Elements (e.g., Na, Ca, Mg, Cl, B)	Excessive salt may damage some crops. Specific ions such as chloride, sodium, and boron at high concentrations may be toxic to some crops. Sodium may cause soil permeability problems.
Microorganisms	Total plate counts, Indicator organisms, Specific microorganism	Fouling. Pathogenic bacteria, parasites and viruses are infectious agents of waterborne disease.
Hypochlorite	Free And Combined Chlorine	Excessive amounts of free available chlorine (>0.05 mg/L) may cause leaf-tip burn and damage some sensitive crops. Some concerns about potential groundwater contamination by chlorinated organics.

adapted from Asano *et al*., 1985

9.1 ENVIRONMENTAL FATE AND EFFECTS OF MICROORGANISMS IN GRAYWATER

9.1.1 Issue

The primary issue for graywater is the potential for human exposure to pathogenic microorganisms from graywater. Concern over this public health issue is the major reason graywater reuse remains illegal in many areas (Ludwig, 1994). This section addresses the environmental component of this issue by describing the sources of microorganisms in graywater, discussing microbial composition and growth in graywater, reviewing the fate and effects of microorganisms in graywater, identifying data gaps, and prioritizing needs for a more complete understanding of the environmental fate and effects of microorganisms in graywater.

9.1.2 Fate of Microorganisms in Graywater

The presence of microorganisms in graywater is clearly documented (Rose *et al*., 1986; Rose *et al*., 1991; Gerba *et al*., 1995, Novotny, 1990). See Table 2 of this report for indicator organism counts in graywater. Laundry and cleaning products are not potential sources of pathogenic microorganisms. Rose et al.,(1991) found that the microbial content of graywater was dependent on the source of the wastewater. Both total and fecal coliform concentrations were greater in shower and bath water than in laundry water. They also observed that the microbial content of graywater was variable and dependent on the occupants of the household. Families without children produced graywater with total coliforms counts of 10^1 CFU/100 mL. Families with small children produced graywater with total coliform counts as high as 10^7 CFU/100 mL. In the same study the bacterial pathogens, *Salmonella typhimurium* and *Shigella dysenteriae*, survived several days when seeded in graywater at pH 6.5 and 25^{o}C. The viral pathogen, Poliovirus type 1, decreased 90 and 99% at 25 and 17^{o}C, respectively, after 6 days in graywater at pH 6.5 (Rose *et al*.,1991).

Several features of graywater systems encourage microbial growth and persistence. Rose *et al.*, 1991 observed increases in the number of microorganisms when graywater was stored. Plate counts of all microorganisms, coliforms, and fecal coliforms increased with storage time in graywater. Although the three pathogenic microorganisms tested did not increase in number in stored graywater, they survived for several days. An explanation for the increase in microbial population is the nutrient material available for microbial growth in graywater. These nutrients can be present in higher concentrations in graywater than in domestic wastewater (Brandes, 1978). Therefore, even small inoculations of microorganisms from laundry or baths can cause the development of high microbial counts in stored graywater. An explanation for pathogen persistence is biofilm formation in graywater systems that can cause pathogen survival (Ford *et al*., 1992).

While it is apparent that untreated graywater contains microorganisms, it is not apparent how graywater impacts the microbial ecology of soil. In a pilot study, indicator bacteria increased in soil after graywater application. However, background levels of indicator bacteria were already high in the soil, probably due to contamination from animal feces (City of Los Angeles, 1992). This search did not find any studies of indicator bacteria counts before and after graywater release in initially uncontaminated soil, nor studies on the transport and persistence in soil of microorganisms released in graywater. However, a review of the numerous studies conducted on the fate of microorganisms in soil shows that many factors, including climate, type of soil or aquifer material, properties of the pore fluids and type of pathogens, influence the fate of pathogens in soil and aquifers (Bitton and Harvey, 1992). A wide range of responses in soil have been observed for different microorganisms. Some pathogens, such as mycobacteria, survive for several months in soils (Bitton and Harvey, 1992). See Table 11 for additional pathogen survival times in soil.

Table 11: Typical Pathogen Survival Times in Soil at 20 to 30 ^{o}C

Pathogen	Survival Time (Days)
Enteroviruses	<100 but usually <20
Salmonella spp.	<70 but usually <20
Vibrio cholera	<20 but usually <10
Entamoeba histolytica cysts	<20 but usually <10

Source: Crook *et al.*, 1994.

In the review of the transport of pathogens through soils and aquifers by Bitton and Harvey (1992), the authors state that between 1971 and 1980 the use of untreated groundwater was responsible for more than one-third of the waterborne disease outbreaks in the United States. This statistic points to the potential for groundwater contamination by pathogenic microorganisms. Currently, the major sources of pathogens are wastewater effluents, residual sludges from waste treatment and septic tank effluent (Bitton and Harvey, 1992). It is unclear at this time if the release of microorganisms in graywater is a potential source of groundwater contamination.

9.1.3 Effects of Microorganisms in Graywater

Transmission of intestinal, skin and respiratory pathogens by graywater is a poorly understood, yet potentially a very harmful effect of graywater (Siegrist, 1977). This search did not find any reported cases of disease transmission by graywater (Ludwig, 1994; City of Malibu, 1995). However, a number of factors lead to concerns over possible public health effects from graywater. These factors include the presence of total coliforms and fecal coliforms in graywater indicating fecal contamination and the possible presence of intestinal pathogens (City of Los Angeles, 1992; Rose *et al*., 1986; Rose *et al*., 1991; Gerba *et al*., 1995, Novotny, 1990); the ability of relatively low counts of waterborne pathogens to cause diseases like dysentery, typhoid, and cholera (Table 12) (Crook *et al*., 1994); and the ability of microorganisms to grow and persist in graywater (Rose *et al*., 1991).

Human exposure to pathogens can occur in the operation of the graywater system and/or in reuse applications (City of Malibu, 1995; Calif. Dept. of Water Resources, 1994; Ludwig, 1994; Kane, 1981). If graywater is used for irrigation, human exposure to microorganisms can occur from eating irrigated plants, contact with irrigated soil, contact with graywater ponded on the soil surface, in contaminated surface water from graywater run-off, and possibly from subsurface contamination of groundwater. If sprinkler irrigation is used, aerosols are another source of human exposure (Crook *et al.*, 1994).

Besides the potential for the transmission of disease-causing microorganisms, an often cited problem with graywater is odor in storage tanks. This is probably due to microbial activity (City of Los

Angeles, 1992; Hypes and Collins, 1974; Olivieri, 1982). The previously mentioned tendency of microorganisms to form biofilms can also cause the effects of blockage, corrosion, and pathogen survival in graywater systems (Ford *et al*., 1992).

Table 12: Infective Doses of Waterborne Pathogens

Pathogens	**Infective Dose Cells**
Escherichia coli	10^6 - 10^{10}
Salmonella typhi	10^4 - 10^7
Vibrio cholerae	10^3 - 10^7
Shigella flexneri 2A	180
Entamoeba histolytica	20
Shigella dysenteriae	10
Giardia lamblia	<10
Cryptosporidium	1-10
Viruses	1 - 10

Source: Crook *et al.,* 1994.

9.1.4 Discussion of Microorganisms in Graywater

The primary issue for graywater is the potential for human exposure to pathogenic microorganisms. The composition of microorganisms in graywater is variable and dependent on a number of factors, including the source of the graywater, the occupants of the household, and storage time. Although there have been no reported cases of disease transmission by graywater, the potential for graywater to spread pathogenic microorganisms is a concern. Some of these concerns can be reduced by limiting graywater distribution to properly designed and maintained below ground distribution systems (see section on Graywater System Design) and treatment of graywater for some reuse applications (see section on Treatment and Disinfection). A number of data gaps exist in the understanding of the fate and effects of microorganisms in graywater related to this public health concern. **Probably the highest priority for public health officials is a microbial risk assessment of graywater to determine the probability of disease transmission.** However, the methodology to achieve this goal is in the developmental stage (Crook *et al.*, 1994). Limited information exists on the impact of graywater on the microbial ecology of soil. Neither the fate of graywater microorganisms in soil (transport and survival) nor the effects (potential for graywater microorganisms to be a source of groundwater contamination) have been adequately evaluated. Also, since the incidence and effectiveness of graywater disinfection systems are unknown, another data gap is brought forth.

9.2 ENVIRONMENTAL FATE AND EFFECTS OF SALTS IN GRAYWATER

9.2.1 Issue

Some cleaning product ingredients, including sodium sulfate, sodium carbonate, sodium tripolyphosphates, sodium citrate, sodium silicate, sodium perborate, and sodium hypochlorite, contribute to the salt content of graywater (Falbe, 1987). A major issue in graywater reuse for irrigation, after public health concerns related to pathogenic microorganisms, is the salt content of the irrigation water. (Westcot and Ayers, 1985). Salt is a concern in water used for irrigation water because of the physical-chemical effects of salt on soil and the inhibitory effects of salt on plants. This describes the source of salts in graywater, reviews the fate and effects of salts in graywater, and identifies data needs.

9.2.2 Fate of Salts in Graywater

Major sources of salt in graywater include cleaning product ingredients, water softener systems, and the local water supply (Table 4 of this report; Rowe and Abdel-Magid, 1995; and Calif. Dept. of Water Resources, 1994). Different authors characterize salts in graywater using different analytical methods. The concentration of salts in graywater can be determined by non-specific measures, such as total dissolved solids (TDS), electrical conductivity, and alkalinity (Table 13). Concentrations of sodium, calcium, magnesium, chloride, and sulfate ions are also used to characterize graywater (Table 13).

Non-specific measurements of salts in graywater and domestic wastewater are as follows.

- Concentrations of TDS in graywater are reported from 420 to 1,700 mg/L (Enferadi, 1986). Concentrations of TDS in domestic wastewater are reported from 250 to 850 mg/L with 150 to 500 mg/L from domestic input (WPCF, 1990; Metcalf and Eddy,1991).
- An electrical conductivity in graywater of 443 dS/m has been reported (Enferadi, 1986).
- Alkaline chemicals include carbonates, bicarbonates and sulfates of sodium, potassium and calcium (Rowe and Abdel-Magid, 1995). Alkalinity in graywater has been reported from 149 to 382 mg/L (Boyle, 1982; Rose *et al*., 1991). Typical alkalinity in domestic wastewater ranges from 50 to 200 mg/L with 100 to 150 mg/L from domestic input (Rowe and Abdel-Magid, 1995).

Concentrations of specific ions in graywater and domestic wastewater are as follows:

- Sodium is a major inorganic ion of wastewater. Concentrations of sodium in tap water increase by 40 to 70 mg/L due to domestic use (van der Leeden *et al*., 1990). Limited data on sodium in domestic wastewater and graywater are available. In one study, average values between 79 and 104 mg/L sodium were estimated for combined bath

and laundry waste water (Hypes and Collins, 1974). In a more recent study, sodium concentrations in graywater were between 45 to 1,090 mg/L with an average value of 118 mg/L (City of Los Angeles, 1992). An estimate of sodium in domestic wastewater is 52 to 82 mg/L based on a median water supply concentration of 12 mg/L (range of 1.1 to 198 mg/L) cited in van der Leedan *et al*., (1992) and inputs from domestic use stated above. Another estimation is the contribution of sodium to graywater from detergents at 15 to 20% of the total sodium concentration in graywater based on average values from two studies of sodium in detergents and the average sodium concentration for graywater from another study. The average concentration of sodium in graywater from detergents was 17 mg/L in a study from the Pima County Cooperative Extension Service (Appendix D - unpublished) and 24 mg/L after dividing by 8.78 for dilution from a typical wash volume of 69 liters to a typical daily household production of graywater of 606 liters using the data from a study from the University of Arizona (Appendix E - unpublished). When
17 mg/L and 24 mg/L are compared to the measurement of 118 mg/L of total sodium in graywater (Table 13), sodium in graywater from detergents is 14 to 20% of the total sodium concentration. These rough estimates may vary by household and need to be validated by actual measurements. These estimates are offered in an effort to put a dimension on the contribution of sodium from cleaning product ingredients in graywater.

- Calcium concentrations generally are increased in domestic wastewater by 15 to 40 mg/L due to domestic use (van der Leeden *et al*., 1990). Calcium concentrations in graywater are reported to range from 4 to 824 mg/L with average values from 9 to 66 mg/L (Brandes, 1978; City of Los Angeles, 1992; Olsson *et al*., 1968).

- Magnesium concentrations generally are increased in domestic wastewater by 15 to 40 mg/L due to domestic use (van der Leeden *et al*., 1990). Magnesium concentrations in graywater are reported to range from 1 to 235 mg/L with average values from 4 to 24 mg/L (Brandes, 1978; City of Los Angeles, 1992; Hypes and Collins, 1974; Olsson *et al*., 1968).

- Chloride is present in water as sodium chloride, calcium chloride and magnesium chloride. Chloride is one of the major inorganic ions in water and wastewater (Rowe and Abdel-Magid, 1995). Chloride concentrations in domestic wastewater range from 15 to 180 mg/L and increase about 20 to 50 mg/L due to domestic use (Rowe and Abdel-Magid, 1995; van der Leeden *et al*., 1990). This increase from domestic use includes contribution of chloride from the usage of sodium hypochlorite in the household (see section on Hypochlorite). Average chloride concentrations in graywater range from 9 to 81 mg/L (City of Los Angeles, 1992; Rose *et al*., 1991). Also of interest is the possible contribution of chloride from the use of hypochlorite as a disinfectant in graywater (see section on Treatment and Disinfection).

- Typical sulfate concentrations in domestic wastewater range from 20 to 50 mg/L, generally increasing about 15 to 30 mg/L due to domestic use (Rowe and Abdel-Magid, 1995). Sulfate concentrations in graywater are reported to range from 0.3 to 40 mg/L (Boyle, 1982; Rose *et al*., 1991).

In a recent pilot study, application of graywater increased salts in the soil (City of Los Angeles, 1992). When any water is applied to soil, changes in the concentration of soluble salts in the soil depend on the concentrating effect of evapotranspiration, precipitation of the constituents of water in the soil, the extent of dissolution of soluble salts from soil weathering, and the extent of salt transport in the soil due to rainfall (Page and Pratt, 1975). Salts from graywater are affected by the same processes in soil. Accumulation of salts in soil is influenced by the soil type and climatic conditions. Salts introduced into the soil environment from irrigation are readily mobile in most soils because there is limited sorption of salts to soils with the possible exception of clay. With sufficient water transport, salts will move through soil. However, salts can accumulate with low rainfall or poorly drained soil (Tisdale and Nelson, 1975).

Table 13: .Measurements of Salts and Selected Ions in Graywater and Domestic Wastewater

	Graywater	Domestic Wastewater	Pick-up From Domestic Use
Total Dissolved Solids (mg/L)	420 - 1,700 [d]	250 - 850 [f,k]	150 - 500 [d,k]
Electrical Conductivity (dS/m)	443[d]	NA	NA
Alkalinity (mg/L)	149 - 382 [b,k]	50 - 200 [i]	100 - 150 [i]
Sodium (mg/L)	45 - 1,090 [c,e] [118] [c]	52 - 82 (estimated)	40 - 70[j]
Chloride (mg/L)	9 [h] 6 - 141 [81][c]	15 - 180 [i]	20 - 50 [j]
Calcium (mg/L)	4 - 18 [9] [a] 26.6[g] 16 - 824 [66][c]	NA	15 - 40 [j]
Magnesium (mg/L)	1.6 - 2.0 [e] 1 - 6 [4] [a] 5.5 [g] 2 - 235 [24] [d]	NA	15 -40 [j]
Sulfates (mg/L)	0.3 - 40 [b,h]	20 - 50 [i]	15 - 30 [i]

[a] Brandes, 1978; [b] Boyle, 1982; [c] City of Los Angeles, 1992; [d] Enferadi, 1986; [e] Hype and Collins, 1975; [f] Metcalf and Eddy, 1991; [g] Olsson *et al.*, 1968, 1978; [h] Rose *et al.*, 1991; [i] Rowe and Abdel-Magid, 1995; [j] van der Leeden *et al.*, 1990; [k] WPCF, 1990; NA - not available; [ ] - numbers in brackets are average values; Sodium in domestic wastewater is estimated as described in text.

9.2.3 <u>Effects of Salts in Graywater</u>

Salt content of the water is the most important parameter, after public health concerns, in determining the suitability of any water source for irrigation (Westcot and Ayers, 1985). Concerns with salinity are based on several factors including:

1) soil osmotic potential
2) specific ion toxicity
3) deterioration of soil physical conditions

Salt accumulation is especially problematic in arid or semi-arid regions and during germination and seedling development. High salt content in water reduces water uptake by plants by lowering osmotic potential (Crook *et al*., 1994). Crops must be chosen carefully to ensure that they can tolerate salts in the irrigation water, and even then the soil must be properly drained and adequately leached to prevent salt buildup (USEPA, 1992).

Some recommended guidelines for water used for irrigation are as follows.

Electrical conductivity (EC) <0.7 dS/m has no restrictions, 0.7 to 3.0 dS/m has slight to moderate restrictions, and >3.0 dS/m has severe restrictions (Crook *et al*., 1994).

Total dissolved solids (TDS) <450 mg/L has no restrictions, 450 to 2,000 mg/L has slight to moderate restrictions, and >2,000 mg/L has severe restrictions (Crook *et al*., 1994).

The affect of graywater on the alkalinity of soil also needs to be considered. Many plants do not tolerate high concentrations of alkali salts. Alkaline chemicals include carbonates, bicarbonates and sulfates of sodium, potassium and calcium (Rowe and Abdel-Magid, 1995). In soils, a build-up of alkali salts can severely reduce plant productivity. The pH of an acid soil is 6.9 or lower while that of an alkaline soil is 7.1 or higher. If the pH of a soil is over 8.0, the pH should be reduced (Calif. Dept. of Water Resources, 1994).

When reusing graywater, the specific ions of most interest are sodium and chloride (Crook *et al*., 1994). Recommended guidelines for the presence of sodium and chloride in irrigation water are as follows.

Sodium levels of > 70 mg/L in sprinkler irrigation water systems may affect sensitive crops (Crook *et al.*, 1994) Graywater is not recommended for sprinkler irrigation systems. Sodium salts can affect the exchangeable cation composition of soil. This lowers the permeability of the soil and the ability to cultivate the land. This usually occurs in the first few inches of soil and is related to high sodium or very low calcium content in the soil or reused water. Soils with high organic matter or oxides have a greater capacity to cope with sodium inputs (Tanji, 1990).

An indication of the potential effect of sodium on soil is the sodium-adsorption ratio (SAR), which is based on the effect of exchangeable sodium on the soil's physical condition. The concentrations of sodium, calcium and magnesium ions in the irrigation water affect the SAR. For reclaimed water, it is also recommended that the SAR be adjusted for alkalinity to include a more correct estimate of calcium in the soil water following irrigation (Crook *et al.,* 1994). A SAR ratio of < 3 qualifies water for unrestricted irrigation. Slight to moderate restrictions are recommended at SAR ratios between 3 to 9. Severe restrictions are recommended at ratios >9 (Crook *et al.,* 1994). A 1992 report on a graywater pilot project conducted by the City of Los Angeles states "Sodium and SAR were both significantly higher in graywater-irrigated soils than in the control soils. This may have a possible effect on soil condition." The authors speculate that this is partially due to the salt content of most of the detergents used in the course of generating the graywater. "Other laundry additives, such as bleach and water conditioning products may have contributed to the higher sodium levels" (City of Los Angeles, 1992).

Chloride concentrations of < 140 mg/L qualify water for unrestricted irrigation. Slight to moderate restrictions are recommended at chloride concentrations of 140 to 350 mg/L. Severe restrictions are recommended at concentrations > 350 mg/L (Crook *et al*., 1994).

Sulfates are important in the growth of plants. Thus, the presence of sulfate in graywater can be helpful to plants, particularly for soils deficient in sulfur (Rowe and Abdel-Magid, 1995). However, under anaerobic conditions, sulfate can be reduced to hydrogen sulfide resulting in increased toxicity, odor, and corrosion (Rowe and Abdel-Magid, 1995). Anaerobic conditions in soils usually occurs when soils are saturated with water.

9.2.4 Mitigation

It has been proposed that the effects of salts on soil, when graywater is reused for irrigation, can be reduced by the following mitigation actions (Calif. Dept. of Water Resources, 1994):

- Minimize use of high-sodium content detergents.
- Avoid using home water softener systems that add sodium chloride to the water.
- In soils with high alkali concentrations, sulfur or ammonium sulfate can be added to the soil to increase productivity.
- In very low rainfall areas, apply fresh water occasionally, instead of graywater, to leach out accumulated salts.
- Amend soil with gypsum to lower pH and avoid using graywater to irrigate acid-loving plants. The use of graywater on ornamentals that do not require acid conditions will cause the least effect followed by usage on fruit trees. Some acid-loving plants have negative effects when irrigated with graywater. Some acid-loving plants are Ash, Azaleas, Begonia, Bleeding Heart (Dicentra), Camellia, Fern, Foxglove, Gardenia, Hibiscus, Hydrangea, Impatiens, Oxalis (Wood Sorrel) Philodendron, Primrose, Rhododendron, Violet, and Xylosma
- Use graywater on salt-tolerant plants such as Oleander, Bermuda grass, date palms, and native desert plants.

It should be noted that these recommendations are based on ardisole soils and arid conditions. Any potential mitigation action should be evaluated for its applicability to climatic condition, soil type, local water quality, graywater application rate, or other appropriate parameters.

9.2.5 Discussion of Salts in Graywater

Application of graywater has the potential to increase salts in the soil. Increased salts in soil can affect soil alkalinity, soil conditions, and plant growth. Salt contributions from the local water source, and information on climatic conditions and soil types should be evaluated prior to using graywater for irrigation. With sufficient water transport, salts will move through soil. Well-drained sandy soils are less vulnerable to damage than clay soils.

When irrigating with graywater total dissolved solids (TDS), alkalinity, and specific ions (i.e., sodium, calcium, magnesium, and chloride) need to be considered. Reported concentrations in graywater of TDS (420 to 1,700 mg/L), electrical conductivity (443 dS/m), sodium (79 to 118 mg/L) and chloride (9 to 81 mg/L) need to be assessed for effects on soil condition and plant growth prior to irrigating with graywater (Enferadi, 1986; City of Los Angeles, 1992; and Rose et al., 1991). Appropriate irrigation practices should be followed to mitigate possible effects.

The presence of sulfate in graywater can be helpful to plants, particularly for soils deficient in sulfur (Rowe and Abdel-Magid, 1995).

There is a need for more data to determine typical salt concentrations in graywater. There is a need to identify regions of the United States, where graywater reuse for irrigation may cause increases in salt concentrations in soil, based on soil types, rainfall, evapotranspiration, and population.

9.3 ENVIRONMENTAL FATE AND EFFECTS OF BORON IN GRAYWATER

9.3.1 Issue

Sodium perborate and borax are cleaning product ingredients and are sources of boron in graywater (Falbe, 1987). The major issue for boron in graywater is the species specific high phytotoxicity towards plants such as fruit trees as it relates to use of graywater for irrigation purposes. This section addresses this issue by describing the sources of boron in graywater, reviewing the fate and effects of boron in graywater, identifying data gaps, and prioritizing needs for a more complete understanding of the environmental fate and effects of boron in graywater.

9.3.2 Fate of Boron in Graywater

Sources of boron in graywater include the local water supply and the usage of cleaning product ingredients such as sodium perborate and borax. Boron concentrations in drinking water rarely go above 1 mg/L and are generally less than 0.1 mg/L (Rowe and Abdel-Magid, 1995). However, boron concentrations in drinking water, as high as 4.9 mg/L, have been measured (USEPA, 1991). In natural waters, boron occurs primarily as a result of leaching of rocks and soils containing boron compounds. In areas of the western United States (California) groundwater concentrations of 100 mg/L of boron are common (USEPA, 1991). Concentrations in surface water in the United States are generally in the range of 0.1 to 5.0 mg/L with concentrations as high as 15 mg/L in certain areas of the southwestern United States (USEPA, 1991).

Limited information is available on the concentrations of boron in graywater. Boron was measured in only one of the graywater studies reviewed from this report. In that study, where seven of eight sites tested used low boron detergents, no boron was detected in graywater storage tanks or in irrigated soil (Sheikh, 1993). In an early study, boron was measured in domestic sewage at 0.4 to 1.5 mg boron/L (Banerji, 1969). In another early study, the range of mineral pickup in domestic sewage between source and disposal for fifteen California cities in 1954 was reported at 0.1 to 0.4 mg boron/L (van der Leeden *et al*., 1990). Extrapolating from the domestic sewage data and assuming pickup in domestic sewage is primarily from the usage of cleaning product ingredients, a rough estimate of the contribution of boron to graywater from cleaning product ingredients is 0.2 to 0.7 mg boron/L, excluding kitchen waste, using the percentages in Table 3 of this report.

In the household laundry process prior to graywater release, sodium perborate is changed to sodium borate (Falbe, 1987). Once boron is released into the environment, the factors that affect boron exposure include concentration, pH, sorption to soil, and leaching by water (USEPA, 1991). If released to natural waters, boron exists primarily as borate ion or as boric acid depending on concentration and pH. If boric acid or borate adsorb to sediments, a long-term source of boron can be established from the continual adsorption-desorption processes at the sediment-water interface. With release of graywater to the environment, most probably through a below surface distribution system, the boron in the graywater will primarily be exposed to soil and secondarily exposed to water and sediment. In soil solutions, boron occurs as undissociated boric acid except in highly alkaline soils (pH > 8.5) where it is in the form of borate ion. The boric acid and borate in soil solutions can adsorb to soil by both physical and chemical processes. The degree of adsorption depends on the type of soil, pH, salinity, organic matter content, oxides of iron and aluminum and clay in soil. In general, adsorption increases directly in response to increases in concentrations of these soil components, but the affinity of boric acid and borates for soil is low. Therefore, boron is easily detached from the soil and leached by water. From this sorption and desorption process in soil, an equilibrium between soil and soil pore space solution is established. The transport of boric acid and borates varies by soil type. Boron compounds can be leached from soil and are quite mobile in sandy soils (Page and Pratt, 1975; USEPA, 1991).

9.3.3 Effects of Boron in Graywater

Boron is a naturally occurring element found in soil, water and sediment (USEPA, 1991). Since boron is a micronutrient for plant growth, boron deficiencies can occur in soil solutions from sandy soils or acid peat soils, soils derived from igneous rocks, soils low in organic matter, and soils irrigated with low boron water. Boron excesses usually occur in soil solutions from geologically young deposits, arid soils, and soils derived from marine sediments (USEPA, 1991).

Rowe and Abdel-Magid (1995) report the relative tolerance of plants to boron in a sandy soil based on the boron concentration in irrigation water. At concentrations in excess of 1 mg/L, boron is toxic to some boron-sensitive plant species. Based on this type of toxicity, the USEPA criterion for long term irrigation on sensitive crops is set at 0.75 mg boron/L for long-term use and 2.0 mg/L for short-term use (USEPA, 1979 and 1992). Preliminary estimates indicate that boron concentrations in graywater are below these levels (0.2 - 0.7 mg boron/L, see Table 3). Examples of a boron-sensitive plant that might be found on a residential property and irrigated by graywater are citrus, apple, pear and cherry trees, and American elm trees. Examples of boron-semi-tolerant plants exhibiting boron toxicity at 2.0 mg/L are sunflowers and zinnias. Examples of boron tolerant plants exhibiting boron toxicity at 4.0 mg/L are palm trees and gladiolus. Most grasses are relatively boron-tolerant at 2.0 to 10 mg/L. Symptoms of boron toxicity include leaf tip burn, yellowing of leaves, and reduced growth. In addition to plant variety, tolerance to boron varies depending upon climatic conditions and soil conditions.

9.3.4 Discussion of Boron in Graywater

A priority need is to develop current data on boron concentrations in typical graywater in order to evaluate the input of boron to graywater from current cleaning products. Although it is known that the presence of boron in graywater is dependent on the quality of the local water supply and inputs from household cleaning products and that boron concentration in local water supplies vary by region and source of water, based on the literature reviewed for this report, data are limited on the concentrations of boron in graywater and domestic sewage.

In some regions, irrigation with graywater containing boron may help remedy soil deficiencies. In other regions, such as arid areas, the addition of boron to soil through graywater reuse needs to be monitored. Since boron tolerance varies by plant type, careful consideration should be made when selecting the plants to be irrigated. Because environmental effects from boron are species specific and dependent on local soil conditions and climate, data are needed on regional variations in boron toxicity based on differences in plant species, soil type, precipitation and evapotranspiration.

9.4 ENVIRONMENTAL FATE AND EFFECTS OF ORGANICS IN GRAYWATER

9.4.1 Issue

Surfactants, organic builders, organic bleaching agents and some minor ingredients in cleaning products are sources of organics in graywater (Falbe, 1987). Biodegradability is a mechanism for reducing environmental concentration of organics in graywater. A potential issue for organics is the fouling of the graywater system from microorganisms, utilizing organics as growth substrates and forming biofilms in distribution systems and in soil. This section addresses biodegradation and fouling by describing the sources of organics in graywater, reviewing the fate and effects of organics in graywater, identifying data gaps, and prioritizing needs for a more complete understanding of the environmental fate and effects of organics in graywater.

9.4.2 Fate of Organics in Graywater

The organic content of graywater depends on the source of the graywater, but is generally more biodegradable than the organic content of domestic wastewater. For example, if kitchen waste is included in the graywater, the organic content of the graywater is higher (as measured by BOD_5 and COD) than if kitchen waste is excluded from the graywater (Table 2, Novotny, 1990). Graywater also has a BOD_5 that is higher than domestic wastewater due to the biodegradable nature of the components of graywater (Laak, 1974 and 1980; Novotny, 1990; and Siegrist, 1977). In one study (Laak, 1974), BOD was measured in wastewater from the kitchen sink (676 mg/L), laundry (282 mg/L), bathroom sink (236 mg/L) and bathtub (192 mg/L). These values, due to their biodegradability, include cleaning product ingredients in all sources with food waste in the kitchen sink water, body dirt in the bathtub water and laundry dirt in the laundry water. In the same study, cleaning product ingredients were found to contribute significantly to the BOD of the wastewaters.

If graywater is released to soil, high removal of organics is expected. In wastewater applied to soil, overall organics removal of $\geq$ 90% has been reported (USEPA, 1978; Ludwig, 1995). However, organics vary in their sorption, volatility and persistence in soil (Schwarzenbach *et al*., 1993). Sorption plays a role in retarding the movement of organics in soil and varies by soil type (McAvoy *et al.*, 1994). Volatilization is generally reduced following infiltration in soil (NRC, 1994). Persistence in soil is influenced by chemical and biological processes. Chemical processes such as hydrolysis degrade organics in soil (Schwarzenbach *et al*., 1993). However, biodegradation is probably the most important process in decreasing the concentration of organic chemicals in soil. A number of factors influence the rate and extent of biodegradation, including the structure and concentration of the compound, the nature of the microorganisms to which the compound is exposed, the environmental conditions of exposure, and the history of exposure (Atlas and Bartha, 1981; Schwarzenbach *et al*., 1993). With these factors in mind, measurements of the biodegradation rates of organic cleaning product ingredients, under conditions simulating graywater reuse for irrigation, are of interest, but were not found in the literature reviewed for this report.

9.4.3 <u>Fate of Surfactants in Graywater</u>

As previously mentioned, surfactants, organic builders, organic bleaching agents and some minor ingredients in cleaning products are sources of organics in graywater (Falbe, 1987). Of these organic cleaning product ingredients, surfactants are the largest source in graywater (Table 4). Therefore, the fate of surfactants in soil is briefly discussed in this section as representative organic cleaning product ingredients.

Most surfactants currently in use biodegrade in surface soils with half-lives of three weeks or less (Knaebel *et al*., 1994). A number of studies on surfactant biodegradation in soil are summarized in Table 14. Early work, using lysimeters, to study septic tank drainage fields measured the disappearance of surfactants in soil. This disappearance was attributed to biodegradation (Swisher, 1987). Subsequent studies of surfactants in soil and sediment have confirmed biodegradation of surfactants under aerobic and anaerobic conditions (Swisher, 1987; Federle and Schwab, 1992).

It should be noted that sorption can alter the biodegradation process. In one study, sorption played a role in retarding the movement of two surfactants, linear alkylbenzene sulfonate (LAS) and distearyl dimethyl ammonium chloride (DSDMAC) in subsurface soil allowing time for biodegradation to occur (McAvoy *et al.,* 1994). In another study, different mineralization patterns were observed when four surfactants were preadsorbed to sand, kaolinite, illite, montmorillonite, or humic acids prior to starting a biodegradation study in soil (Knaebel *et al*., 1994). These studies were not conducted on graywater, but suggest that the soil to which graywater is released and sorption processes in the soil are important factors in the fate of graywater constituents.

Table 14 : Biodegradation of Surfactants and Degradation Intermediates in Soil

Surfactant	Percent Reduction	Half-life	Comment	Reference
diethyl ester dimethyl ammonium chloride	35 - 45%		mineralization	Giolando *et al*., 1995

nonyl phenol	89%		removal	Marcomini *et al*., 1989
nonyl phenol mono-ethoxylate	91%		removal	Marcomini *et al*.., 1989
nonyl phenol di-ethoxylate	90%.		removal	Marcomini *et al*., 1989
C_{12-15} alcohol ethoxylate$_7$	90%		mineralization	Howells *et al*., 1984
C_{12} alcohol ethoxylate $_{8-9}$	25 - 69%		mineralization in 11 different soils without pre-exposure	Knaebel *et al*., 1990
nonyl phenol	90%		removal semi-aerobic	Marcomini *et al*., 1991
nonyl phenol mono-ethoxylate	90%		removal semi-aerobic	Marcomini *et al*., 1991
C_{13} linear alkylbenzene sulfonates		1 to 20 days	degradation	Larson and DeHanau, 1988
C_{10-14} linear alkylbenzene sulfonates		3 to 35 days	mineralization	Ward, 1987
linear alkylbenzene sulfonates		5 to 25 days 68 to 117 days	summer winter	Litz *et al*., 1987

9.4.4 <u>Effects of Organics in Graywater</u>

A potential effect of organics in graywater is the fouling of the graywater system. The use of biodegradable ingredients is encouraged as a way to decrease environmental loadings. However, microorganisms, utilizing organics as growth substrates, can form biofilms in distribution systems and in soil (see section on microorganisms). These biofilms can clog filters, emitters, and soil causing the system to function poorly and reducing the purification potential of the soil (see section on soil as treatment). The inclusion of kitchen waste increases the potential for fouling of graywater systems (Kourik, 1990). However, a properly designed and maintained system can prevent fouling (Boyle, 1982; Ludwig, 1995).

9.4.5 Effects of Surfactants in Graywater

Since surfactants are estimated to represent a significant part of the organic cleaning product ingredients in graywater and the majority of graywater is presumed to be released to soil, the concentrations of surfactants in graywater and the effects of surfactants on plants and soil are briefly discussed in this section.

Only one of the studies reviewed for this report measured surfactants in graywater. In that study, the concentration of surfactants in graywater was measured as 22 mg MBAS/L (Hypes and Collins, 1974). In domestic wastewater, Rowe and Abdel-Magid (1995) describe a range of total surfactant concentrations from 1 to 20 mg/L. Since the data on concentrations of surfactants in graywater are limited, an extrapolation from the domestic sewage data, assuming pick-up in domestic sewage is primarily from the usage of cleaning product ingredients, gives a rough estimate of the contribution of surfactants to graywater from cleaning product ingredients of 2 to 37 mg total surfactants/L, excluding kitchen waste, using the percentages in Table 3 of this report.

No data on the concentrations of surfactant in graywater irrigated soil were found in this review of the available literature. The concentrations of surfactants in graywater irrigated soil is determined by loading rate, degradation rate and transport of the surfactants in the soil of interest (Knaebel *et al*., 1994; Kuhnt, 1993; McAvoy *et al.*, 1994; Schwarzenbach *et al*., 1993).

This literature review did not locate any toxicity tests using residential graywater. However, two recent studies of surfactants and plant growth in hydroponic chambers are potential models of a graywater system. In one study, three anionic surfactant-based materials (IgeponTC42, Ivory and lecithin) were tested for acute toxicity of hydroponically grown lettuce seedlings. Igepon and Ivory exhibited acute toxicity thresholds at 0.2 g/L and lecithin exhibited an acute toxicity threshold at 0.8 g/L (Greene, 1994). Another study was conducted using synthetic graywater containing a body shampoo. The major ingredient of the body shampoo was Igepon TC42 in a hydroponic growth system for lettuce plants. The body shampoo was lethal to lettuce seedlings at $\geq$ 1.2 g/L while the mature lettuce plants were able to tolerate a concentration of 1.2 g/L. When exposed to the roots of mature lettuce plants, degradation of the shampoo occurred as evidenced by a drop in chemical oxygen demand (COD). A pre-treatment system exposing the graywater at 1.2 g/L of body shampoo to the roots of the mature lettuce plants prior to reuse for hydroponic growth of lettuce seedlings was capable of producing healthy plants from seedlings (Jacquez and Montoya, 1994).

Substantial information is available on the environmental and human safety of surfactants (SDA, 1991; SDA, 1993; and Talmadge, 1994). These include extensive studies of effects on aquatic organisms, as well as studies of effects on soil microorganisms and terrestrial plants. Besides terrestrial plant and microbial toxicity studies, the impact of surfactants on soil physics, soil chemistry, and soil biology are of interest in evaluating application of graywater to soil. These impacts can be positive effects (e.g., enhanced plant growth) or negative effects (e.g., worsening of soil structure) (Kuhnt, 1993). Further evaluation of these potential effects appears to be warranted. An additional noteworthy effect of anionic surfactants is the increased transport of microorganisms and apparent increase in free-living microorganisms in soils containing surfactants. These properties may be useful for *in situ* bioremediation of recalcitrant hydrophobic organic compounds (Jackson *et al*., 1994 and Barber *et al*., 1995).

The earthworm is the most widely tested invertebrate for estimating risk to soil-dwelling organisms. Tests of LAS toxicity to two strains of earthworms, *Eisenia foetida* and *Lumbricus terrestris* have shown that the 14-day LC_{50} was greater than the maximum test concentration of 1000 ?g/g for *Eisenia* and greater than the maximum test concentration of 1333 ?g/g for *Lumbricus*. Based on weight and burrowing behavior, the NOECs for *Eisenia* and *Lumbricus* are 250 and 667 ?g/g, respectively (Mieure *et al.*, 1990).

Upon reviewing the available phytotoxicity data for terrestrial plants, surfactant concentrations of 40 to 100 mg/L are generally needed to effect mature plants. A summary of information on surfactant phytotoxicity to terrestrial higher plants from three reviews is shown in Table 15 (Talmadge, 1994; SDA, 1991; and SDA, 1993). At low concentrations, surfactants have been shown to enhance plant growth (SDA, 1991; SDA, 1993). Dilute graywater also has been observed to be beneficial to plant growth (Ludwig, 1994). No problems have been reported with typical household graywater irrigated to tolerant ornamental shrubs or grasses through below surface distribution systems (Ludwig, 1994). However, surfactants are reported to effect seedling growth at concentrations ranging from 10 ?g/L to 100 mg/L depending on the surfactant and the plant species (Table 15). The wide range in acute toxicity data for surfactants has been attributed to species differences, test methodology, and sample composition (Kimerle, 1995). If compared to the estimated concentrations of total surfactant in graywater of 2 to 37 mg/L (Table 4), and assuming no treatment or removal, some exposure and effects concentration are estimated to overlap. A more detailed comparison of concentrations of specific surfactants in graywater to the reported effect concentrations is not possible because concentrations of specific surfactants in graywater were not found in the search of the literature for this report.

A comprehensive set of environmental toxicity data were reported for the cationic surfactant diethyl ester dimethyl ammonium chloride (DEEDMAC) (Giolando *et al*., 1995). Since graywater will most likely be discharged to soil, data on earthworms and plants are of particular interest in evaluating the effect of the surfactant in graywater exposed to soil. DEEDMAC has a 14 day No Observed Effects Concentration (NOEC) of 23 mg/kg (behavioral effect) with earthworms and no mortality at the highest test concentration of 50 mg/kg soil. DEEDMAC had a 14 day NOEC $\geq$ 50 mg/kg soil for lettuce and oat with the highest test concentration at 50 mg/kg.

Environmental exposures of surfactants have been reported in sludge amended soil, sewage recharged groundwater aquifers, freshwater sediments, marine sediments, and river water (Kimerle, 1995; Kuhnt, 1993; Zoller, 1994; Barber *et al*., 1988; Tabor and Barber, 1995 and Trehy *et al*., 1996). For LAS (the most widely used surfactant) demonstrated exposures provide generally accepted safe levels for aquatic and terrestrial organisms (Kimerle, 1995; Rowe and Abdel-Magid, 1995). Of particular interest to the fate of graywater are data from septic tank systems. Properly sited, designed, and maintained septic tanks do not appear to contribute organics or surfactants to groundwater. Extensive studies of the fate of LAS in a septic tank/tile field system have detected no LAS above background levels of <10 ? g/L in the aquifer (Rapaport *et al*., 1995)

Table 15: Effects of Selected Surfactants on Terrestrial Plants

Surfactant	LOEC [a]	NOEC [b]	Comments
alcohol ethoxylates		100 mg/L	no effect on intact higher plants
alkylphenol ethoxylates	10 ? g/L		inhibition of growth in young plants, growth inhibition in mature plants occurs at concentrations orders of magnitude higher.
	20 mg/L		white birch seedling growth
	100 mg/L		jack pine seedling growth
linear alkylbenzene sulfonates	10 mg/L		orchid seedling growth
	50 mg/L		on average, no effect to plant growth
			growth stimulation of bean and tomato plants at LAS concentrations of 25 and 40 mg/L, respectively
alkyl sulfates	50 mg/L		growth of rice
alpha olefin sulfonates		40 mg/L	tomato, barley and bean germination and growth
diethyl ester dimethyl ammonium chloride (DEEDMAC)		? 50 mg/L	lettuce and oats emergence and growth

[a] Lowest observed effect concentration (LOEC) at watering concentrations.

[b] No observed effect concentration (NOEC) at watering concentrations.

9.4.6 **Discussion of Organics in Graywater**

A major advantage for organics in graywater is the potential for biodegradability as a mechanism for reducing environmental concentration. The overall concentration of organics is greater in graywater than in domestic sewage as measured by BOD_5 and COD. Removal of organics from wastewater applied to soil is also expected. Most surfactants, the major organic cleaning product ingredient in graywater, quickly biodegrade in soils with half-lives of three weeks or less. Although there is substantial data on the biodegradability of cleaning products in soil, the biodegradation rates of organic cleaning products in soils under conditions simulating graywater reuse for irrigation should be assessed

Since the data on concentrations of specific organic cleaning product ingredients in graywater are limited, a priority need is to develop data on the concentration of specific organic cleaning product ingredients in graywater.

Based on estimated anionic and nonionic surfactant concentrations in graywater of 5 to 15 and 0.4 to 4.1 mg/L, respectively (Table 3) and since the effects level for certain surfactants ranges over several orders of magnitude (from 10 ?g/L to 100 mg/L, Table 15), further assessment of the terrestrial plant effects of certain classes of surfactants with typical graywater application rates and soil conditions is needed.

A detailed comparison of concentrations of specific surfactants in graywater to the reported effect concentrations is not possible because concentrations of specific surfactants in graywater were not found in the search of the literature for this report. This is a data gap that should be addressed.

The earthworm is the most widely tested invertebrate for estimating risk to soil-dwelling organisms. Based on a terrestrial toxicity study of LAS on two species of earthworms, there is little acute toxicity and only minor chronic effects on growth and burrowing abilities. The level of toxicity appears to be 1-2 orders of magnitude lower than the likely exposure concentration of this common surfactant.

Because sorption plays an important role in the fate of organics in soils, further assessment of the sorption to soils of organic cleaning product ingredients in graywater is needed.

No priority data needs exist related to organics and graywater system fouling.

9.5 ENVIRONMENTAL FATE AND EFFECTS OF HYPOCHLORITE IN GRAYWATER

9.5.1 Issue

The fate and effects of hypochlorite are addressed as follows:

- The environmental fate and effects of residual hypochlorite.
- The environmental fate and effects of the major break down products of sodium hypochlorite (i.e., sodium and chloride).
- The fate and effects of the byproducts of hypochlorite (i.e., adsorbable organic halides (AOX)).

Hypochlorite is used in this report as an inclusive term for sodium hypochlorite and other compounds such as potassium, lithium or calcium hypochlorite that have commercial uses. This section addresses the major issues for hypochlorite in graywater by describing the source of hypochlorite in graywater, reviewing the fate and effects of hypochlorite in graywater, identifying data gaps, and prioritizing needs for a more complete understanding of the environmental fate and effects of hypochlorite in graywater. The environmental fate and effects of sodium and chloride from the breakdown of sodium hypochlorite are reviewed in both this section and the section of this report on salts in graywater. The role of hypochlorite in graywater disinfection and odor control is discussed in the section of this report on treatment and disinfection. The fate of the chlorinated organic by-products of hypochlorite are discussed in this section.

9.5.2 Fate of Hypochlorite in Graywater

Sodium hypochlorite is the most common “chlorine” bleach used in cleaning products (Falbe, 1987). Factors affecting the fate of hypochlorite in graywater include chemical decomposition, pH, concentration and sorption. Although studies of the fate of hypochlorite in graywater were not found in this search, the majority of hypochlorite from bleach and detergents breaks down to chloride during the laundry process and in reactions with organics in domestic sewage (Falbe, 1986). In one study, more than 96% of the hypochlorite broke down or reacted within 2 minutes after it was added to domestic sewage. Hypochlorite was predominately reduced to chloride as a result of its oxidizing action on inorganic and organic compounds (Overleggroep Deskundigen Wasmiddelin-Milie, 1989). Because of this decomposition, hypochlorite concentrations have not been detected in most domestic wastewater (WPCF, 1990; Rowe and Abdel-Magid, 1995). Other studies have shown that in a typical laundry washing process, an initial concentration of 200 mg hypochlorite/L is reduced by 60% to 80 mg/L prior to discharge from the laundry machine (J. Martinez, personal communication). Hypes and Collins (1974), measured residual chlorine in graywater at tap water baseline levels (<0.05 mg/L) in a graywater consisting of combined bath and laundry wastewater. Unfortunately, the concentration of sodium hypochlorite initially added to the graywater, if any, was not clearly documented in the study. No other studies reviewed for this report measured hypochlorite in graywater. There is a need to better estimate the concentration of hypochlorite discharged in typical residential graywater.

The major breakdown products of sodium hypochlorite are sodium and chloride (Smith, 1994). Chloride concentrations in the water supply of 100 of the largest U.S. cities range from 0 to 540 mg/L with a median value of 13 mg/L increasing by 20 to 50 mg/L from domestic inputs (van der Leeden, 1990). Measurements of chloride concentrations in raw domestic wastewater range from 15 to 180 mg/L (Rowe and Abdel-Magid, 1995). Average chloride concentrations in graywater range from 9 to 81 mg/L (City of Los Angeles, 1992; Rose *et al*., 1991). Sodium concentrations in the water supply of 100 of the largest U.S. cities range from 1.1 to 198 mg/L with a median value of 12 mg/L increasing by 40 to 70 mg/L due to domestic input (van der Leeden *et al*., 1990). An estimate of sodium concentrations in raw domestic wastewater based on concentrations in typical water supply and domestic input is 52 to 82 mg/L. Limited data on sodium in graywater are available. In one study, average values between 79 and 104 mg/L sodium were estimated for combined bath and laundry waste water (Hypes and Collins, 1974). In a more recent study, sodium concentrations in graywater were between 45 to 1090 mg/L with an average value of 118 mg/L (City of Los Angeles, 1992). These data are summarized in Table 16.

Table 16: Concentration of Sodium and Chloride in Different Water Sources

Water Source	Sodium (mg/L)	Chloride (mg/L)
100 of the largest US cities without domestic input [a]	1.1 - 198 (median is 12)	0 - 540 (median is 13)
100 of the largest US cities, with domestic input [a]	1.1 - 198 (median is 67)	0 - 540 (median is 48)
Raw domestic wastewater [b]	52 - 82	15 - 180
Graywater, City of Los Angeles [c]	45 - 1090 (average of 118)	average of 9 - 81
Graywater, combined bath and laundry waste water [d]	79 - 104	

[a] Values from van der Leeden *et al.*, 1990.

[b] Values from Rowe and Abdel-Magid, 1995.

[c] Values from City of Los Angeles, 1992.

[d] Values from Hypes and Collins, 1975.

This increase of sodium chloride in wastewater due to domestic inputs includes a contribution from the use of sodium hypochlorite in the household. An estimate of sodium chloride from the use of sodium hypochlorite in a household is as follows. If a household uses one cup (5.25%) of bleach per day for laundry and hard surface cleaning, that would generate approximately 21 g of sodium chloride in the household waste stream, assuming 100% conversion to NaCl (J. Martinez, personal communications). Based on an average production of graywater at 606 L (160 gals) per household (Calif. Dept. of Water Resources, 1995), 21 g diluted in 606 L equals 35 mg/L of sodium chloride from sodium hypochlorite in graywater from a typical household of four people. This 35 mg/L of sodium chloride is 18% of the total estimated combined sodium and chloride in graywater from Table 2 (199 mg NaCl/L). This rough estimate is offered to place a dimension on the contribution of sodium chloride from the breakdown of sodium hypochlorite in graywater. The contribution will vary by household and geographic location and should be validated by actual measurements.

Along with the chemical decomposition of sodium hypochlorite to sodium and chloride, a small amount of sodium hypochlorite used in homes reacts with household soils to form chlorinated organic by-products (Smith *et al*., 1995). Adsorbable organic halides (AOX) occurring at an average concentration of 4.1 mg/L in laundry washwater are for the most part unidentified, but include chloroform, dichloroacetic acid, trichloroacetic acid, dichloroacetonitrile, bromodichloromethane, and dibromochloromethane. No chlorinated phenols, chlorinated dibenzo-*p*-dioxins, dibenzofurans or other volatile or semi-volatile compounds have been detected (Smith *et al*., 1995). This indicates that the pattern of chlorinated by-products from the use of sodium hypochlorite differs from by-product patterns of other chlorination processes.

Smith *et al.,*(1995) have reported removal of these by-products by septic tanks. The chlorinated organic by-products did not appear to accumulate in septic system leachfields and were most likely removed by biological and chemical decomposition. When comparing the fate of by-products in septic system leachfield and in graywater discharge to soil, the systems are similar with the exceptions that by-products in graywater are not exposed to sewage and by-products in graywater are released to the top 9 to 12 inches of soil as opposed to deeper soils with typical septic system leachfields (Calif. Dept. of Water Resources, 1994).

9.5.3 Effects of Hypochlorite in Graywater

The majority of hypochlorite from bleach and detergents is rapidly changed to chloride during the laundry process and in wastewater. Thus, hypochlorite is not normally detected in domestic wastewater (WPCF, 1990; Rowe and Abdel-Magid, 1995). The concentration of hypochlorite discharged in typical residential graywater is unclear and is a data gap.

The literature contains information on the harmful effects on plants of solutions containing hypochlorous acid and hypochlorite as measured by “free available chlorine”. If water containing 0.05 mg free available chlorine/L is used for irrigation, it may cause leaf-burn or inhibit growth of sensitive plants such as potatoes and tobacco (Tisdale and Nelson, 1975). Concentrations at less than 1 mg/L usually pose no problems to most plants and concentrations of 5 mg/L or more cause severe damage to most plants. Concentrations of hypochlorite that are harmful to plants have not been reported in typical domestic wastewater or graywater.

9.5.4 Discussion of Hypochlorite in Graywater

Based on the information in the characterization section of this report, which indicates a wide range of inorganic and organic material in graywater and studies of the fate of hypochlorite in both laundry wash water and domestic sewage, between 60 to 96% of hypochlorite added is expected to be transformed through reduction to chloride and other degradative processes in graywater prior to discharge. Breakdown in graywater should be dependent on the concentration of organics and inorganics present in the graywater and the duration of graywater storage. However, actual measures of the concentration of hypochlorite in typical residential graywater were not found in this literature search. Data on the concentration of hypochlorite in graywater are needed in order to assess environmental effects from hypochlorite, if any, from typical graywater reuse.

Based on studies in septic system leachfields, the by-products from the use of sodium hypochlorite appear to decompose in the environment. When comparing the fate of by-products in septic system leachfield and in graywater discharge to soil, the lack of exposure to sewage in graywater systems may reduce sorption and biodegradation. Conversely, release of graywater in top soil rather than the deeper soils of a septic system may enhance biodegradation. Additional data are needed on the fate of chlorinated organic by-products in graywater discharged to soil. Further clarification is needed regarding soil removal processes for chlorinated organic by-products from sodium hypochlorite in household graywater.

The breakdown of sodium hypochlorite to sodium and chloride contributes to the overall concentration of both ions in graywater. Both typical domestic usage of sodium hypochlorite and the use of hypochlorite to disinfect graywater may add sodium and chloride to graywater and may impact sensitive plants irrigated with graywater irrigation. The contribution of sodium and chloride to graywater from hypochlorite needs to be evaluated and validated.

The role of hypochlorite in graywater disinfection and odor control is discussed in the section of this report on treatment and disinfection.

9.6 ENVIRONMENTAL FATE AND EFFECTS OF NUTRIENTS IN GRAYWATER

9.6.1 Issue

The major issues for the nutrients phosphorus and nitrogen in graywater are the potential for excessive plant growth and leaching of nitrates into groundwater. Depending on composition, cleaning product ingredients may contribute to both phosphorus and nitrogen in graywater. This section addresses the major issues for nutrients in graywater by describing the concentration of nitrogen and phosphorus in graywater, reviewing the fate and effects of nitrogen and phosphorus in graywater, identifying data gaps, and prioritizing needs for a more complete understanding of the environmental fate and effects of nutrients in graywater.

9.6.2 Nitrogen

The reported concentrations of total nitrogen (1 to 17 mg/L) in graywater are low in comparison to domestic wastewater (20 to 80 mg/L) (Novotny, 1990; Rose *et al*., 1991; and WPCF, 1990). Addition of graywater nitrogen to soil should be beneficial to plant growth. Excessive plant growth may occur only if graywater is introduced to freshwater environment from run-off (Ludwig, 1994; Rowe and Abdel-Magid, 1995; USEPA, 1992). However, in a properly sited, designed and maintained septic system, graywater run-off to surface waters should not occur.

The potential for nitrogen in graywater to reach groundwater as nitrates appears to be low. When nitrogen in the form of ammonia enters soil, it can undergo a biological transformation to nitrite and then to nitrate (nitrification). This changes the positively charged ammonium cation (NH_4^+) to the negatively charged nitrate anion (NO_3^-). Nitrate is mobile in soil and can be further transformed to nitrogen and nitrous gases by denitrification under appropriate low oxygen conditions such as water saturated soil. Removal rates of nitrogen can be high if denitrification is optimized. Nitrogen is also removed from soil by plants and by volatilization (Page and Pratt, 1975). Overall, nitrogen removal of 12 to 93% in wastewater has been reported in rapid-infiltration land treatment systems. The wide range of removal efficiencies is attributed to wastewater loading rates, BOD-to-nitrogen ratios, and variability in the types of soil used (Crites, 1985; NRC, 1994).

9.6.3 Phosphorus

Prior to 1994, phosphorus-based builders in cleaning products were a source of phosphorus in graywater, but concentrations of total phosphorus (5 to 15 mg/L) in graywater are in the same range as in domestic wastewater (Falbe, 1987; Novotny, 1990; and Rose *et al*., 1991). Addition of graywater phosphorus to soil should be beneficial to plant growth. Excessive plant growth may occur only if graywater is introduced to freshwater environment from run-off (Ludwig, 1994; Rowe and Abdel-Magid, 1995; USEPA, 1992). However, in a properly sited, designed and maintained septic system, graywater run-off to surface waters should not occur.

Phosphorus released to soil from graywater should be removed by sorption, precipitation reactions and plant uptake (Page and Pratt, 1975). Soil has a capacity to retain phosphorus. If the application of phosphorus is moderate, as is the case with graywater, most of the phosphorus will be retained in the surface soil.

9.6.4 Discussion of Nutrients in Graywater

Phosphorus and nitrogen are essential nutrients for plant growth and they normally enhance the value of reused water for irrigation. Because the potential for nitrogen in graywater to reach groundwater is low due to denitrification and removal from soil by plants and volatilization, there is not a priority data need to evaluate the fate and effects of nitrogen. Also, since phosphorus released to soil from graywater should be removed by sorption, precipitation reactions and plant uptake, there is not a priority data need to evaluate the fate and effects of phosphorus in graywater.

10.0 SUMMARY OF PRIORITIES

The use of household graywater as a means to conserve potable water and to reduce demands on wastewater treatment is growing. Graywater contains a mixture of cleaning product ingredients and other household wastes. There are many things about graywater that are unknown. The number of households using graywater is not known. Since the current trends in graywater reuse appear to be direct discharge to soil and below surface irrigation, the evaluation of graywater in this report focuses on fate and effects in soil. Based on information obtained for this report, an identified priority data gap is quantitative information on the production, reuse, and discharge of graywater by regions of the United States. The following constituents of graywater also are identified as constituents of environmental interest. These constituents are microorganisms, salts, boron, hypochlorite, organics, and nutrients. The primary issues and priority data needs related to graywater and the constituents of graywater have been discussed and are summarized below.

Several features of graywater should be considered in assessing the environmental fate and effects of cleaning product ingredients in graywater. These features are as follows.

- In general, graywater is primarily reused for irrigation and is directly discharged to soil without undergoing typical residential or municipal wastewater treatment. Currently, the recommended graywater system design for irrigation consists of filtration and below surface distribution.

- The second most likely reuse of graywater is in toilet flushing. Graywater reused in toilet flushing is subsequently discharged in domestic sewage to a POTW or septic tank.

- Cleaning product ingredients in graywater used for irrigation are not exposed to domestic sewage or the removal processes in domestic sewage, such as sorption and biodegradation, except when reused for toilet flushing.

- The composition of graywater is variable, but, in general, the concentration of cleaning product ingredients in graywater is higher than in domestic sewage. The concentration of cleaning product ingredients in graywater is estimated to be approximately two times higher than cleaning product ingredients in domestic sewage.

- ✍ Graywater contains a mixture of cleaning product ingredients and other household waste.

From the review of the literature for this report, data gaps and priority data needs have been identified first for graywater and then for each identified constituent of environmental interest in graywater.

10.1 GRAYWATER

Quantitative information on graywater reuse and discharge to the environment is not available. Data are needed on the production, use, and discharge of graywater by region of the United States. A survey is needed to determine the number of households using graywater systems.

The following constituents of graywater have been identified as constituents of priority environmental interest. These constituents are microorganisms, salts, boron, hypochlorite, and organics. The issues related to graywater and priority data needs for each of these constituents are summarized below.

10.1.1 Microorganisms

The primary issue for graywater is the potential for human exposure to pathogenic microorganisms.

Probably the highest priority for public health officials is a microbial risk assessment of graywater to determine the probability of disease transmission.

Neither the fate of graywater microorganisms in soil (transport and survival) nor the effects (potential for graywater microorganisms to be a source of groundwater contamination) have been adequately evaluated.

10.1.2 Salts

The major issue in graywater reuse for irrigation, after public health concerns related to pathogenic microorganisms, is the salt content of the irrigation water. There is a need to understand the tolerance of arid soils to graywater.

There is a need for more data to determine typical salt concentrations in graywater and the contribution of cleaning products to these concentrations.

There is a need to identify regions of the United States, where graywater reuse for irrigation may cause increased salts in soil, based on soil types, rainfall, evapotranspiration, and population.

10.1.3 <u>Boron</u>

The major issue for boron in graywater is its phytotoxicity towards specific species of plants as related to reuse of graywater for irrigation.

A priority need is to develop current data on boron concentrations in typical graywater in order to evaluate the input of boron to graywater from current cleaning products.

Because environmental effects from boron are species specific and dependent on local soil conditions and climate, data are needed on regional variations in boron toxicity based on differences in plant species, soil type, precipitation and evapotranspiration.

10.1.4 <u>Organics</u>

The major issues for organics in graywater are biodegradability and toxicity. Nonspecific measures, such as BOD_5 and COD, indicate that the organic content of graywater is generally more biodegradable than the organic content of domestic wastewater.

A data need is an assessment of the biodegradation rates of organic cleaning products in soils under conditions simulating graywater reuse for irrigation.

A priority need is to develop data on the concentrations of specific organic cleaning product ingredients in graywater.

Further data are needed on sorption to soils by specific organic cleaning product ingredients in graywater.

10.1.5 <u>Hypochlorite</u>

The three major issues for hypochlorite in graywater are as follows: 1) the environmental fate and effects of residual hypochlorite; 2) the environmental fate and effects of the break down products of sodium hypochlorite (i.e., sodium and chloride) and 3) the fate of the byproducts of hypochlorite (i.e., adsorbable organic halides (AOX)).

Data on the concentration of hypochlorite in graywater are needed in order to assess the environmental effects, if any, from typical graywater reuse.

The contribution of sodium and chloride to graywater from hypochlorite needs to be evaluated and validated.

Additional data are needed on the concentration and fate of chlorinated organic by-products in graywater discharged to soil.

10.1.6 <u>Nutrients</u>

The major concern for the nutrients, phosphorus and nitrogen, in graywater are the potential for leaching of nitrates into groundwater and excessive plant growth.

Based on the available literature, nutrients from graywater should enhance soil and not cause environmental problems. Therefore, there are no priority data needs to evaluate the fate and effects of nitrogen and phosphate in graywater.

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APPENDIX A: ADDRESSES AND PHONE NUMBERS OF CONTACTS

Phone contacts were made to a number of individuals and organizations in an effort to obtain the most current information on graywater. The individuals and organizations contacted are as follows

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ADDRESSES AND PHONE NUMBERS OF PHONE CONTACTS (Continued)

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Authority(MWRA)
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Water Environment Federation
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Water Reuse Association of California
915 L Street, Suite 1000
Sacramento, CA 95814

Water Wiser
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Denver, CO 80235
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APPENDIX B: GENERALIZED SOIL TYPES BY REGION IN THE UNITED STATES

Generalized Soil Types

Spodosols

Most Spodosols in the United States are in New England, New York, the northern Great Lake states (especially Minnesota and Wisconsin), Alaska, in the high mountains of the West and along the Atlantic coast in the South including Florida. They are 5.1% of the soil area in the United States. They are generally present in sandy soil under conifers. Their soil moisture regime is aquic (saturated by ground water and free of dissolved oxygen) or udic (not dry in any part for more than 90 days per year cumulative). Most Spodosols have little silicate clay. The particle-size class is mostly sandy, coarse-loamy, or coarse-silty. The vegetation of these soils is coniferous, rain forest, palms or savanna if not cultivated or grazed.

Inceptisols

Inceptisols are the dominant soils on the landscape in large areas of gentle to steep slopes in widely separated humid parts of the United States. They are 18.2% of the soil area in the United States. Their soil moisture regime is aquic, ustic (limited moisture but sufficient during the plant growth season), and xeric (moist and cool in the winter and hot and dry in the summer). Inceptisols are clayey with montmorillonite. Vegetation appropriate for slopes grows on this soil.

Alfisols

Alfisols are the dominant soils on the landscape in large widely separated areas and are 13.4% of the soil area in the United States. Usually formed under forests with a shallow layer of organic carbon. A distinct clay layer is apparent. Their soil moisture regime includes aquic, udic, ustic and xeric.

Mollisols

Mollisols are dominant soils in the central part of the United States and are 24.6% of the soil area in the United States. They are a combination of very dark brown to black surface horizon originally formed under grasses. They have a deep layer of organic carbon. Their soil moisture regime is dominantly aquic, udic, ustic or xeric. Sufficient moisture is present to sustain grass growth. These very dark colored, base-rich soils of the steppes are cultivated to produce grains, sorghum, corn and soybeans.

Vertisols

Vertisols are the dominant soils on the landscape in only a few areas of the United States and are only 1.0% of the soil area. They occur mainly in east-central and southeastern Texas, west-central Alabama, and east-central Mississippi. The central concept of Vertisols is that of clayey soils that have deep wide cracks at some time of the year and have high bulk density between the cracks. They require a high content of expanding and contracting clay. Seasonal variation in soil moisture causes the cracks to form. The vegetation of these soils is primarily grass with some forest or desert shrubs if not cultivated. **Graywater irrigation may be problematic because of the low hydraulic conductivity of these soils.**

Ardisols

Ardisols are the dominant soils in arid areas that are mostly west of the 101st meridian in the United States. They are 11.5% of the soil area in the United States. Their soil moisture is predominantly aridic with insufficient moisture for mesophytic plant growth. There is little or no leaching in these soils and soluble salts accumulate. Crusty surfaces may prevent infiltration of water. Salts, carbonates and silicate clays are present in these soils. Their vegetation is grass and cacti, but their surface is often bare. These soils are used for seasonal grazing or irrigated crops. **Arid soils may be problematic soils for graywater irrigation because of the potential to increase salt and boron concentrations in the soils.**

Entisols

Entisols are most extensive on steep, actively eroding slopes in the western United States. They are also present in coastal marshes, flood plains and glacial washout plains. They are 7.9% of the soil area in the United States. These mineral soils have soil consist of newly deposited materials and have moisture regimes that are aquic, udic, ustic, xeric and torric (arid). **Under arid moisture conditions these soils are problem soils for graywater irrigation because of potential to increase salt and boron concentrations in the soils.**

Xeralfs

Xeralfs are mostly reddish Alfisols that have a xeric moisture regime. These soils are dry for extended periods in the summer. They occur on moderate to steep slopes of foothills and low mountains in central and southern California. They are 0.9% of the soil area of the United States. The vegetation of these soils is native grasses, sparse to thick shrub coverage, or forests. **In the dry summer period these soils are problem soils for graywater irrigation because of potential to increase salt and boron concentrations in the soils.**

GENERALIZED SOIL TYPES BY REGIONIN THE UNITED STATES (cont.)

Ultisols

Ultisols are highly weathered soils present in the southeastern part of the United States and less extensive in the slopes of California, Oregon, Washington and Hawaii. They are 12.9% of the soil area in the United States. They are found in regions where rainfall is high relative to evaporation and excess water for leaching exists in virtually every year. Their soil moisture regime is aquic, udic, ustic or xeric. They contain appreciable amounts of translocated silicate but few bases. Kaolin, gibbsite, and aluminum-interlayered clays are common in their clay fraction and montmorillonite may be present. The vegetation of these soils is coniferous or hardwood if not cultivated.

APPENDIX C: SUPPLIERS OF COMMERCIALLY AVAILABLE GRAYWATER SYSTEMS AND EQUIPMENT

Agwa Systems
801 South Flower Street
Burbank, CA 91502
(800)473-9426

AlasCan
3400 International
Fairbanks, AK 99701
(907)452-5257

Aqua-Flo Supply
453 Lopez Road
Goleta, CA 93117
(805)967-2374

Bi-Cep, Inc.
20 Indian Valley Lane
Telford, PA 18969
(215)723-3178

Biological Mediation Systems
P.O. Box 8248
Fort Collins, CO 80526
(800)524-1097

Clivus Eco-Logical Resource Retrieval Technology
1 Elliot Square
Cambridge, MA 02138
(800)4-CLIVUS
(617)491-0051

Cycle H2O (Graywater for toilet flushing)
Star Route, Box 2
Williams, AZ 86046
(800)292-5342

Drip Irrigation Garden
16216 Raymer Street
Van Nuys, CA 91406

Fluid Systems
2800 Painted Cave Road
Santa Barbara, CA 93105
(805)964-1211

Geoflow
200 Gates Road
Sausalito, CA 94966
(800)828-3388

Geoflow Drip Irrigation
236 W. Portal Avenue, #327
San Francisco, CA 94127
(415)621-6008

Hanson Associates
Lewis Mill
3205 Poffenberger
Jefferson, MD 21755
(301)371-9172

Harmony Farm Supply
P.O. Box 451, 4050 Ross Road
Graton, CA 95444
(707)823-9125

Iris Water Systems
1578 10th Street
Arcata, CA 95521
(707)826-9569

Jandy Industries
P.O. Box 6101
Novato, CA 94948
(800)227-1442

Man Ray Irrigation
P.O. Box 641501
Los Angeles, CA 90064

(818)989-5999

(310)312-3060

SUPPLIERS OF COMMERCIALLY AVAILABLE GRAYWATER SYSTEMS AND EQUIPMENT (Continued)

Marfor Company
P.O. Box 2793
Dublin, CA 94568
(510)829-4390

Natural Gardening Company (The)
217 San Anselmo Avenue
San Anselmo, CA 94960
(415)456-5060

Orenco Systems
814 Airway Avenue
Sutherlin, OR 97479-9012
(503)459-4449

Outdoor Concepts
Box 12539
La Crescenta, CA 91224
(818)951-4519

Pacific Echo, Inc.
23540 Telo Avenue
Torrance, CA 90505
(800)421-5196

RBR Enterprises
HC 62 Box 3812
Camp Verde, AZ 86322
(800)292-5342

Real Goods
966 Mazzoni Street
Ukiah, CA 95482-3471
(800)762-7325

ReWater Systems
438 Addison Avenue
Palo Alto, CA 94301
(415)324-1307

Waste Not, Inc.
P.O. Box 571
Little River, CA 95456
(707)937-1268

Water Cycle
P. O. Box 1841
Santa Rosa, CA 95402
(805)874-2602

Water Conservation Systems, Inc.
Concord, MA 01742
(800)462-3341

Water Maide
2995 Glenwood Drive, #207
Boulder, CO 80301
(303)442-7570

Water Recycler
1973 Cordilleras Road
Redwood City, CA 94062
(415)369-7010

Water Recycling Systems
4852 Avenue Vista Verde
Palmdale, CA 93551
(805)722-0370

Water Save
914 Prospect Avenue
Hermosa Beach, CA 90254
(310)379-3575

Water Saver (washing machine rinse separator)
1248 West 134th Street, #6
Gardena, CA 90247

Urban Farmer Store (The)
2833 Vincente Street
San Francisco, CA 94116
(800)753-3747

APPENDIX D: DETERGENT COMPOSITION AND GRAYWATER

From a study prepared by the Office of Arid Lands Studies, in cooperation with the Soil, Water and Plant Analysis, University of Arizona, and sponsored by Tucson Water (University of Arizona, 1992).

Method of Analysis

All the detergents and related clothes washing products in the list below (e.g., fabric softeners) were purchased during May 1992 from various supermarkets, specialty stores, and other vendors in the Tucson, Arizona, metropolitan area.

The amount of product used in this study was based on the manufacturer's instructions for a cool to warm-water wash in a top-loading machine. The average volume of a top-loading machine is 19 gallons, based on data published by C*onsumer Reports.* Each product was dissolved in distilled/deionized water, the "cleanest" water possible, "clean" water having none or only very small amounts of dissolved salts minerals (see table below). Tap water can contain salts and minerals in widely-varying amounts depending on its source. Using distilled/deionized water avoided addition of salts from tap water.

DETERGENT COMPOSITION AND GRAYWATER (continued)

Product Name	P/L [a]	Conductivity (? mhos/cm) at 25 °C	Alkalinity as $CaCO_3$ (mg/L)	Sodium (mg/L)	Boron (mg/L)	Phosphate (mg/L)
Ajax Ultra	P	1130	219	292	0.040	11.2
Alfa Kleen	L	25.6	16.8	3.71	<< [c]	<<< [d]
All	P	2030	659	492	0.10	NT [e]
All Regular	L	116	29.8	39.3	<<	<<<
Amway	P	939	310	227	<<	4.00
Ariel Ultra	P	1020	247	280	0.030	10.8
Arm and Hammer	P	2450	1160	572	<<	<<<
Bold	L	46.7	68.6	9.74	<<	<<<
Bonnie Hubbard Ultra	P	1560	617	377	0.036	<<<
Calgon Water Softener	P	1290	345	359	<<	22.9
Cheer Free	L	307	80.3	94.7	<<	<<<
Cheer Ultra	P	710	149	171	0.076	<<<
Chlorox 2	P	2880	1430	672	11.2	<<<
Dash	P	1060	482	238	2.14	<<<
Dreft Ultra	P	737	328	189	9.75	<<<
Downy Fabric Softener	L	6.37	NT	< [b]	<<	<<<
Ecovcover	L	132	63.7	24.3	<<	<<<
ERA Plus	L	102	15.3	26.3	<<	<<<
Fab Ultra	P	1140	199	443	<<	21.7
Fab 1-Shot	Packet	501	108	109	<<	5.26
Fresh Start	P	510	106	132	0.026	8.28
Gain Ultra	P	792	300	180	0.058	<<<
Greenmark	P	1690	568	395	<<	1.67
Ivory Snow	P	258	219	70.8	<<	NT
Oasis	L	89.6	16.2	<	<<	<<<

Oxydol Ultra	P	1030	501	272	11.3	<<<

DETERGENT COMPOSITION AND GRAYWATER (continued)

Product Name	**P/L [a]**	**Conductivity (? mhos/cm) at 25 °C**	**Alkalinity as $CaCO_3$ (mg/L)**	**Sodium (mg/L)**	**Boron (mg/L)**	**Phosphate (mg/L)**
Par All Temperature	P	2350	431	529	0.049	2.67
Purex Ultra	P	1010	278	231	<<	<<<
Sears Plus	P	2500	1200	635	<<	<<<
Shaklee	L	19.0	12.1	6.48	<<	<<<
Shaklee Basic L	P	1030	285	230	<<	<<<
Snuggle Fabric Softener	L	2.60	NT	<	<<	<<<
Sun Ultra	P	1490	653	335	<<	1.58
Surf Ultra	P	989	302	249	<<	13.7
Tide with Bleach	L	329	58.3	95.0	2.30	<<<
Tide Regular	L	291	61.2	93.8	0.030	<<<
Tide Ultra	P	959	236	243	0.098	10.7
Valu Time	P	1650	460	371	0.034	1.79
White King	P	266	165	74.0	1.83	NT
White Magic Ultra	P	1140	194	273	0.035	18.5
Wisk Advanced Action	L	221	72.4	56.8	7.41	<<<
Wisk Power Scoop	P	1160	360	319	<<	9.77
Woolite	P	1040	22.3	239	0.17	<<<
Yes	L	42.5	10.3	6.40	<<	<<<
Tap Water	NA	317	11.8	42.7	0.042	<<<
Distilled/Deionized Water	NA	2.03	3.78	<	<<	<<<

[a] P: Powder, L: Liquid

[b] <: Less than the sodium detection limit of 1.0 mg/L

[c] <<: Less than the boron detection limit of 0.025 mg/L

[d] <<<: Less than the phosphate detection limit of 1.2 mg/L

[e] NT: Testing of sample not possible

APPENDIX E: DETERGENT COMPOSITION - GRAYWATER FOR PLANTS

Detergent	Sodium(mg/L)	Conductivity (? mhos/cm)	Alkalinity (as $CaCO_3$mg/L)	Boron (mg/L)	Phosphate (mg/L)
Ivory Flakes	5.0	66	39	0.0053	0.96
Breeze	16.7	327	39	0.0775	20.0
Cheer	22.5	359	43	0.035	23.6
Tide	14.2	346	50	< 0.0125	12.4
Bold	19	352	43	0.0275	13.2
Cold Power	18.4	402	100	0.06	27.2
Perform	12.75	464	104	0.03	8.4
Salvo	18.0	464	77	0.02	52.4
Fab	19.25	495	60	0.07	32.0
All	23.4	555	81	0.49	36.4
Dash	36.0	763	83	0.0175	46.8
Downy Fabric Softener	3.5	22.7	70	< 0.012	0.4

Source: Pima County Cooperative Extension Service, 1992.