GRAYWATER LITERATURE SEARCH

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Texas Onsite Wastewater Treatment Research Council

ON-SITE
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Completed by the

San
Antonio
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Texas Cooperative
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CWR
CENTER FOR
WATER RESEARCH

University of Texas, San Antonio

Graywater Literature Search

Prepared for the
Texas Onsite Wastewater Treatment Research Council

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Background

Graywater has promising potential as a resource that can be used to supplement or replace potable water for the purpose of landscape irrigation. However, limiting state regulations as well as health concerns associated with its use preclude graywater from being used as efficiently as possible. The San Antonio Water System in conjunction with The Texas Section of the American Water Works Association, The City of Austin, The Lower Colorado River Authority, and The Center for Water Research at the University of Texas in San Antonio hosted the Texas Graywater Summit on December 12, 2002.

The goal of the summit was to bring together regulators and members of the private sector to examine the current status of graywater regulations and identify what actions need to be taken in order to make graywater use more viable for the citizens of Texas. The majority of the Summit body agreed that graywater can be used effectively for landscape irrigation, but that further research should be conducted to maximize the safety and benefit of graywater use. An important step in this effort is to identify and examine existing graywater research.

In December of 2003, The San Antonio Water System (SAWS) was awarded a grant by the Texas Onsite Wastewater Treatment Research Council (TOWTRC) to perform such a literature search.

Scope of Work

Based on TOWTRC recommendations, SAWS partnered with the Texas Cooperative Extension at Texas A&M and the Center For Water Research at the University of Texas, San Antonio to perform the literature search. The search focused on specific topics relating to graywater that have been designated by TOWTRC.

Dr. Bruce Lesikar of the Texas Cooperative Extension (TCE) and Dr. Enos Innis of the Center for Water Research, UTSA (CWR) each selected a graduate student to perform the literature and related summary work. An extension assistant from the TCE was also selected to evaluate methods of graywater dispersal.

The draft final report includes a bibliography of graywater literature, an abstract for each article in the bibliography, a summary of findings based on the literature, recommendations for future research efforts, and the development of protocol for evaluating existing graywater systems.

Initial Planning Meeting

Scheduling conflicts prevented research participants from meeting as a group for the initial planning meeting. Instead, San Antonio Water System staff met individually with representatives of Texas A&M and UTSA to discuss each university's role in the graywater literature search. Calvin Finch and Brian Lillibridge met with Dr. Enos Innis of the CWR on June 19, 2003, and with Dr. Bruce Lesikar from the TCE on June 23, 2003. SAWS staff discussed the objectives of the study with each of the university representatives and developed research assignments for each university based on their areas of interest.

Research Assignments

In order to maximize resources and avoid duplication of efforts, each university was assigned specific subject areas for the literature search. Subject areas were assigned as follows:

Center for Water Research, UTSA

1. Treatment necessary for graywater use.
2. Sources of graywater.
3. Characteristics of graywater.
4. Levels of pathogens, viruses, and other contaminants in graywater.
5. Uses for graywater.
6. Current graywater regulations for the following states: Alabama, Alaska, Arizona, Arkansas, California, Colorado, Connecticut, Delaware, Washington D.C., Florida, Georgia, Hawaii, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, and Missouri.

Texas Cooperative Extension, Texas A&M

1. Graywater System design and construction.
2. Methods of surface and subsurface graywater disposal.
3. Characteristics of graywater irrigated soil versus non-graywater irrigated soil.
4. Evaluation of systems that blend graywater with other sources of non-potable water (condensate, reverse osmosis, reject water, rain water, etc.).
5. Current graywater regulations for the following states: Montana, Nebraska, Nevada, New Hampshire, New Jersey, New Mexico, New York, North Carolina, North Dakota, Ohio, Oklahoma, Oregon,

Pennsylvania, Rhode Island, South Carolina, South Dakota, Tennessee, Texas, Utah, Vermont, Virginia, Washington, West Virginia, Wisconsin, and Wyoming.

Bibliography

Each graduate student collected reference information for the bibliography individually. In order to assure that information was collected in a standardized format, a database template was been created using Microsoft Access and distributed to both universities. The Access database program was selected for its ability to hold large amounts of text in each cell (important for abstract/summary collection) and for the flexibility in which it stores and queries data. The Access database format also allowed collected reference information to be easily converted into final bibliography format.

Graduate students were instructed to cite references using Modern Language Association (MLA) documentation style. When possible, existing abstracts for references were entered into the database verbatim. In the absence of an abstract, the graduate students created a brief summary of the reference for database entry.

Regulations

A similar database template was created for the collection of graywater regulation information. There are no currently existing graywater regulations fro many of the states in the U.S. Several of the states have regulations that define what graywater is, but do not include provisions that allow for its use. The information contained in the summary table is only for states with regulations that define graywater and how it may be treated and applied.

Recommendations and Final Draft

The graduate students found a fairly succinct body of literature on graywater. The majority of the references identified were found in scholarly journals or industry related publications. Many of the same articles and papers were cross-referenced in multiple publications. Most of the articles that appeared in journals have peer review status. One source of information that has not been well documented is internet-based sources. Much of the information contained in the internet sources appears to be a rehashing of various literatures. Unless the internet source contains a referenced article, it is often difficult to determine the source and peer review status of the information.

The recommendations for future research and system evaluation protocol have been generated based on an examination of the existing literature.

Section II

Summary of Findings / Sate Regulations

Summary of Findings

Treatment Necessary for Graywater Use

The treatment necessary for graywater use is dictated by the final end use of the water. Graywater to be used for the purpose of landscape irrigation requires the least amount of treatment. At a minimum, settling and filtration is needed to prevent clogging of the distribution system.

When used for the purposes such as toilet flushing or secondary rinsing, graywater must be treated thoroughly to remove microbial contaminants since the potential for human contact is greatly increased. Some sates also require that graywater used for toilet flushing must be dyed so that it is easily distinguished from potable water.

Sources of Graywater

Wastewater flows generated by bathtubs, showers, lavatory sinks, and clothes washing machines (excluding laundry that contained soiled diapers) are consistently defined as accepted sources of graywater in the literature and current state regulations. Other sources that are less frequently defined as graywater include wastewater from utility sinks (provided they are not used for the disposal of hazardous substances), hot tub drainage water, and condensate from air conditioning equipment or boilers.

Wastewater from kitchen sinks and dish washing machines is generally excluded from graywater sources because of the potential to introduce microbial contaminants and/or oils and greases that would negatively impact the receiving environment.

Characteristics of Graywater

The characteristics of graywater vary over time and space. Three factors significantly affect graywater composition: water supply quality, the composition of the system that transports both gray and drinking water, and the activities in the house" (Eriksson et al. 2002). For example, Casanova, Gerba, and Karpiscak (2001) found that the levels of fecal coliforms were higher in a house with two adults and one child than in a household with two adults. Additionally, the treatment process will influence the graywater's final character. Added chemicals such as chlorine will persist for a time (March, Gaul, Simonet 2002), and the effectiveness of the treatment method and the length of time the graywater is stored will influence the levels of suspended solids, nutrients, bacteria, and viruses. In sum, the components of graywater vary with environment and treatment. (See Table 1.)

Table 1. Characterization of Graywater.

Characteristic	**Unit**	**Hypes 1974**	**Jeppesen 1993 (includes kitchen waste)**	**Casanova, Gerba, Karpiscak 2001**	**Rose et al. 1991**	**Trujillo et al. 1998**
Fecal coliforms	CFU/100 mL			8.03×10^7		
Arsenic	mg/L	<0.01				
Barium	mg/L	<1	41			
Cadmium	mg/L	0.01	NA			
Chromium	mg/L	<0.05	NA			
Copper	mg/L	0.11	130			
Iron	mg/L	0.11	700			
Lead	mg/L	0.04	NA			
Magnesium	mg/L	2.0	14			
Manganese	mg/L	<0.05	31			
Nickel	mg/L	<0.05	NA			
Selenium	mg/L	<0.01				
Silver	mg/L	<0.05				
Sodium	mg/L	80	73			
Zinc	mg/L	0.62	100			
Ammonia	mg/L	0.18				
Calcium	mg/L	16				
Chloride	mg/L	25		20.54	9.0	
Cyanide	mg/L	<0.02				
Fluoride	mg/L	0.81				
Nitrate/Nitrite	mg/L	0.9	0.3		0.98	
Phosphorus	mg/L	59	8.1		9.3	26
Sulfate	mg/L	117	35	59.59	22.9	
BOD	mg/L	328	159	64.85		260
CCE	mg/L	20				
COD	mg/L	452				
pH	pH units	7.2	7.3	7.47	6.54	
Suspended Solids	mg/L	33				160
Total Solids	mg/L	382				
Turbidity	mg/l, SiO_2 equiv.	49	100	43	76.3	

All values are arithmetic means.

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Levels of Pathogens, Viruses, and Other Contaminants in Graywater

The "Residential Graywater Reuse Study" performed by the Water Conservation Alliance of Southern Arizona in 1998 contains information on microbial pathogens found in graywater (see tables below). The study was supported by the Arizona Department of Water Resources, the Arizona Department of Environmental Quality, and the Pima County Department of Environmental Quality and was used by to develop Arizona's existing graywater regulations.

The results of this study showed that the higher level of fecal coliform bacteria was present in the graywater coming from the kitchen sink. Kitchen sinks represent a significant contamination source, most likely caused by the large amount of organic matter introduced by food preparation and dishwashing. These activities provide a significant nutrient source for organisms already present in the water. Compounding the problem from sink wastewater is the fact that washing meat and poultry introduces organisms into the graywater collected from the kitchen sink. The study recommended that the graywater coming from the kitchen sink be excluded from the graywater used for irrigation purposes and directed to the sewage system. The results of the study showed that the lowest levels of *Fecal coliform* bacteria were found in the graywater coming exclusively from washing machines.

The following tables have been excerpted directly from the "Residential Graywater Reuse Study" performed by WaterCASA and published by the University of Arizona.

The complete study may be viewed at:
www.watercasa.org/research/residential/resindex.htm

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

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

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

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

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

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

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

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

Table 13:
PROTOZOAN PARASITES

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

Uses for Graywater

Potential options for application is most notably irrigation and toilet flushing, but other applications include road construction operations, industrial processes reuse, cooling tower make-up water, car washing and other cleaning applications, and firefighting. Treatment costs generally determine the feasibility of most end uses. The costs required to treat graywater to the level necessary for a specific use must be weighed against the cost of using potable water or other sources of reclaimed water for the same purpose.

Graywater System Design and Construction

There are many types of graywater systems, but most contain a storage tank, piping, filters, a pump, valves and controls (NAPHCC, 1992, p v). Dual piping systems are used to direct the black water to a municipal sewer line or onsite septic system and the graywater to a storage tank. Generally, filters are placed in the storage tank or at the entry or exit valves. At this point, some systems treat the graywater further while others apply the graywater directly to the landscape. The level of treatment necessary depends how the graywater is to be reused (Lesikar, Persyn, Garcia 1998). Graywater reused for toilet flushing or for surface irrigation will need to be well filtered and disinfected, and in some instances, dyed to prevent confusion with potable water. Graywater used for subsurface irrigation may require only coarse filtration because the risk of human or vector contact with the effluent is reduced and the soil mantle will often purify the graywater (Chen 1974).

Examples of Treatment options

Constructed Wetlands
Hydroponics
Reverse Osmosis
Media filtration
Sedimentation/filtration
Biological Treatment
Disinfection
Chlorine/Bromine
Iodine
Ultraviolet irradiation

Regardless of the design, the following factors, outlined in Jeppeson (1993, p 29-31), need to be considered while installing a graywater system.

- **Prevent Cross Flow:** Pipes and outlets need to be clearly marked and color coded, and authorized back flow prevention devices should be installed on potable water fixtures.

- **Overflow to House Drain:** There must be an overflow line for times when there is too much graywater for the system to handle, or when diapers have been washed or harmful chemicals introduced (Emmerson 1998). This line should carry overflow to the house line that connects to the sanitary sewer or septic system. The overflow line should have the capacity to handle the total inflow to the system.

- **Scour to House Drain**: This allows buildup of solids to be removed from the graywater system to the house drain.

- **Pump Systems**: The pump system should be able to completely empty the storage tank if necessary to avoid extended storage of graywater.

- **Hopper:** Should direct settleable solids towards the scour outlet. The system should be adequately vented to avoid buildup of noxious gases.

- **Accidental Ingestion prevention:** Pipes should be clearly labeled and color-coded, and appropriate warning signs should be used.

Additionally, both the storage time of the graywater and the amount of maintenance that must be performed by the operator should be limited. The former is because graywater quality has been shown to decline over time (Dixon et al. 1999); the latter is because the quality of the effluent depends on proper system maintenance, and system owners will perform recommended maintenance to varying degrees.

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Methods of Surface and Subsurface Graywater Dispersal

- **Soil Absorption Fields**
- **Drip irrigation, surface and subsurface:** Drip irrigation systems are constructed of drip tubing with pressure compensating emitters. The emitters allow 0.42 to 1.15 gallons of water per hour to contact the soil. Drip systems provide a constant, slow application of water to the soil (Lesikar, Persyn, Garcia 1998)
- **Evapotranspiration Systems:** A trench is dug and an impermeable liner is laid down if the soil is permeable. No liner is needed if the soil is highly impermeable. A layer of gravel is placed above the liner and then a top layer of sand is laid down. The effluent flows into the gravel layer where it is stored until the sand wicks it to the surface where it is evaporated or transpired by plants in the sand layer. This system requires pretreatment, usually via a septic tank (Anda et al. 2001).
- **Low Pressure Dosing System:** Small diameter PVC pipes are placed in trenches that are dug in areas to be irrigated. Holes in the pipes allow water to leave the pipes to be absorbed by the media that fills the trenches, usually gravel, until the water is taken up by the surrounding soil and plants (Lesikar, Persyn, Garcia 1998)
- **Bubbler Distribution:** In a bubbler system, water is delivered to an irrigation tube via a system of buried small diameter PVC pipes. The irrigation tube is flush with the soil surface and linked to the PVC piping by a threaded connector. Bubbler systems wet the soil surface but do not spray water into the air (Lesikar, Persyn, Garcia 1998).
- **Ponding:** Graywater is allowed to collect in ponds until it either evaporates or percolates through the soil. Ponding is generally not recommended.
- **Spray:** Graywater is sprayed into the air via a system of pressurized pipes and emitters. Spray distribution is generally not recommended for graywater because it introduces more of a health risk than other systems and potentially has a more pronounced odor (Jeppeson, 1993, 021).

Site characteristics such as slope (Knight et al. (2000) and soil type (Ho et al. 2001) must be taken into account when a distribution system is selected. In addition, any surface distribution system must be accompanied by a treatment system that expels high quality effluent.

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Characteristics of Graywater Irrigated Soil

Few studies have focused on the effects of graywater irrigation on the soil. However, a study done by the Los Angeles Office of Water Reclamation evaluated the microbial and chemical composition of graywater irrigated soil and tap water irrigated soil. They detected no *Salmonella*, *Shigella*, or *Entamoeba histolytica* in the graywater, graywater irrigated soil, or in control soils. They concluded that either none of the people living at the test sites shed these organisms, or that the organisms were killed in the storage tank which contained detergent. In addition, they could find no clear evidence of a difference between the graywater and tap water irrigated soils. While this evidence is encouraging, a more recent study found that graywater irrigated soil contains a higher level of Fecal Coliforms, see Table 1.

Both studies found that levels of indicator organisms fluctuate widely. Potential factors in these fluctuations are: presence of children, type and maintenance of the graywater system, soil characteristics, temperature, and method of graywater dispersal. Similarly, chemical characteristics of graywater-irrigated soil vary with conditions. For example, Vasquez-Montiel et al. (1996) found that nitrate accumulated in the soil when crops drip irrigated with wastewater were at the end of their growing season, but nitrate did not accumulate earlier in the growing season. This occurred because the nitrogen in the water exceeded the plants' needs as their growth slowed. Conversely, the researchers saw little phosphorus build up at any time during the study, because phosphorus was removed primarily by soil processes. The soil mantle is often capable of purifying irrigation graywater, but this capacity can be overloaded which can cause negative outcomes such as soil clogging (Chen, 1974).

Table 1. Geometric Averages of Fecal Coliforms in Soil (Casanova et al. 2001)

Factor	Fecal Coliforms (CFU/g dry soil) Graywater irrigated soil	Fecal Coliforms (CFU/g dry soil) Background soil
With Children	1.26 X 10^3	8.99 X 10^0
Without Children	3.24 X 10^1	4.07 X 10^0
Including Kitchen Sink	1.56 X 10^3	2.61 X 10^0
Excluding Kitchen Sink	2.69 X 10^1	8.25 X10^0
In Ground Storage	7.85 X10^0	4.57 X 10^0
Above Ground Storage	N/A	N/A
With Animals	1.72 X 10^2	5.88 X10^0
Without Animals	1.88 X 19^2	1.05 X 10^1

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Evaluation of Blended Graywater Collection Systems

Literature that examines "blended" or combination collection systems is limited. Table 2 shows the findings of three references that discuss such systems. Graywater is difficult to combine with other sources of nonpotable water due to the fact that it requires a relatively short storage time in order to minimize microbial growth and prevent odor problems. For this reason, graywater is particularly incompatible with rainwater collection, which requires a large tank with long-term storage capabilities in order to account for variability in precipitation patterns. The added expense of treating graywater to the extent necessary to make it compatible for storage with other types of nonpotable water is cost prohibitive for small-scale systems.

Table 2. Evaluation of systems that blend graywater with other sources of non-potable water.

Study	**System**	**Method**	**Results**
Dixon, Butler, Fewkes 1999	Single store reuse system	Used a mathematical model to predict long term system performance	Addition of rainwater to graywater does not appreciably increase the systems water savings efficiency. The authors reason that the efficient capture of rainwater would require a large storage tank because the amount of rainwater available is so variable. Conversely, graywater availability is more constant and graywater benefits from a shorter storage time, so it is best stored in a smaller tank. The larger tank needed to accommodate the rainwater would undermine the efficiency of the single store graywater system.
Hills, Smith, Hardy, Birks 2001	Complex system that enables the Millennium Dome to treat recycled rain, grey, and ground water for reuse in WC and urinal flushing.	N/A	Paper provides detailed description of the Millennium Dome's water reuse system

Lodge, Judd, Smith 2002	Ultrafiltration membrane	Used statistical model to explain membrane fouling of Millennium Dome UF membrane	Impact of graywater was not statistically significant because it has a low daily volume. Surface water was more fouling than ground water.

References

Dixon A, Butler D, Fewkes A. 1999. **"Water Saving Potential of Domestic Water Reuse Systems Using Greywater and Rainwater in Combination"**. Water Science and Technology 39 (5):25-32.

Hills S, Smith A, Hardy P, Birks R. 2001. "**Water Recycling and the Millennium Dome"**. Water Science and Technology 43(10):287-294.

Lodge BN, Judd SJ, Smith AJ. 2002. **"A Statistical Method for Quantifying the Different Fouling Effects of Three Combined Water Sources On an Ultrafiltration Membrane"**. Desalination 142: 143-149.

Current graywater regulation of the 50 states.

Most of the literature refers back to Arizona or New Mexico as the benchmark states for regulations and precedence for integrated use. Other states with noted regulations or guidelines include Alabama, Arkansas, California, Colorado, Connecticut, Delaware, Florida, Georgia, Hawaii, Idaho, Kentucky, Maine, Maryland, Massachusetts, Michigan, Minnesota, and Missouri. The states of Alaska, Illinois, Indiana, Iowa, Kansas, Louisiana, and Mississippi do not have established guidelines.

Several states define graywater sources in their regulations, but do not include provisions for its use. With the exception of Arizona and New Mexico, in most states, the requirements for the handling of graywater differ little from those for blackwater. The same type of collection system and the same amount of treatment is required before dispersal. Some states (Maryland, Maine, and others) allow for "innovative and appropriate technology" to treat graywater. These states allow unique systems or technology that can be tailored to specific site conditions and do not require the same treatment functions as a standard septic systems. These systems are reviewed on a case by case basis and must be approved by the governing agency before installation and use.

The following tables summarize the regulations for states that define and allow graywater reuse.

STATE	AGENCY	TITLE/CHAPTER	WEBSITE	DO RULES APPLY TO RESIDENTIAL ?	FLOW LIMITS	DO RULES APPLY TO COMMERCIAL ?
ALABAMA	Alabama Department of Public Health, Environmental Services	Onsite Sewage Disposal Subdivision	www.adph.org/environmental/onsitesewage.pdf	Yes	N/A	Yes
ARIZONA	Arizona Department of Environmental Quality	R18-9-701 ADEQ Administrative Code	www.sosaz.com/public_services/title_18/18-09.htm	Yes	N/A	Yes
ARKANSAS	Arkansas Department of Health Sanitary Division	Alternate Systems Manual	www.healthyarkansas.com/rules_regs/general_sanitation.pdf	Yes	N/A	Yes
CALIFORNIA	California Department of Water Resources, Water Conservation Office	California Plumbing Code, Appendix G: Graywater systems	www.owue.water.ca.gov/docs/Revised_Graywater_Standards.pdf	Yes	N/A	Yes
COLORADO	Colorado Department of Public Health and Environment	Guidelines on Individual Sewage Disposal Systems	www.cdphe.state.co.us/op/regs/waterregs/100284.pdf	Yes	N/A	Yes
CONNECTICUT	Connecticut Department of Public Health	Public Health Code Regulations & Technical Standards	www.dep.state.ct.us./dph	Yes	N/A	Yes
FLORIDA	Florida Department of Health, Bureau of Onsite Sewage Programs	Public Health Chapter 381.0065; Florida Administrative Code 64E-6	www.doh.state.fl.us/Environment/OSTDS/pdfiles/forms/64e6.pdf	Yes	75	Yes
GEORGIA	Georgia Department of Human Resources, Division of Public Health	Department of Human Resources Ch 290-5-26	www.state.ga.us/rules/index.cgi?base=290/5/26	Yes	>500	Yes
HAWAII	Hawaii Department of Health, Wastewater Branch	TITLE 11 Department Of Health - Chapter 62 Wastewater Systems	www.hawaii.gov/doh/rules/11-62.pdf	Yes	150	Yes
IDAHO	Idaho Division of Environmental Quality	IDAPA 16.01.03 Rules for Individual/Subsurface Sewage Disposal Systems	http://www.deq.state.id.us/waste/tgm-master_jan01.pdf	Yes	N/A	No
KENTUCKY	Kentucky Department of Public Health, Protection and Safety Division	902 KY Administrative Regulations 10:085	http://chs.ky.gov/publichealth/environmental.htm	No	N/A	No
MAINE	Maine Department of Human Services, Bureau of Health, Division of Health Engineering	1509.0 Separated Laundry Disposal Systems	www.yorkmaine.org/planboard/mestate_subsurface_waste_water_disposal_rules.pdf	Yes	N/A	No
MARYLAND	Maryland Department of the Environment, Water Management Administration	Innovative and Alternative Program	www.dsd.state.md.us/comar	No	N/A	No
MASSACHUSETTS	Massachusetts Department of Environmental Protection	310 CMR 15.000, Title 5: Innovative and Alternative Systems	www.state.ma.us/dep/brp/wwm/t5itprog.htm	Yes	10000	No
MICHIGAN	Michigan Department of Environmental Quality, Health and Water	Act 421 P.A., Acceptable Alternative Graywater Systems	www.weblife.org/humanure/appendix3	Yes	N/A	Yes
MINNESOTA	Minnesota Pollution Control Agency/Water Quality	Chapter 7080.9010 Alternative/Experimental Systems	www.revisor.leg.state.mn.us/arule/7080	Yes	1000	Yes

STATE	AGENCY	TITLE/CHAPTER	WEBSITE	DO RULES APPLY TO RESIDENTIAL ?	FLOW LIMITS	DO RULES APPLY TO COMMERCIAL?
MONTANA	Department of Environmental Quality	DEQ 4	http://www.deq.state.mt.us/wqinfo/Sub/Index.asp	No	N/A	No
NEVADA	Dept. of Human Resources	R129-98 Sewage Disposal Administrative code	www.leg.state.nv.us/Register/R129-98Adopted.html	Yes	N/A	Yes
NEW JERSEY	Department of Environmental Protection	N.J.Administrative Code 7:9A	www.state.nj.us/dep/dwq/pdf/njac79a.pdf	Yes	75% of black water	Yes
NEW MEXICO	Environment Department	House Bill 114	http://legis.state.nm.us (use bill finder for 114)	Yes	250	No
NEW YORK	Department of Health	10NYCRR Appendix 75-A	www.dec.state.ny.us/website/ppu/grnbldg/gbprop.pdf	Yes	75 gpd/bedroom	No
NORTH DAKOTA	ND dept of Health Environmental Health Division	Ch. 62-03-16-01individual sewage treatment	www.weblife.org/humanure/appendix3	Yes	N/A	Yes
OREGON	Dept of Environmental Quality Water Quality Division	OR administrative rules ch918 division 790	www.cbs.state.or.us	Yes	N/A	Yes
PENNSYLVANIA	Dept of Environmental Protection Bureau of Water Quality	Title 25 Environmental protection CH.73	www.weblife.org/humanure/appendix3	Yes	N/A	Yes
RHODE ISLAND	Dept of environmental management	Ch. 12-120-002		No	N/A	No
SOUTH DAKOTA	Department of Environment and Natural Resources	Administrative Rule: ARSD 74:53 Water Supply and Treatment Systems. Specifically, sections 74:53:01:38 and 74:53:01:19	http://legis.state.sd.us/rules/rules/7453.htm	Yes	minimum of 25 gal/day/person	Yes
TEXAS	Texas Commission On Environmental Quality	Existing rules under 30 TAC, Chp. 285, Subchapter H. Currently working on a set of rules to fulfill HB 2661	www.tceq.state.tx.us/oprd/rules/pdflib/285h.pdf	No	N/A	No
WASHINGTON	Department of Ecology	Publication No. 98-37 WQ; Section E1		Yes	N/A	Yes
WISCONSIN	Department of Commerce	Chapter Comm 82, Wis. Adm. Code; specifically Comm 82.34, 82.40, 82.41, and 82.70	http://www.legis.state.wi.us/rsb/code/codtoc.html	No	N/A	No

STATE	LAVATORY	BATHTUB OR SHOWER	KITCHEN SINK	CLOTHES WASHING MACHINE	DISH WASHING MACHINE	UTILITY SINKS	FLOOR DRAINS	CONDENSATE DRAINS	WATER TREATMENT DEVICES	OTHER	OTHER DESCRIPTION
ALABAMA	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Effluent from residential spa permitted.
ARIZONA	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No	Yes	all sources except kitchen sinks and toilets may be permitted
ARKANSAS	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No	No	
CALIFORNIA	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No	Yes	the type of system shall be determined on the basis of location, soil type, and ground water level and shall be designed to accept all graywater connected to the system from the building.
COLORADO	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	excluding toilet fixtures
CONNECTICUT	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	no flush toilet fixtures are connected
FLORIDA	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	except kitchen sink waste. Where separate graywater and black water systems are used, the size of the black water system can be reduced by not more than 25%.
GEORGIA	No	No	No	No	No	No	No	No	No	Yes	Gray water means wastewater generated by water-using fixtures and appliances, excluding water closets, urinals, bidets, kitchen sinks, and garbage disposal
HAWAII	No	No	No	No	No	No	No	No	No	Yes	Means liquid waste from a dwelling or other establishment produced by bathing, washdown, minor laundry, and minor culinary operations, and specifically excluding toilet waste.
IDAHO	Yes	Yes	No	No	No	No	Yes	No	No	No	rules permit graywater systems only as experimental systems
KENTUCKY	No	No	No	No	No	No	No	No	No	No	means wastewater generated by using fixtures and appliances, excluding the toilet and the garbage disposal.
MAINE	No	No	No	No	No	No	No	No	No	No	
MARYLAND	No	No	No	No	No	No	No	No	No	No	gray water designs are currently allowed on a case-by-case basis
MASSACHUSETTS	Yes	Yes	No	Yes	No	No	No	No	No	No	a disposal system is still needed for the graywater
MICHIGAN	No	No	No	No	No	No	No	No	No	Yes	wastewater which does not receive human body waste or industrial waste which has been approved for use by a local health department
MINNESOTA	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Use of alternative systems is allowed only in areas where a standard system cant be installed or isn't the most suitable method treatment.

STATE	LAVATORY	BATHTUB OR SHOWER	KITCHEN SINK	CLOTHES WASHING MACHINE	DISH WASHING MACHINE	UTILITY SINKS	FLOOR DRAINS	CONDENSATE DRAINS	WATER TREATMENT DEVICES	OTHER	OTHER DESCRIPTION
MONTANA	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Section 2.27: wastewater other than toilet wastes or industrial chemicals, including, but not limited to, shower and bath wastewater, kitchen wastewater, and laundry wastewater.
NEVADA	No	No	No	No	No	No	No	No	No	Yes	Any source not containing human body, industrial, or garbage disposal waste.
NEW JERSEY	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Graywater means that portion of the sanitary sewage that does not include discharges from water closets or urinals.
NEW MEXICO	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Excludes laundry water from the washing of material soiled with human excreta, such as diapers.
NEW YORK	No	No	No	No	No	No	No	No	No	No	Household water without toilet wastes.
NORTH DAKOTA	No	No	No	No	No	No	No	No	No	Yes	Water carried from bathrooms, kitchens, laundry fixtures, and other household plumbing.
OREGON	No	No	No	No	No	No	No	No	No	Yes	All wastewater and sewage from plumbing fixtures system approved by the environmental quality commission or dept of environmental quality under ORS chapter 468, 468A, and 468B. Gray water is technically defined as sewage and still requires a septic tank and drainfield, although the septic system can be reduced in size.
PENNSYLVANIA	No	No	No	No	No	No	No	No	No	Yes	Liquid waste including kitchen and laundry wastes and water softener backwash, shall be discharge to a treatment tank.
RHODE ISLAND	No	No	No	No	No	No	No	No	No	No	
SOUTH DAKOTA	No	No	No	No	No	No	No	No	No	Yes	Definition 24: Graywater is the wastewater generated by water-using fixtures and appliances which do not discharge garbage or urinary or fecal wastes.
TEXAS	No	No	No	No	No	No	No	No	No	No	
WASHINGTON	Yes	Yes	Yes	Yes	No	No	No	No	No	No	
WISCONSIN	No	No	No	No	No	No	No	No	No	No	Chapter Comm. 81.01. Def. 112: Graywater means wastewater contaminated by waste materials, exclusive of urine, feces or industrial waste, deposited into plumbing drain systems.

STATE	PRETREATMENT REQUIRED	SETTLING REQUIRED	BIOLOGICAL TREAMENT	FILTRATION	OTHER	OTHER NOTES
ALABAMA	No	No	No	No	Yes	Circumvent a septic and in effluent disposal field.
ARIZONA	No	No	No	No	No	
ARKANSAS	No	No	No	No	Yes	Requires a conventional septic tank and absorption field.
CALIFORNIA	No	No	No	No	Yes	
COLORADO	No	No	No	No	Yes	Shall meet septic standards.
CONNECTICUT	No	No	No	No	Yes	Septic and leaching system at least 1/2 the capacity.
FLORIDA	No	No	No	No	Yes	Retention tank < 30 inches of liquid depth.
GEORGIA	No	No	No	No	No	
HAWAII	No	No	No	Yes	Yes	Includes absoption trenches, beds mounds, seepage pits.
IDAHO	No	No	No	Yes	Yes	Separate plumbing system from blackwaste & kitchen.
KENTUCKY	No	No	No	No	No	
MAINE	No	No	No	No	No	
MARYLAND	No	No	No	No	No	
MASSACHUSETTS	Yes	No	No	Yes	No	Cesspool or precast leaching pit.
MICHIGAN	No	No	No	No	Yes	Requires local health department approval.
MINNESOTA	No	No	No	No	Yes	Septic systems are required for graywater systems.
MONTANA	No	No	No	No	No	Section 5.3: Graywater must be provided the same treatment required for all other wastewaters.
NEVADA	No	No	No	No	Yes	3-way valve, overflow and emergancy drain required.
NEW JERSEY	No	No	No	No	No	Grante on case by case approval.
NEW MEXICO	No	No	No	No	No	Graywater storage tanks must be covered.
NEW YORK	No	No	No	No	No	Same as other household wastewater.
NORTH DAKOTA	No	No	No	No	Yes	Sewage shall pass through a septic or equivalent.
OREGON	No	No	No	No	Yes	Split waste method.
PENNSYLVANIA	No	No	No	No	No	
RHODE ISLAND	No	No	No	No	No	
SOUTH DAKOTA	No	No	No	No	No	Graywater tanks conform to requirements for septic tanks. Minimum horizontal distances of graywater system from pertinent ground features expressed in feet: wells > 100 feet deep, cisterns or reservoirs, high water line of lakes, streams or impoundments = 100; Wells < 100 feet deep, springs, or water suction lines = 150; pressurized water lines = 25; dwelling or occupied building = 20; property line - all sides = 10.
TEXAS	No	No	No	No	No	
WASHINGTON	No	No	No	No	No	
WISCONSIN	No	No	No	No	No	Table 82.70-1 gives the standards to which water must be cleaned for reuse.

STATE	SURFACE DISCHARGE	REQUIREMENTS	SUBSURFACE DISCHARGE	REQUIREMENTS	MAINTENANCE REQUIRED	DESCRIPTION	PERMIT REQUIRED
ALABAMA	No		Yes	in the absence of water under pressure, graywater shall be disposed of by an effluent distribution line of 50 linear feet per dwelling.	No	No new recommendations besides the EDF system are proposed.	No
ARIZONA	Yes		Yes		No	N/A	No
ARKANSAS	No		Yes		Yes	A 35% reduction in the absorption field size will be granted.	No
CALIFORNIA	Yes	Surfacing of graywater means ponding, running off or other release of graywater from the land surface. Shall not be used for vegetable gardens.	Yes	the system shall discharge into subsurface irrigation fields and may include surge tanks and appurtenances, as required by the Administrative Authority.	Yes	No permit for any graywater system shall be issued until a plot plan with appropriate data satisfactory to the Administrative Authority has been submitted and approved.	Yes
COLORADO	No		No		No	N/A	No
CONNECTICUT	Yes		Yes		Yes		Yes
FLORIDA	No		Yes		No	Onsite graywater tank and drainfield systems may at the homeowners discretion, be utilized in conjunction with an onsite black water system where a sewerage system is not available for blackwater disposal. A separate laundry waste tank and drainfield system may be utilized for residences and may be required by the county public health unit where building codes allow for separation of discharge pipes of the residence to separate stubouts and where lot sizes and setback allow system constructions.	Yes
GEORGIA	No		No		No		No
HAWAII	No		Yes	In residential developments when there is 10,000 square feet or more of land area for each individual wastewater system.	No		No
IDAHO	No	Graywater may not be used for irrigation of vegetables. Graywater shall not be applied on the land surface or allowed to reach the land surface.	Yes		No		Yes
KENTUCKY	No		Yes		Yes	When improved performance of a septic system may be attained by separating laundry graywater waste flows from other residential waste flow for new system installations, or as repair for existing systems, such separation shall be accomplished in the following manner: a) Graywater sewer for the washing machine shall be separated form the main house sewer; b) laundry graywater shall discharge into a lateral bed or trench of a minimum of 100 square feet of bottom surface soil absorption area for a two bedroom and an additional 50 square feet for each additional bedroom; c) new system installation where laundry wasteflow separation exists are permitted a 15% reduction in the primary system lateral field requirements shall be allowed only for sites with soils in soil groups I-III. On sites with soils in soul group IV, such	No
MAINE	No		Yes	A separated laundry field requires an application for subsurface wastewater disposal system completed by a licensed site evaluator and a permit to install the system	No		No
MARYLAND	No		No		No		No
MASSACHUSETTS	No		Yes		Yes	Non-traditional graywater systems such as those which use constructed wetlands are approved on a piloting site-specific basis.	Yes
MICHIGAN	Yes	Self-contained systems that do not have an on-site discharge should not be required to connect to an available public sanitary sewer system.	Yes		Yes	testing protocol or by an equivalent independent testing agency and procedure. Lacking this testing procedure, the local health department should require performance data prior to approval.	Yes
MINNESOTA	Yes	The drainage system in new dwellings or other establishments shall be based on a pipe diameter of two inches to prevent installation of a water flush toilet	Yes		Yes	Garbage grinder shall not be to the drainage system. For repair or replacement of an existing system, the existing drainage may be used.	Yes

STATE	SURFACE DISCHARGE	REQUIREMENTS	SUBSURFACE DISCHARGE	REQUIREMENTS	MAINTENANCE REQUIRED
MONTANA	No		No		No
NEVADA	No		Yes	Graywater may be used for underground irrigation if approved by the administrative authority before such a system may be constructed, altered, or installed.	Yes
NEW JERSEY	No	Case by case approval.	No	Case by case approval.	No
NEW MEXICO	No	Distribution system must provide for overflow into the sewage collection or on-site wastewater disposal system. System must be sited outside of a floodway. Gray water must be vertically separated at least five feet above the ground water table. Gray water pressure piping must be clearly identified as a nonpotable water conduit. Gray water must be used on the site where it is generated and cannot run off property lines. Ponding is prohibited, application of gray water must be managed to minimize standing water on the surface and standing water cannot remain for more than 24 hours. Gray water cannot be sprayed. Gray water use within municipalities or counties must comply with all applicable municipal or county ordinances.	No		No
NEW YORK	No		No		No
NORTH DAKOTA	No		Yes		No
OREGON	No		Yes	Graywater may be disposed of by the state building codes division approved non-water carried plumbing units such as recirculating oil flush or compost toilets.	No
PENNSYLVANIA	No		No		No
RHODE ISLAND	No		No		No
SOUTH DAKOTA	No		No	Effluent from graywater systems may be recycled for toilet use, conveyed to adsorption fields, mounds, or seepage pits, or used for irrigation of lawns and areas not intended for food production. Percolation tests shall be conducted and the minimum size of absorption area shall be determined in accordance with 74:53:01:29 to 74:53:01:32, inclusive	No
TEXAS	No		No		No
WASHINGTON	No		No		No
WISCONSIN	No		No		No

Section III

Bibliography with Abstracts

Bibliography (including abstracts/summaries)

1. Afshar, A., and M.A. Marino. **"Optimization models for Wastewater Reuse in irrigation".** Journal of Irrigation and Drainage Engineering. v115.2 (1989):185-202.

Peer Reviewed: YES

Mathematical models are formulated to develop management guidelines for an integrated wastewater reuse plan involving the use of reclaimed wastewater to irrigate summer crops. A linear-programming allocation model is used to allocate the available land area and wastewater to different crops. Information provided by the allocation model is used in a pipeline model to determine the optimal diameter of the distribution system. Statistical properties of natural runoff in conjunction with the generated wastewater are used to determine the optimal design and operation parameters of the storage facility (reservoir). The latter is determined by a chance-constrained linear-programming (CCLP) model that minimizes the required capacity and provides information on the reliability of the system or its failure. Reliability of the CCLP model is examined by means of a simulation model. The models are applied to three cities in California, and the results are discussed.

2. Al Jayyousi, O. **"Focused Environmental Assessment of Greywater Reuse in Jordan".** Environmental Engineering and Policy. v3.1-2 (2002): 67-73.

Peer Reviewed: YES

This paper aims to assess both the opportunities and constraints for greywater (GW) reuse for irrigation. A case study was conducted for 25 users who used GW for small-scale irrigation for the period 1997-1999. Laboratory analyses of plant, soil, and GW were conducted. A focused environmental assessment was carried out to determine the viability of GW reuse for irrigation. The study concluded that GW reuse is feasible under specific conditions. Policy implications and recommendations for modifications of building code were outlined.

3. Albrechtsen, H.J. **"Microbiological Investigations of Rainwater and Graywater Collected for Toilet Flushing".** Water Science and Technology. v46.6-7 (2002): 311–16.

Peer Reviewed: YES

Seven Danish rainwater systems were investigated with respect to the microbial water quality. The general microbiological quality (total numbers of bacteria (AODC)), and heterotrophic plate counts on R2A and Plate Count Agar in the toilets supplied with rainwater were approximately the same as in the reference toilets supplied with drinking water. However, in 12 of the 27 analysed samples one or more pathogens were observed (Aeromonas sp., Pseudomonas aeruginosa, Legionella non-pneumophila, Campylobacter jejuni, Mycobacterium avium, and Cryptosporidium sp.). These pathogens were not found in any of the reference toilets (32 toilets). This means that the use of rainwater introduced new, potentially pathogenic micro-organisms into the households which would normally not occur in toilets supplied with water from waterworks. Furthermore, four graywater systems were investigated where water from the shower and hand wash basin was reused. The graywater systems gave more problems in terms of bad smell and substantially higher numbers of E. coli and Enterococcus in some toilet bowls supplied with graywater.

4. Almeida, M.C., D. Butler, and E. Friedler. **"At-Source Domestic Wastewater Quality".** Urban Water. v1(1999): 49-55.

Peer Reviewed: YES

Accurate measurement of flow and quality determinands for single or small numbers of dewllings is difficult due to the intermittent nature of flows at source. In this paper, at-source pollutographs are calcualted using an alternative approach based on survey data of domestic appliance usage together with measured flow and loads per use. The wastewater pollutograph is built up from the contributions of various appliances. The individual usage of each appliance has been characterised by its frequency together with discharge, duration and loads. The proposed methodology can be used to derive dry weather flow inputs to water quality models, and to assess the impact of changes in local water use and treatment.

5. Anda, M., K. Mathew , and G. Ho. **"Evapotranspiration for Domestic Wastewater Reuse in Remote Indigenous Communities of Australia".** Water Science and Technology. v44.6 (2001): 1-10.

Peer Reviewed: NO

In the past sewage ponding in indigenous settlements was commonplace as a result of overcrowding combined with inappropriate septic tank and leach drain design, installation and operation. The response over the past 10 years has been to develop reticulated sewerage systems to lagoons when the funds become available. These are often successful in terms of operation, improved public health and low maintenance but are expensive and wasteful of limited water supplies. Evapotranspiration (ET) is an effective method for on-site domestic effluent disposal in areas of Western Australia with soils of low permeability. Evapotranspiration systems have been established in a number of communities both for research/demonstration and as specified by architects. The systems usually follow two septic tanks for the disposal of all domestic effluent. A case study will be presented for a remote indigenous community where the ET systems installed for greywater only have been monitored over the last two years since installation. The use of evapotranspiration has enabled reuse of effluent for successful examples of revegetation and food production and points to the need for a holistic approach to design and service delivery in these communities that includes a total environmental management plan.

6. Anderson, J.M. **"Current Water Recycling initiatives in Australia: Scenarios for the 21st Century".** Water Science and Technology. v33.10-11 (1996): 37-43.

Peer Reviewed: NO

Australia is a relatively dry continent with an average runoff of 50 mm per year. The use of water resources in some river basins is approaching the limits of sustainability. Some adverse environmental impacts have been observed resulting from water diversions and from both reclaimed water and stormwater discharges. The paper describes current water recycling initiatives in Australia. These include: beneficial reuse of reclaimed water for urban, residential, industrial, and agricultural purposes; recycling of greywater and stormwater; advanced treatment using membrane technology; and water efficient urban design. Some possible water recycling scenarios for Australia in the 21st century are examined. The implications of these scenarios are discussed.

7. Anon. **"Florida Cities Encourage Gray Water Separation".** Biocycle. v25.1(1984): 55.

Peer Reviewed: NO

In an effort to increase sewage treatment plant capacity and allow more water to filter through the ground to replenish the aquifers, several Florida cities are promoting the use of separate gray water systems via financial incentives. In 1982, Longwood, outside of Orlando, received permission from the state to test the use of a small septic system which traps the gray water - bath, shower, lavatory, dish and laundry waters - and then filters it through the drainage fields. Black water - toilet, kitchen sink/garbage disposal, latrine and dishwasher waters - would go into the conventional collection system. Use of the separate tanks would be encouraged in new home and commercial construction. In return for installing the system, the initial sewage hookup fee would be reduced to $375.00 from $475.00, and monthly sewage costs reduced by $3.00.

8. Asano, T., and A.D. Levine . **"Wastewater Reclamation Recycling and Reuse: Past Present, and Future".** Water Science and Technology. v33.10-11 (1996): 1-14.

Peer Reviewed: NO

The scientific basis for the current status of wastewater reclamation, recycling and reuse has evolved from developments in water and wastewater engineering coupled with increasing pressures on water resources. Milestone events that have led to the safe use of reclaimed wastewater are reviewed. The role of engineered systems associated with reclaimed wastewater is discussed in the context of the natural hydrologic cycle. A synopsis of the significant studies that form the basis for current regulatory approaches and technological innovations is presented. Current water reclamation strategies incorporate multiple measures to minimize health and environmental risks associated with various reuse applications. A combination of source control, advanced treatment process flow schemes, and other engineering controls provides a sound basis for increased implementation of water reuse applications. The feasibility of producing reclaimed water of a specified quality to fulfill multiple water use objectives is now a reality due to the progressive evolution of technologies and risk assessment procedures. Future water reuse directions are charted.

9. Asano, T., L.Y. C. Leong , M.D.Rigby , and R.H. Sakaji. **"Evaluation of the California Wastewater Reclamation Criteria".** Water Science and Technology. v26.7-8 (1992): 1513-24.

Peer Reviewed: NO

The State of California's Wastewater Reclamation Criteria is under review and will be revised and expanded to include several new regulations on the use of reclaimed municipal wastewater. To provide a scientific basis for the evaluation of the existing and proposed

Criteria, enteric virus monitoring data from secondary and tertiary effluents were evaluated. These virus data were obtained from special studies and monitoring reports, covering the period from 1975 to 1989, including ten municipal wastewater treatment facilities in California. Based on the enteric virus data from these reports, and using the current Criteria as a guide, four exposure scenarios were developed to determine the risk of water borne enteric virus infection to humans as a consequence of wastewater reclamation and reuse. The exposure assessments included food crop irrigation, landscape irrigation for golf courses, recreational impoundments, and groundwater recharge. The virus enumeration and the resulting risk assessments described in this paper provide a comparative basis for addressing the treatment and fate of enteric viruses in wastewater reclamation and reuse. The analyses show that annual risk of infection from exposure to chlorinated tertiary effluent containing 1 viral unit/100L in recreational activities such as swimming or golfing is in the range of 10 (super) -2 to 10 (super)-7, while exposures resulting from food-crop irrigation or groundwater recharge with reclaimed municipal wastewater is in the range of 10 (super) -6 to 10 (super) -11. The risk analyses are also used to demonstrate that the probability of infection can be further mitigated by controlling exposure to reclaimed wastewater in the use area.

10. Badawy, A.S., J.B. Rose , and C. P. Gerba. **"Comparative Survival of Enteric Viruses and Coliphage on Sewage Irrigated Grass".** Comparative Journal of Environmental Science and Health. vA25.8 (1990): 937-52.

Peer Reviewed: YES

The fate of coliphage and human enteric viruses on turf grass was studied in order to elucidate the potential risk to public helath when grass is irrigated with activated sludge treated sewage effluent. The survival of seeded coliphage MS-2, poliovirus type 1, and rotavirus SA-11 was studied outdoors during winter and summer. Virus inactivation rates were influenced by temperature as well as by type of virus. Coliphage, poliovirus, and rotavirus average inactivaiton rates (K=log inactivated/hr) were 0.17, 0.06 and 0.10 per hour respectivley, during the winter (4-10 degrees C). In contrast, during the summer (36-41degrees C) K = 0.45, 0.37, and 0.20 per hour for MS-2, polio virus, and roavirus, respectively. To achieve a 99% (2 log(base 10)) virus inactivaiton on turf grassess after the application of sewate effluents, 8 to 10 hours would be needed during the summer and 16 to 24 hours would be needed during the winter.

11. Benson, J., I. Caplan, and R. Jacobs. **"BlackWater and Graywater on U.S. Navy Ships: Technical Challenges and Solutions".** Naval Engineers Journal. v111.3 (May 1999).

Peer Reviewed: YES

In anticipation of more stringent environmental regulations, the increasing costs of waste disposal, and the need for naval combatants to operate unimpeded in littoral waters, the U.S. Navy has identified the need to develop technologies which are appropriate for the control and treatment of blackwater and graywater. This paper will describe the status of development efforts by the Carderock Division, Naval Surface Warfare Center (CDNSWC) and its supporting contractors, under sponsorship of Naval Sea Systems Command (NAVSEA) and the Office of Naval Research. The challenge was to develop treatment systems that meet Navy shipboard requirements for affordability, compactness, low manning/maintenance, high reliability and safety, and EM, noise, vibration and shock. Membrane ultrafiltration based systems, incorporating aerobic biological pre-treatment and ultraviolet light post treatment disinfection, have been developed to meet these requirements. Both external and in-tank membrane systems will be described in terms of performance, system operation and space and weight advantages.

12. Bingley, E.B. **"Greywater Reuse Proposal in the Relation to the Palmyra Project".** Desalination. v106 (1996): 371-5.

Peer Reviewed: YES

With the world-wide interest in the reuse of wastewater, the State housing authority, Homewest, decided to carry out an experiment with the reuse of wastewater from one of their residential properties. All wastewater from house fixtures other than the toilets is to be piped to a biological treatment plant. The treated water is then to be chlorinated and recycled to the houses for flushing of toilets. This water is then discharged to the deep sewerage scheme.

13. Bouhabila, E.H., R. B. Aim , and H. Buisson. **"Fouling Characterisation in Membrane Bioreactors".** Separation and Purification Technology. v22-23 (2001): 123-132.

Peer Reviewed: YES

Compared with conventional wastewater treatment processes, membrane bioreators offer several advantages, e.g. high biodegradation efficiency, smaller sludge production and compactness. However, membrane fouling is the main limitation to faster development of this process. An experimental study has been performed using hollow fibers (pore size 0 .1 micrometers) immersed in an aerated tank for treating synthetic wastewater representative of dairy effluent. For the same organic load (5.7 kg COD/m (super) 3 per day) the COD removal efficiency, the sludge production and fouling ability were compared in three reactors operated at different sludge ages (10, 20, and 30 days). COD removal was high: 95-97.5%. The sludge production decreased from 0.31 to 0.16 kg MLSS/kg COD (inf) removed when the sludge age increased fro 10 to 30 days. Concerning the fouling ability of the sludge, a specific experiment (measurement of the specific resistance and hydraulic resistance during filtration) was designed to determine the influence on membrane fouling of the three fractions of the sludge: suspended solids, colloids and solutes. All the experiments confirm the importance of the interstitial matter -- colloids and solutes -- in membrane fouling. Consequently, bubbling can be expected to be only partially efficient, as bubbles are efficient for limiting particle deposition and polarisation phenomena, but not for internal fouling. Increasing the air flow rate form 1.2 to 3.6 m (super) 3 /m (super) 3 (inf) membrane area per hour, it was possible to decrease the total resistance -- thus increasing the filtrate flux -- by a ratio of 3. However, for given conditions of aeration, periodic backwashing gave an additional efficiency by decreasing internal fouling. In optimal conditions of backwashing (15 s every 5 min) the resistance could be decreased by 3.5-fold.

14. Bouwer, H., P. Fox , and P. Westerhoff. **"Irrigating With Treated Effluent".** Water Environment and Technology. v10.9 (1998): 115-120.

Peer Reviewed: NO

Current regulations for agricultural irrigation with treated effluent do not consider the groundwater effects. Chemicals present in irrigation water remain in the soil until they are used by plants, adsorbed by soil particles, or leached from the upper soil layers. A typical leaching fraction of a well designed irrigation system is 20%. That is, 80% of the water is used by plants for evapotranspiration and 20% percolates into deeper soil, carrying excess chemicals with it. This prevents salt accumulation in the root zone and any resulting salinity damage to crops or other plants. However, because all the chemicals carried by effluent irrigation water are leached out in only 20% of that water in this case, all nonbiodegradable chemical concentrations in the deep percolation water are five times higher than those in the effluent. This is a concern, because many of the contaminants that remain in the effluent after treatment are potentially harmful. Of particular concern the following organic carbon compounds: disinfeciton byproducts (DBPs) such as chlorine, pharmaceutically active chemicals (PACHs) from domestic, pharmaceutical, ad hospital waste discharges, and THM precursors. Little is known about the behavior of these chemicals in the ground or about their potential health impacts. However, if they reach the ground water with the effluent, the groundwater level will rise with bad water which could contaminate wells. Once this occurs, the pumps will be shut off which allows the groundwater level to rise still further bringing it in range of agricultural contaminants such as pesticides. The groundwater could potentially rise high enough to damage deep basements, underground pipelines and other structures. This will necessitate reopening the contaminated wells to lower the groundwater level which will create a contaminated water disposal problem. To avoid these problems, all significant effluent irrigation projects should be preceded by a groundwater impact analysis (GIA) to make the best available predictions of 1. how the projects will affect groundwater quality and water table elevations, 2. how the situations can best be handled, 3. what damage and liability can be expected.

15. Boyle, W.C. R. L. Siegrist, and C. C. Saw. **"Treatment of Residential Graywater With Intermittent Sand Filtration".** Alternative Wastewater Treatment - Low-Cost Small Systems, Research and Development,. Oslo, Norway. September 7-10, 1981 .

Peer Reviewed: YES

This paper discusses the results of a research program designed to gain information on the treatment of graywater in the waste modification scheme. The study consisted of graywater characterization, septic tank-intermittent sand filter studies, and factorial analysis of sand size and filter loading. graywater characterization consisted of sampling graywater from two residences and analysis to evaluate settling properties and particle size characteristics. The septic tankintermittent sand filter studies were conducted over a 14-month period at one residence, utilizing a pilot-sized septic tank and sand filter system. Sand columns installed in the field at one home were employed for the factorial analysis studies. Residence characteristics are outlined and unit treatment processes are described. Results indicate that residential graywater contains substantial amounts of pollutants and that kitchen sink wastewater in the graywater stream is a major contributor to high levels of these pollutants. graywater can be treated effectively by employing a septic tank-intermittent sand filter system; however, fecal indicator concentrations remain high. The graywater treatment system described in this work does not offer a substantial improvement in cost savings, effluent quality, or manageability over similar systems for total residential waste.

16. Brown, S.H., E.B. White, M. Pechulis, and R. Garman. **"Integrated Liquid Discharge System for Waste Disposal on Future Surface Combatants".** Naval Engineers Journal. v111.3 (May 1999): 285-291.

Peer Reviewed: YES

National and international regulations restrict the overboard discharge of ship-generated liquid waste. During the twenty-first century, discharges of untreated sewage, graywater, and oily wastes will be further restricted in many littoral areas throughout the world. Future surface combatants will operate primarily in these littoral areas. Consequently, the Naval Sea Systems Command (NAVSEA) SEA 03R24 initiated a research and development (RDT&E) program to provide future United States (U.S.) Navy surface combatants with the capability to destroy liquid wastes aboard ship, maximizing shore independence, and minimizing waste off-load costs in foreign and domestic ports. Under this R&D program, the Carderock Division of the Naval Surface Warfare Center (NSWCCD) developed a liquid waste abatement strategy called the integrated liquid discharge system (ILDS). The ILDS contains three distinct elements; non-oily liquid waste treatment, oily waste treatment, and thermal destruction. The basis of the ILDS is to minimize each of the waste streams so that a shipboard thermal destruction system can be used to process the remaining volume of waste.

17. Burrows, W.D., M.O. Schmidt, R.M. Carnevale , and S.A. Schaub. **"Nonpotable Reuse: Development of Health Criteria and Technologies For Shower Water Recycle".** Water Science and Technology. v24.9 (1991):81-88.

Peer Reviewed: NO

The U.S. Army is evaluating recycle of field shower water as a conservation practice in arid regions and is seeking to define appropriate technologies and health criteria. Shower wastewaters at a military installation have been characterized in terms of physical, chemical and microbiological parameters. Two treatment technologies have been investigated. Microfiltration cartridges with a nominal pore size of 0.2 micrometers achieved consistent removals of 71 plus or minus 15% of total organic carbon (TOC) and better than 99% of turbidity from synthetic shower water containing 50 to 100 mg/L of TOC as soap. An alternative treatment technology utilized powdered activated carbon and coagulation/flocculation/sedimentation followed by diatomaceous earth filtration. A TOC reduction of 70 plus or minus 15% was achieved in three separate studies, although at a cost of 1 g/L or more of powdered activated carbon. Revised quality criteria for recycled shower water have been developed with guidance from the national Research Council Parameters which can practically be measured in the field are primarily associated with microbiological safety. Therefore, the safety of recycled shower water with respect to chemical contamination must depend on design considerations.

18. California Department of Water Resources, Office of Water Use Efficiency. **"Graywater Guide: Using Graywater In Your Home Landscape".** California Office of Water Reuse Efficiency. (1995).

Peer Reviewed: NO

California's Graywater Standards are now part of the State Plumbing Code, making it legal to use graywater everywhere in California. These standards were developed and adopted in response to Assembly Bill 3518, the Graywater Systems for Single Family Residences Act of 1992. This Guide was prepared to help homeowners and landscape and plumbing contractors understand the Graywater Standards and to help them design, install and maintain graywater systems.

19. Casanova, L.M., C.P. Gerba, and M. Karpiscak. **"Chemical and Microbial Characterization of Household Graywater".** Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances & Environmental Engineering. vA36.4 (2001): 395-401.

Peer Reviewed: YES

In arid areas, the search for efficient methods to conserve water is of paramount importance. One of the methods of water conservation available today is graywater recycling - the reuse of water from the sinks, showers, washing machine, and dishwasher in a home. The purpose of this project was to characterize the chemical and microbial quality of graywater from a single-family home with two adults. Water samples from a graywater holding tank were analyzed over a seven-month period for total coliforms, fecal coliforms, fecal streptococci, Staphylococcus aureus (S. aureus), Pseudomonas aeruginosa (P. aeruginosa), and coliphages. The pH, turbidity, biological oxygen demand (BOD), suspended solids (SS), electrical conductivity (EC), sulfates (SO sub(4)), and chlorides (Cl) were also measured. The mean numbers of total coliforms, fecal coliforms, fecal streptococci, and P. aeruginosa were 8.03 x 10 super(7), 5.63 x 10 super(5), 2.38 x 10 super(2), and 1.99 x 10 super(4) CFU/100 mL, respectively. S. aureus and coliphages were not detected. In the chemical analysis, mean values of 7.47 for pH, 43 nephelometric turbidity units (NTU) for turbidity, 64.85 mg/L for BOD, 35.09 mg/L for SS, 0.43 mS/cm for EC, 59.59 mg/L for SO sub(4), and 20.54 mg/L for Cl were measured. These data were compared to data taken in 1986 and 1987, when two adults and one child lived in the household. Analysis showed no statistically significant difference in levels of total coliforms and suspended solids between the two data sets. There were statistically significant differences in levels of fecal coliforms, pH, turbidity, chlorides, sulfates, and BOD between the two households. Fecal coliforms, turbidity, and BOD were higher in the household with two adults and one child. Levels of Cl, SO sub(4), and pH were higher in the household with two adults.

20. Casanova, L.M., V. Little, R.J. Frye, and C.P.Gerba. **"A Survey of the Microbial Quality of Recycled Household Graywater".** Journal of the American Water Resources Association. v37.5 (2001): 1313-20.

Peer Reviewed: YES

In arid regions where populations are expanding and water is scarce, people are searching for ways to conserve and reuse water. One way homeowners can conserve water is by recycling graywater - wastewater from household sinks, showers, bathtubs, and washing machines. Graywater is used mostly for landscape irrigation. Since graywater is wastewater, reusing it raises concerns about disease transmission, either by contact with the water or the irrigated soil. The purpose of this study was to assess how factors such as number and age of household occupants, types of graywater storage, and sources of graywater used affect the microbial quality of graywater and soil irrigated with graywater. Samples were collected over twelve months from eleven Tucson, Arizona households recycling graywater. Samples of graywater, soil irrigated by graywater, and soil irrigated by potable water were collected. We found that graywater irrigation causes a statistically significant increase in levels of fecal coliforms in soil when compared to soil irrigated with potable water. Graywater from the kitchen sink significantly increases levels of these bacteria in water and soil. Children also cause a statistically significant increase in fecal coliform levels in graywater and soil, possibly introducing a small amount of additional risk in graywater reuse.

21. Chaplin, S. W. **"Alternative Supplies: Rainwater Collection Systems, Graywater Systems, and Composting Toilets".** Proceedings of

Conserv 93; The New Water Agenda. Las Vegas, NV. December 12-16, 1993

Peer Reviewed: NO

This paper provides an overview of three alternative technologies that have the potential to save significant quantities of water and simultaneously reduce a water utility's pumping and treatment costs: Gray water systems, rainwater collection systems, and composting toilets. This overview includes a discussion of each technology's cost and performance, as well as precautions that users should take to avoid problems. Case studies document some of the sites where these technologies have been successfully implemented. This paper is designed to familiarize water professionals with these technologies and encourage their implementation in appropriate situations.

22. Chen, K.Y. **"Soil Mantle As a Purification System For Grey Water".** Manual of Grey Water Treatment Practice. Ed. J.H.T. Winneberger: Ann Arbor, MI: Ann Arbor Science, 1974. 89-102.

Peer Reviewed: NO

The functions of a grey water treatment tank are threefold: (1) the removal of solids, (2) storage and long-term digestion of sludge solids, and (3) separation of fluids and solids, including both floatable and settleable solids. The effluent fluid, which is relatively free of solids in comparison with the untreated household grey water, can be more readily infiltrated into soils. However, the effluent still contains relatively large quantities of impurities which will be subsequently removed in the soil system. These impurities could include infectious agents, nutrients, detergents, solid residues, and toxicants such as hydrogen sulfide and trace metals. This paper describes the removal and fates of such impurities from wastewater by the soil system. The physical framework of soil consists of intermingled clay, silt, sand, gravel, stones, and organic matters. The arrangement of theses particles into aggregates determines soil structure which determines its permeability, which in turn, determines how water moves through it. Chemical processes that take place in the soil include chemical sorption and base-exchanging and many others. Soil microorganisms live mainly on the surface of colloidal particles and partly in soil solutions and are responsible for most of the decomposition of organic matter in the soil. The number of microorganisms decreases with depth. The soil can remove most of the particulate forms of pollutants and some soluble contaminants by straining, physical sorption, flocculation and sedimentation mechanisms.

23. Christova-Boal, D., R.E. Eden, and S. Mcfarlane. **"An Investigation Into Greywater Reuse For Urban Residential Properties".** Desalination. v106 (1996): 391-397.

Peer Reviewed: YES

Continuing moves towards full cost recovery for potable water and the impending privatization of water supplies in the Melbourne area have enhanced public interest in the reuse of wastewater, and particularly the domestic use of greywater. Victoria University of Technology, together with support from Melbourne Water and the Department of Health and Community Services, has been investigating the practicalities, costs and social attitudes of using greywater in and around the home. Four "typical" Melbourne homes were selected and plumbed to utilize greywater for toilet flushing and garden irrigation. Social surveys were conducted by mail and phone to homeowners to determine perceived attitudes towards greywater reuse. Greywater from baths, showers, laundry troughs and washing machines is being examined for physical, chemical and microbiological parameters to determine the potential health and environmental risks associated with reuse. Soil tests were also undertaken on gardens to determine any long-term detrimental effects that might occur as a result of using greywater. This paper describes the greywater testing, results of filtration and filter designs, appropriate disinfectants, and physical findings to date. The two-year project is due for completion early in 1995.

24. Cicek, N., Winnen, Suidan, Wrenn, Urbain, and Manem. **"Effectiveness of the Membrane Bioreactor in the Biodegradatoin of High Molecular Weight Compounds".** Water Resources. v32.5 (1998): 1553-1563.

Peer Reviewed: YES

This paper presents biological and physical performance data from a pilot-scale membrane bioreactor system fed with synthetic wastewater containing high molecular weight compounds. At steady state, high effluent quality was obtained and maintained for about 350 days. The membrane was effective in retaining heterotrophic microorganisms and MS-2 viruses, eliminating the need for effluent disinfection. The flux through the membrane decreased rapidly with increasing total suspended solids (TSS) concentration between 2 and 15 g/L. The flux increased linearly with the transmembrane pressure (TMP), before reaching a maximum. A linear relationship between the maximum flux and the cross flow velocity (CVF) for different TSS concentrations was observed. The ability of the bioreactor culture to degrade high molecular weight compounds in the wastewater, and the mechanisms involved in this process were examined in detail by performing respirometry experiments. Casein was used as the model compound and different initial substrate to biomass ratios (S (inf) o / X (inf)o) were tested. In experiments with high S(inf)o / X(inf)o , several observations were made: (1) the oxidation of casein occurred in two distinct steps, (2) the yield coefficient is smaller than 0.15 mg VSS/mg COD consumed, and (3) nitrification does not occur. Under low S (inf)o / X(inf)o conditions, using (super)14 C-casein, the following observations were made: (1) complete hydrolysis of casein occurs very fast (less than 100h) and (2) oxygen uptake and nitrogen measurements suggest nitrification takes place

25. City of Los Angeles, Office of Water Reclamation. **"Graywater Pilot Project: Mid-course Report".** . City of Los Angeles, Office of Water Reclamation: Los Angeles, CA, 1992.

Peer Reviewed: NO

The primary objectives of the study are: (1) to obtain reliable quantitative data from actual use of gray water systems under realistic conditions, and (2) to make recommendations to the City Council based on the findings of the project, for safe use of gray water in the City of Los Angeles.

The gray water pilot project consists of eight gray water test systems installed at residences in the City of Los Angeles, sampled monthly and monitored over a year-long period for safety and water savings. Samples of soils and water are tested at a certified laboratory for indicator bacteria, disease organisms, and chemicals to compare areas receiving gray water with those irrigated with tap water.

Three of the disease-causing organisms monitored in the sampled soils--Salmonella, Shigella, and Entamoeba histolytica--were negative at all sites in all sampling rounds, in gray water and in soil--both control and gray-water irrigated. Roundworms were found in the soils of both control and gray-water -irrigated areas, in a few instances. It may be concluded that (1) none of the residents in any of the test sites shed pathogenic organisms, or (2) disease organisms that may have been present were killed in the detergent-laden environment of the storage tank. Apparently, neither the gray water nor the soil carried these particular organisms. Sodium, chloride, calcium, magnesium, total salts, and pH were measured in gray water and the soil saturation extract to determine if any of the agronomic characteristics of the soil might be affected by gray water irrigation. For the same purpose, sodium adsorption ratio (SAR) was computed for each sample from the basic data. A comparison of these data for control and gray-water-irrigated soils fails to show any consistent pattern or observable differences of any significance. The wide fluctuation of the results and lack of consistency may indicate absence of any short-term impacts on soil characteristics important for plant growth. Even the one site that has consistently used regular powder detergents available on the market exhibits acceptable values for chloride and SAR in the soil. The gray water systems involved in the pilot project have performed very well in the first six months of their operation. Where maintenance of the filter has been infrequent, clogging of drip irrigation systems has occurred, with attendant slow flow and pump damage. A few mechanical problems with valves, pumps and other components--unrelated to the gray water system--have been encountered. From the results presented above, including baseline data, it is clear that backyard soils are contaminated, whether they are from the control areas or from gray-water-irrigated areas. Therefore, the general sanitary practice of washing soiled hands and avoiding direct contact with the dirt in the yard are as valid for sites irrigated with tap water as those irrigated with gray water. If these data can be generalized, the clear implication is that gray water irrigation--even on the surface--does not elevate the level of indicator organisms or pathogens in the soils. It appears that use of gray water at the pilot sites, even with surface application, does not pose a significant risk to the users or the community. Since pilot project sites were controlled, inspected, and repaired as needed, broad generalization of this conclusion may be unwise. However, certain specific generalizations appear justifiable, e.g.: * Indicator bacteria in the soil generally do not seem to increase with gray water application. It is possible that he soil is already so heavily contaminated that the contribution of gray water is "lost in thenoise". *Disease organisms, normally capable of surviving in the soil for a few days, are not present in gray-water-irrigated areas. Neither have these organisms been detected in the gray water sampled from the storage tanks. This may indicate either a healthy test population, or a mechanism for deactivation of pathogens. * Individuals assigned the task of cleaning gray water filters--some do so without protective gloves, in spite of instruction to the contrary--have not reported any adverse effects. The following recommendations are tentative at this mid-course reporting stage: 1. Continue the pilot project through the planned 12 sampling events (rounds). Prepare final report and recommendations. 2. Draft ordinance for the City Council consideration to permit gray water systems in the City of Los Angeles. 3. Track state and local legislation and code changes affecting gray water use and make recommendations accordingly. 4. Add boron to the list of parameters to be measured on gray water and the soil saturation extract for one complete sampling event (round).

26. Crook, J., R.Y. Surampalli. **"Water Reclamation and Reuse Criteria in the U.S.".** Water Science and Technology. v33.10-11 (1996): 451-462.

Peer Reviewed: NO

Increasing demands on water resources for domestic, commercial, industrial, and agricultural purposes have made water reclamation and reuse an attractive option for conserving and extending available water supplies. Also, many water reuse projects are implemented to eliminate a source of contamination in surface waters or as a least-cost alternative to meeting stringent discharge requirements. Reclaimed water applications range from pasture irrigation to augmentation of potable water supplies. Water reclamation and reuse criteria are principally directed at health protection. There are no federal regulations governing water reuse in the U.S.; hence, the regulatory burden rests with the individual states. This has resulted in differing standards among states that have developed criteria. This paper summarizes and compares the criteria from some states that have developed comprehensive regulations. Guidelines published by the U.S. EPA and the rationale behind them are presented for numerous types of reclaimed water applications

27. Czemiel-Berndtsson, J.C., and I. Hyvonen. **"Are There Sustainable Alternatives to Water-based Sanitation System? Practical Illustrations and Policy Issues".** Water Policy. v4 (2002): 515-30.

Peer Reviewed: YES

There are several reasons to reconsider present urban water and wastewater policy including limitations of a conventional sanitary system, better understanding of nature and its principles gained during last decades, and the goal of society to achieve sustainable development. In this paper principles of new designs of alternative sanitation systems are illustrated, examples of technical and non-technical aspects of the eventual change are given, and difficulties to achieve changes are discussed. The analysis shows that major barriers to a change of conventional sanitation include present law and regulations, lower priority for water and nutrients in the schemes of municipal responsibilities, investments and commitments in conventional infrastructure, and also common resource perception of water and nutrients. While the issue of designing precise system of incentives is left to economists, lawyers, and politicians the paper does deal with the obstacles to change present urban water and wastewater policies and gives possible examples of supportive measures.

28. Diaper, C., A. Dixon, D. Butler, A. Fewkes, S.A. Parsons, M. Strathern, T. Stephenson, and J. Strutt. **"Small Scale Water Recycling Systems - Risk Assessment and Modelling".** Water Science and Technology. v43.10 (2001): 83–90.

Peer Reviewed: YES

This paper aims to use quantitative risk analysis, risk modelling and simulation modelling tools to assess the performance of a proprietary single house grey water recycling system. A preliminary Hazard and Operability study (HAZOP) identified the main hazards, both health related and economic, associated with installing the recycling system in a domestic environment. The health related consequences of system failure were associated with the presence of increased concentrations of micro-organisms at the point of use, due to failure of the disinfection system and/or the pump. The risk model was used to assess the increase in the probability of infection for a particular genus of micro-organism, Salmonella spp, during disinfection failure. The increase in the number of cases of infection above a base rate rose from 0.001% during normal operation, to 4% for a recycling system with no disinfection. The simulation model was used to examine the possible effects of pump failure. The model indicated that the anaerobic COD release rate in the system storage tank increases over time and dissolved oxygen decreases during this failure mode. These conditions are likely to result in odour problems.

29. Dixon, A., D. Butler, A. Fewkes, and M. Robinson. **"Measurement and Modelling of Quality changes in Stored Untreated Grey Water".** Urban Water. v1.4 (2000): 293-306.

Peer Reviewed: YES

This paper describes an investigation into stored untreated grey water quality processes and the development of a computer simulation for those processes. A laboratory study was carried out to investigate the changes in water quality with increasing residence time, and the results were used to calibrate and verify the model. Model results gave a good fit for dissolved oxygen (DO) concentrations, but only a reasonable fit for chemical oxygen demand (COD). Still, the main trends of model and laboratory COD data were broadly represented. Measurement and model results tend to confirm the initial hypothesis of four major processes in operation: settlement of suspended solids, aerobic microbial growth, anaerobic release of soluble COD from settled organic matter and atmospheric reaeration. Storing grey water for 24 h may significantly improve water quality through rapid settlement of organic particles, however, storage beyond 48 h leads to depleted DO levels and potential aesthetic problems. A more detailed model of COD fractions within grey water (with the relevant measured data) in conjunction with a characterisation of particulate settling velocities should lead to improvements in model predictions.

30. Dixon, A., D. Butler, and A. Fewkes. **"Water Saving Potential of Domestic Water Reuse Systems Using Greywater and Rainwater in Combination".** Water Science and Technology. v39.5 (1999): 25-32.

Peer Reviewed: NO

For a sustainable urban future, society must move towards the goal of efficient and appropriate water use. Reuse of domestic greywater and rainwater has a significant role to play in this task. In this study, rainfall time series have been used in conjunction with estimates of domestic water appliance usage generated by the Monte-Carlo simulation technique to predict long term system performance. Model results show that changes in the attributes of household occupancy, roof area, appliance type and storage volume affect the water saving efficiency of a single store reuse system. Considering greywater and rainwater in combination, the greatest rate of increase of efficiency with storage size occurs in the range 0-100 litres. Further analysis of small volume storage and reuse indicates that savings of up to 80% of the WC flush water can be made with less than 50 litres storage. However, the collection of rainwater in addition to greywater in a single store reuse system offers little improvement in water saving efficiency. Small volume domestic water reuse systems lend themselves to application in the urban housing environment and therefore offer potential in the move towards a more sustainable city.

31. Dixon, A.M., D. Butler, and A. Fewkes. **"Guidelines for Greywater Re-use: Health Issues".** Journal of the Chartered Institution of Water and Environmental Management. v13.5 (1999): 322-26.

Peer Reviewed: YES

This paper discusses the potential threat to health associated with the microbial contamination of greywater. Although it has been shown that greywater may contain large numbers of potentially pathogenic microorganisms, the incidence of disease is dependent upon more than just the concentration of organisms. Other factors include the degree of exposure and the health and age of the affected individuals. Proposed guidelines for the re-use of greywater focus upon faecal coliform contamination and suggest limits based upon the end use of recycled water. The paper (a) proposes modifications to the guidelines to better represent the delicate balance between protection of public health and the levels of risk posed by greywater re-use within the context of everyday human activity, and (b) attempts to identify areas where there is either an expectation for the responsibility or a personal acceptance of the responsibility with regard to public or personal health.

32. Dixon, D., J. Daly, H. Dorr, and R. Peterson. **"Enhanced MARPOL IV Sewage and Graywater Pollution Prevention - Holland America Line Westours Case Study".** Transactions - Society of Naval Architects and Marine Engineers. v110 (2003): 453-472.

Peer Reviewed: YES

Presented in this paper is a synopsis of the status of MARPOL Annex authorizations, current federal and state sewage and graywater regulations, latest EPA/GAO action and the International Council of Cruise Lines mandatory waste management practices. The efforts of Holland America Line Westours to comply with pollution regulations and a review of their upgraded sewage and graywater treatment equipment, procedures and internal reporting in excess of the regulations are examined. Through this examination and understanding of the current regulations and capabilities available for both existing vessels and new designs, it is hoped educated decisions can be made about future regulations.

33. Eden, R.E. **"Wastewater Reuse -- Limitations and Possibilities".** Desalination. v106 (1996): 335-38.

Peer Reviewed: YES

The use of wastewater is permitted in Victoria provided that the water quality meets certain standards. These standards are based on the specific purpose of the water and the method(s) used to distribute wastewater. Public health must not be compromised nor flora or fauna (domestic or national) adversely affected.

34. Emmerson, G. **"Every Drop is Precious: Greywater as an Alternative Water Source".** . Queensland Parliamentary Library, Publication and Resources Section. Research Bulletin No 4/98. (1998).

Peer Reviewed: NO

Less than 1 per cent of the total water on the planet is readily available for human use. Some 26 countries already have more people than their water supplies can support. In some of these countries, a liter of water costs four to five times that of a liter of petrol. Australia's water supply has not reached such a critical stage, but increasing demands on water and an ever-increasing population means that water supply is becoming a serious issue. Alternative sources of water can potentially save significant amounts of precious drinking water. One alternative source of water is greywater. Greywater is the water that goes down domestic bathroom and laundry drains. If this water is diverted for relatively safe applications such as garden irrigation, then a family can reduce their water usage by around 40-50 per cent, obviously a significant saving. With an increasing number of people paying for each drop of water they use through water meters, systems offering savings are going to become important. Greywater reuse also offers environmental benefits. Less nitrogen and phosphorus are released into waterways and hence may reduce the occurrence of algal blooms. Despite the opportunities offered by greywater reuse systems, they cannot be viewed as a water conservation panacea. A level of caution should be exercised with their use. Greywater has the potential to contain significant contaminants. Hence public health and the environment may be at risk. In addition, the current low cost of water may make the installation of such systems uneconomic. Greywater reuse systems are used in Queensland, however the current legislation generally prohibits the use and installation of such systems. Many people are unaware that their use of greywater is potentially illegal unless permission from the local authority has been obtained. The Queensland Government is currently reviewing its legislation on greywater reuse. This Bulletin is a review of existing information and scientific data as it pertains to the reuse of greywater as a water conservation measure. Throughout the Bulletin, specific issues that warrant further research are highlighted. Technologies available for greywater reuse applications are the current regulatory, planning ad management issues affecting the use of greywater reclamation systems.

35. Eriksson, E., K. Auffarth, M. Henze, and A. Ledin. **"Characteristics of Grey Wastewater".** Urban Water. v4.1 (March 2002): 85-104.

Peer Reviewed: YES

The composition of grey wastewater depends on sources and installations from where the water is drawn, e.g. kitchen, bathroom or laundry. The chemical compounds present originate from household chemicals, cooking, washing and the piping. In general grey wastewater contains lower levels of organic matter and nutrients compared to ordinary wastewater, since urine, faeces and toilet paper are not included. The levels of heavy metals are however in the same concentration range. The information regarding the content of xenobiotic organic compounds (XOCs) is limited. From this study, 900 different XOCs were identified as potentially present in grey wastewater by the use of tables of contents of household chemical products.

36. Farwell, L. **"Graywater: A Secure Future for Landscapes?".** Proceedings of Conserv 93; The New Water Agenda. Las Vegas, NV. December 12-16, 1993

Peer Reviewed: YES

The bulk of this article is a reprint of the California Plumbing Code's provisions for graywater systems for single family dwellings. This paper gives reasons for gray water development in California, and gives brief answers to important questions, such as Will graywater use interfere with the use of reclaimed water?

37. Fittschen, I., and J. Niemczynowicz. **"Experiences With Dry Sanitation and Greywater Treatment in the Ecovillage Toarp, Sweden".** Water Science and Technology. v35.9 (1997): 161–170.

Peer Reviewed: YES

Experiences with dry sanitation and greywater treatment in the ecovillage Toarp, Sweden, are described, based on field studies and a survey. Technical, environmental and social issues were evaluated. The greywater was treated effectively concerning BOD7, COD, Tot-N, Tot-P and thermostable coliforms. Dry sanitation was implemented in order to recycle human excrements locally, but people's request for an environmentally sound way of life was confronted with major technical and operational problems. Composting toilets were implemented without sufficient knowledge and usage directions, resulting in partly disastrous operational results. In consequence, the majority of the ecovillage's composting toilets are now replaced by water toilets. The experiences in Toarp indicate a high demand in research activities concerning dry sanitation. Necessary research and development are described. Depending on the results, dry toilet systems might not only stay a sanitary solution in widespread areas but become a future tool to recycle human excrements.

38. Folke, Gunther. **"Wastewater Treatment By Greywater seperation: Outline for a Biologically Based Greywater Purification Plant in Sweden".** Ecological Engineering. v15 (2000): 139-146.

Peer Reviewed: YES

This paper looks critically at the popular composite wastewater treatment method, its constraints and proposes fraction separation and treatment alternative based on ecoengineering – constructed wetlands/wet parks.Treatment system is based on; - infiltration and subsurface flow in the soil - biochemical interaction with plants. - Active microbial performance. - High overall effectiveness. System test and efficiency was recorded as follows; Nitrogen (N) – lower than drinking water standards. Phosphorus (P) – 99.5% removal BOD7 - detectable but very low. Fecal streptococci – below detection. Thermostable coliforms – below detection.

39. Foxon, T.J., et al. **"An Assessment of Water Demand Management Options Froma Systems Approach".** Journal of the Chartered Institution of Water and Environmental Management. v14.3 (2000): 171-178.

Peer Reviewed: YES

A systems approach is used to model the urban water and wastewater system. Scenarios are developed for the implementation of a range of water demand management measures, including (a) leakage reduction, (b) the increasing use of water metering, (c) the replacement of standard WCs by low-flow WCs, and (d) the introduction of greywater recycling systems. These measures are assessed according to the water saving, cost per unit of water saved, and other indicators of the relative contribution to the sustainability of the system. Preliminary assessments of selected environmental costs and benefits are also included.

40. Futselaar, H., R.J.Zoontjes, T. Reith, and I.G. Racz. **"Economic Comparison of Transverse and Longitudinal Flow Hollow Fiber Membrane".** Desalination. v90 (1990): 345-61.

Peer Reviewed: YES

The presently used hollow fiber membrane modules consist of a bundle of fibers in a cylindrical polymer or metal shell parallel to the shell axis. The feed solution flows either through the lumen or at the outside parallel to the fibers. This paper compares the performance of these modules with a new transverse flow module where the hollow fibers are positioned perpendicularly to the flow direction. For both types of modules the product costs are calculated for desalination by reverse osmosis and Dextran concentration by ultrafiltration. These calculations are based on literature data. The main conclusion is that the application of the transverse flow module is only attractive if the permeation resistance is mainly determined by the hydrodynamics (ultrafiltration) and not attractive if the membrane permeability is the main resistance (reverse osmosis).

41. Gajurel, D.R., Z. Li, and R. Otterpohl. **"Investigation of the Effectiveness of Source Control Sanitation Concepts Including Pre-Treatment With Rottebehaelter".** Water Science and Technology. v48.1 (2003): 111–18.

Peer Reviewed: YES

High levels of nutrients recovery can be achieved with source control sanitation - technologies are already available. Separation toilets for example separate urine that can be used in agriculture with some crop restrictions as a fertiliser after about 6 months of storage. The grey water has very low loads of nitrogen and can be treated in different combinations of biological and physical treatment and reused. Faecal matter with flush water from the separation toilet can be discharged into Rottebehaelter (an underground pre-composting tank) that retains solid material and drains liquid to a certain extent. Investigation of Rottebehaelter in the different sites and laboratory experiments showed that retained faecal material still contained a high percentage of water. However, odour was not noticed in those Rottebehaelters that have been examined. One of the major advantages of this system over other forms of pre-treatment as the septic tanks is that it does not deprive agriculture of the valuable nutrients and soil conditioner from human excreta. It has to be stated that maintenance is a crucial factor. As an intermediate result of the intensive research of Rottebehaelter it seems that these systems are rather a way of solids retaining, de-watering and long-term storage before the contents are further treated.

42. Gander, M., B. Jefferson, and S. Judd. **"Aerobic MBRs for Domestic Wastewater Treatment: A Review With Cost Considerations".** Separation and Purificaiton Technology. v18-19 (2000): 119-130.

Peer Reviewed: YES

Membrane bioreactors (MBRs) present a means of intensively biologically treating high COD or BOD wastewaters but, like other membrane processes, are constrained by their tendency to foul. Fouling is the general term given to those phenomena responsible for increasing membrane hydraulic resistance. It can be reduced by maintaining turbulent conditions, operating at sub-critical flux and/or by the selection of a suitable fouling-resistant membrane material. The performance of various MBRs is appraised with reference to (i) fouling propensity, and (ii) removal of organics and microorganisms. Energy costs for the two process configurations for MBRs, submerged and side-stream, are reported with particular attention paid to aeration and recycle pumping costs. A number of commercial plants treating domestic wastewater are described, with further details of the most recent full-scale MBR for sewage treatment tabulated. It is shown that he side-stream configuration has a higher total energy cost, but up to two orders of magnitude, compared with the submerged system due to the recycle component. The submerged configuration operates more cost effectively than the side stream configuration with respect to both energy consumption and cleaning requirements, with aeration providing the main operating cost component as it is required for both mixing and oxygen transfer. On the other hand, the lower flux under the submerged system operates implies a higher membrane area and thus a higher associated capital cost. It is concluded that the MBR is highly effective treatment process for wastewater treatment in areas requiring a high quality effluent (such as discharge to bathing waters or water reuse) or specialisation in the microbial community (e.g. high strength liquors, elective nitrification).

43. Garland, J.L., L.H. Levine, N.C. Yorio, J.L. Adams, and K.L. Cook. **"Graywater Processing in Recirculating Hydroponic Systems: Phytotoxicity, Surfactant Degradation, and Bacterial Dynamics".** Water Research. v12 (Aug. 2000): 3075-86.

Peer Reviewed: NO

Incorporation of human hygiene water (graywater) into hydroponic plant production systems, and subsequent recovery of the water transpired by the plants, is one potential means for water purification and recycling in bioregenerative life support systems under development for long duration space missions. Surfactant phytotoxicity and the potential for growth of human-associated microorganisms were assessed in studies of wheat and lettuce in controlled environmental chambers to provide baseline information for future studies with actual graywater streams. Igepon TC-42 (sodium N-coconut acid-N-methyl taurate), a surfactant designated for use on the International Space Station and a common ingredient of soaps and detergents, was added to plant systems in three different modes: (1) pulse addition of 875 mg m super(-2) growing area once a day, (2) continuous addition of 875 mg m super(-2) over the course of a day, and (3) variable addition of 0-3000 mg m super(-2) d super(-1) based on plant water demand. The survival of three human-associated bacteria (Escherichia coli, Staphylococcus aureus, and Pseudomonas aeruginosa) in the plant nutrient delivery systems were monitored following introduction 6 (wheat) or 3 (lettuce) days after planting (DAP). Igepon rapidly disappeared (i.e., a half-life of less than 1 h) following an initial adaptation period lasting less than 2 days. Microbial degradation of Igepon was supported by appearance of the degradation intermediate methyl taurine and an increase in the numbers of bacteria able to grow on media containing Igepon as the sole carbon source in the Igepon treated systems relative to the control. Wheat growth was not significantly affected by any of the Igepon treatments, but lettuce yield was significantly reduced in the pulse and continuous treatments. E. coli and S. aureus decreased below detection limits within 3-5 days within the systems, but P. aeruginosa persisted in the rhizosphere, nutrient solution, and nutrient delivery system biofilm for the duration of the wheat (70-day) and lettuce (28-day) experiments.

44. Gerba, C.P., T.M. Straub, J.B. Rose, M.M. Karpiscak, K.E. Foster, and R.G. Brittain. **"Water Quality Study of Graywater Treatment Systems".** Water Resources Bulletin. University of Arizona v 31:1 (1995): 109-16.

Peer Reviewed: NO

A residential single family dwelling was retrofitted to recycle graywater for landscape irrigation and toilet flushing. The objective of this study was to determine improvements in graywater quality by evaluating five simple graywater treatment systems that were easily adapted to the household plumbing. The treatment systems consisted 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, and (5) 20-mum cartridge filtration. Water quality parameters measured were fecal and total coliform indicator bacteria, nitrates, suspended solids, and turbidity. Reductions in bacterial concentration, suspended solids and turbidity were achieved by all systems tested. Treatment reduced nitrate concentrations to an average of 2.6 mg/liter. Reductions in suspended solids, and turbidity were influenced more by the quality of the graywater entering the treatment system than the efficiency of the systems themselves. The water hyacinths and sand filtration system provided the best graywater quality in terms of the concentrations of fecal indicator bacteria. The system providing the best water quality in regard to average suspended solids after treatment was the water hyacinths, copper ion, and sand filtration system, and the best average turbidity was achieved by the copper/silver ion generating unit with sand filtration. All systems were capable of significant reductions in fecal indicator bacteria, suspended solids, and turbidity; however, additional treatment or disinfection would be necessary to further reduce the level of coliform and fecal coliform bacteria to achieve regulatory standards in the State of Arizona.

45. Ginsberg, P. **"Greywater Doesn't Have To Be Wastewater".** Probe Post. v6.1 (1983): 23-25.

Peer Reviewed: NO

There are three main reasons for treating greywater with an on-site system. The foremost reason is to reduce overall water consumption by recycling treated waste-water. Depending on the amount of treatment, the water can be reused for washing cars, flushing toilets or watering lawns and gardens. Secondly, an on-site greywater system is useful in cases where a waterless composting toilet is used to treat toilet wastes. The third reason is to reduce the load on a septic tank or a municipal sewage treatment system.

46. Gray, S., and N. Booker. **"Wastewater Services for Small Communities".** Water Science and Technology. v47.7-8 (2003): 65–71.

Peer Reviewed: YES

Connection to centralised regional sewage systems has been too expensive for small-dispersed communities, and these townships have traditionally been serviced by on-site septic tank systems. The conventional on-site system in Australia has consisted of an anaerobic holding tank followed by adsorption trenches. This technique relies heavily on the uptake of nutrients by plants for effective removal of nitrogen and phosphorus from the effluent, and is very seasonal in its efficiency. Hence, as these small communities have grown in size, the environmental effects of the septic tank discharges have become a problem. In locations throughout Australia, such as rural Victoria and along the Hawkesbury-Nepean River, septic tanks are being replaced with the transport of sewage to regional treatment plants. For some isolated communities, this can mean spending $20,000-$40,000/household, as opposed to more common connection prices of $7,000/household. This paper explores some alternative options that might be suitable for these small communities, and attempts to identify solutions that provide acceptable environmental outcomes at lower cost. The types of alternative systems that are assessed in the paper include local treatment systems, separate blackwater and greywater collection and treatment systems both with and without non-potable water recycling, a small township scale treatment plant compared to either existing septic tank systems or pumping to a remote regional treatment facility.The work demonstrated the benefits of a scenario analysis approach for the assessment of a range of alternative systems. It demonstrated that some of the alternatives systems can achieve better than 90% reductions in the discharge of nutrients to the environment at significantly lower cost than removing the wastewater to a remote regional treatment plant. These concepts allow wastewater to be retained within a community allowing for local reuse of treated effluent.

47. Gregory, J.D., R. Lugg, and B. Sanders. **"Revision of the National Reclaimed Water Guidelines".** Desalination. v106 (1996): 263-68.

Peer Reviewed: YES

This paper provides the background to the development of the Australian guidelines for the use of reclaimed water. USEPA and WHO guidelines are discussed. The current draft guideline format is outlined. This includes values for the thermotolerant coliforms set at four levels for a variety of applications depending on degree of human contact. Levels of treatment are recommended along with safeguards for particular applications.

48. Gunter, F. **"Wastewater Treatment By Greywater Separation: Outline for a Biologically Based Greywater Purification Plant in Sweden".** Ecological Engineering. v15 (2000): 139-146.

Peer Reviewed: NO

The current system of wastewater treatment in industrial societies severely restricts the possibility of nutrient recycling. One of the biggest constraints is the mixing of the part of the sewage water containing a high concentration of nutrients with greywater, which contains fairly low amounts. The MIx-First-and-Separate-LAter (MIFSLA) approach to waste water management has led to a wastewater system the function of which is to first mix and then to remove urine and faeces from the greywater. The aim of this article was to analyse this problem and to propose a method for wastewater treatment where the different components of the wastewater are treated according to their individual qualities. The focus is placed on the treatment of greywater with ecotechnological methods. The greywater purification plant is designed to enhance the subsurface flow of water and biological interactions of plants and microorganisms in a triplicate riparian ecotone. Preliminary calculations of the efficiency of such a system indicate that the residual nutrient content of the water would be about 0.06 mg N 1 (super)-1 and 0.02 mg P 1 (super)-1, which is less than 1/10 of drinking water standards. After one year of use, tests have given the results of 0.007 mg N (super)-1 and 0.02 mg P 1 (super)-1. Bacteria was reduced with 3-4 powers of ten (to detection level) in the pond system, and nor detected after final treatment.

49. Hammes, F., Y. Kalogo, and W. Verstraete. **"Anaerobic Digestion Technologies for Closing the Domestic Water, Carbon and Nutrient Cycles".** Water Science and Technology. v41.3 (2000): 203-211.

Peer Reviewed: NO

Sustainable wastewater treatment requires that household wastewater is collected and treated separately from industrial wastewater and rainwater run-offs. This separate treatment is, however, still inadequate, as more than 70% of the nutrients and much of the chemical oxygen demand (COD) and potential pathogens of a domestic sewage system are confined to the few liters of black water (faeces, urine and toilet water). Whilst grey water can easily be filter treated and re-used for secondary household purposes, black water requires more intensive treatment due to its high COD and microbial (pathogens) content. Recently developed vacuum/dry toilets produce a nutrient rich semi-solid waste stream, which, with proper treatment, offers the possibility of nutrient, carbon, water and energy recovery. This study investigates the terrestrial applicability of Life Support System (LSS) concepts as a framework for future domestic waste management. The possibilities of treating black water together with other types of human-generated solid waste (biowaste/mixed wastes) in an anaerobic reactor system at thermophilic conditions, as well as some post treatment alternatives for product recovery and re-use, are considered. Energy can partially be recovered in the form of biogas produced during anaerobic digestion. The system is investigated in the form of theoretical mass balances, together with an assessment of the current feasibility of this technology and other post-treatment alternatives.

50. Hellström, D. **"Exergy Analysis of Nutrient Recovery Processes".** Water Science and Technology. v48.1 (2003): 27–36.

Peer Reviewed: YES

In an exergy analysis, the actual consumption of resources in physical and chemical processes is calculated. Energy and chemical elements are not consumed in the processes - they are only transformed into other forms with lower quality. The principals of exergy analysis are illustrated by comparing different wastewater treatment systems for nutrient recovery. One system represents an end-of-pipe structure, whereas other systems include source separation of grey water, black water, and urine. The exergy flows analysed in this paper are those related to management and treatment of organic matter and nutrients. The study shows that the total exergy consumption is lowest for the system with source separation of urine and faeces and greatest for the conventional wastewater treatment system complemented by processes for nutrient recovery.

51. Hills, S., A.Smith, P. Hardy, and R. Birks. **"Water Recycling at the Millennium Dome".** Water Science and Technology. v43.10 (2001): 287-94.

Peer Reviewed: NO

Thames Water is working with the New Millennium Experience Company to provide a water recycling system for the Millennium Dome which will supply 500m (super) 3 / d of reclaimed water for WC and urinal flushing. The system will treat water from three sources: rainwater - from the Dome roof; greywater - from handbasins in the toilet blocks; groundwater - from beneath the Dome site. The treatment technologies will range from "natural" reedbeds for the rainwater, to more sophisticated options, including biological aerated filters and membranes for the greywater and groundwater. Pilot scale trials were used to design the optimum configuration. In addition to the recycling system, water efficient devices will be installed in three of the core toilet blocks as part of a programme of research into the effectiveness of conservation measures. Data on water usage and customer behaviour will be collected via a comprehensive metering system. Information from the Dome project on the economics and efficiency of on-site recycling at large scale and data on water efficient device, customer perception and behaviour will be of greater value to the water industry. For Thames Water, the project provides vital input to the development of future water resource strategies.

52. Ho, G., S. Dallas, M. Anda, and K. Mathew. **"On-site Wastewater Technologies in Australia".** Water Science and Technology. v44.6 (2001): 81-88.

Peer Reviewed: NO

Domestic wastewater reuse is currently not permitted anywhere in Australia but is widely supported by the community, promoted by researchers, and improvised by up to 20% of householders. Its widespread implementation will make an enormous contribution to the sustainability of water resources. Integrated with other strategies in the outdoor living environment of settlements in arid lands, great benefit will be derived. This paper describes six options for wastewater reuse under research by the Remote Area Developments Group (RADG) at Murdoch University and case studies are given where productive use is being made for revegetation and food production strategies at household and community scales. Pollution control techniques, public health precautions and maintenance requirements are described. The special case of remote Aboriginal communities is explained where prototype systems have been installed by RADG to generate windbreaks and orchards. New Australian design standards and draft guidelines for domestic greywater reuse produced by the Western Australian State government agencies for mainstream communities are evaluated. It is recommended that dry composting toilets be coupled with domestic greywater reuse and the various types available in Australia are described. For situations where only the flushing toilet will suffice, the unique "wet composting" system can be used and this also is described. A vision for household and community-scale on-site application is presented.

53. Howarth, D., and D. Sayers. **"Practical Aspects of Household Graywater Recycling".** Conserv 99 Water Efficiency: Making Cents in the Next Century. Monterey, CA . January 31-February 3, 1999

Peer Reviewed: NO

A study of graywater recycling in the home was conducted by the National Water Demand Management Centre as part of its program of technical research. This investigation was a pioneering study which will provide valuable information to the many individuals and organizations who are expressing interest in water recycling schemes. The trial examined three aspects of graywater recycling in the household environment: water consumption savings and associated cost savings from reduced water bills; water quality of the graywater - relating the quality as measured to proposed graywater guidance or other applicable sources of reference; and, acceptability to the user of having a graywater recycling system fitted in the home. Studies of domestic consumption reveal that 35% of water used in the home in the United Kingdom is for flushing the toilet. graywater recycling systems have the potential to save a large proportion, if not all, of this and can therefore be considered a useful tool in demand management. This paper discusses the results from 14 months of trials with the graywater units.

54. Jackson, R., and E. Ord. **"Greywater Re-use - Benefit or Liability? The UK Perspective".** Water. v21 (June 2000): 38-40.

Peer Reviewed: YES

There is no doubt that, even in a temperate climate such as the UK enjoys, there is an urgent need to conserve water. This is underlined by, for example, the way that controls on abstractions are changing. The UK government is planning to curtail water abstraction by managing water resources in a more sustainable way. Abstraction licensing by the Environment Agency will, for the first time, become time limited, and these time limited licenses are to be reviewed every six years in line with the EU framework directive on water resources. Furthermore, the world is quickly becoming urbanised as people migrate to cities. In 1951 less than 30% of the world's population lived in cities. By 1985 this figure had increased to 41% and it is projected that by 2025 more than 60% of the world's population will live in urban areas. In the UK, a suggested doubling of the number of homes to be built in the southeast, outside London, to 1.1 million over the next 16 years would necessitate long-range thinking and severely test current water resource strategies. In such a context, greywater can be seen as a benefit. Greywater is usually described as all sources of domestic water that have been used once, apart from toilet and bidet wastewater (which is known as blackwater). Greywater has, by definition, relatively low levels of microbiological contamination which has led to it being reused as a source of non-potable water. Greywater can be used for various tasks but is most commonly used for toilet flushing alone, although care must be exercised even in this use as greywater can quickly degenerate into a hazardous microbial cocktail.

55. Jefferson, B., A. Laine, S. Parsons, T. Stephenson, and S. Judd. **"Technologies for Domestic Wastewater Recycling".** Urban Water. v1.4 (December 1999): 285-292.

Peer Reviewed: NO

Domestic wastewater recycling is still in its infancy and as such, there is a paucity of reliable information relating to both the nature of grey water and the range of recycling technologies available. The lack of water quality standards and the poor understanding of the nature of grey water have led to the development of a plethora of technologies for recycling application. The paper discusses the relative merits of the different options and describes the current situation within the UK.

56. Jefferson, B., A.L. Laine, T. Stephenson, and S.J. Judd. **"Advanced Biological Unit Processes for Domestic Water Recycling".** Water Science and Technology. v43.10 (2001): 211-18.

Peer Reviewed: YES

The potential of advanced biological unit operations for the recycling of grey and black waters has been evaluated. The membrane bioreactor (MBR) demonstrated the greatest efficacy towards water recycling in terms of all the quality determinants. Both the biologically aerated filter (BAF) and the MBR were able to effectively treat the organic and physical pollutants in all the types of wastewater tested. The main difference was observed in terms of the microbiological quality, measured as total coliforms. The open bed structure of the BAF enabled passage of coliforms whereas the complete barrier of the MBR produced a non detectable level in the effluent. The MBR process complied with commonly adopted water recycling quality standards for the all determinants during the grey water trials and failed only in terms of total coliform counts once black water had been introduced into the feed. The MBR was seen as a particularly suitable advanced biological process as it was very effective at stabilising out the considerable load variations encountered during the trial.

57. Jefferson, B., J.E. Burgess, A. Pichon, J. Harkness, S.J. Judd. **"Nutrient Addition to Enhance Biological Treatment of Greywater".** Water Research. v35.11 (April 2001): 2702-10.

Peer Reviewed: YES

This study compares the chemical oxygen demand (COD) removal and respiration rates of a microbial population treating real and synthetic greywaters dosed with nutrients supplements. The nutrient composition of the real and synthetic greywaters was analyzed and the dosing regime for nitrogen, phosphorus and a range of trace metals planned accordingly. The doses consisted of eight single additives (macronutrients and trace metals) to the control greywater and six trace metal additions to C:N:P balanced greywater. The COD removal for the control real and synthetic greywater in lab-scale activated sludge systems (0.038 and 0.286 kg COD kg/MLSS/d, respectively) confirmed nutrient limitation and the poor degree of greywater treatment. Nutrient dosing increased the COD removal rate and oxygen uptake rate in many cases. The greatest stimulation of microbial activity was observed with zinc additions to C:N:P balanced real greywater (1.29 kg COD kg/MLSS/d over 30 times the control). Inhibitory effects to various extents were rare and limited mainly to the addition of metals to synthetic greywater. The dominance of chemicals effects was observed on addition of some micronutrients; notably iron and aluminium, metals on which many coagulants for use in biotreatment of other wastewater are based. The data indicate that the impact of understanding microbial processes and the nutrients required for wastewater treatment can only serve to optimize process efficiency for the proposed treatment of greywater.

58. Jeppesen, B. **"Domestic Greywater Re-use: Australia's Challenge for the Future".** Desalination. v106.1-3 (1996):311-15.

Peer Reviewed: YES

Under a grant from the Urban Water Research Association of Australia, the Brisbane City Council has advanced Australian research into domestic greywater re-use. This hard work has established that domestic greywater does contain chemicals and microorganisms that can be harmful to public health and the environment. Greywater can even emit noxious odours. However, if domestic greywater could be re-used to water lawns and ornamental gardens, the average household potable water usage could be reduced by between 30-50%. Public acceptance of the principle is high, but this must be balanced against the incorrect perception that greywater is innocuous. The challenge now facing Australian Water Authorities is how to fully utilize this valuable resource without: compromising public health, causing detrimental impact to the environment or down grading the livability of our residential areas. Only through total management and public awareness of the issues is this possible. To help achieve these goals the Brisbane City Council is presently developing guidelines for the application of domestic greywater re-use for sewered areas in Australia. This paper provides a brief overview of this research and an insight into the direction of these proposed guidelines.

59. Karpiscak, M. M., R.G. Brittain, and M. A. Emelity. **"Residential Water Conservation and Reuse Demonstration: Casa del Agua and Desert House".** Water Resources Planning and Management and Urban Water Resources. (1993): 694-97.

Peer Reviewed: NO

Occupied single-family homes can provide factual data as well as create an active real-world setting for education of the public. The installation of water-efficient fixtures, rainwater harvesting, and systems for graywater storage and reuse can potentially reduce potable water use by over 50 percent. Casa del Agua and Desert House demonstrate that efficient resource utilization can become an integral part of a comfortable and quality living environment.

60. Karpiscak, M. M., K.E. Foster, and N. Schmidt. **"Residential Water Conservation: Casa del Agua".** University of Arizona: Water Resources Bulletin. v26:6 (1990): 939-948.

Peer Reviewed: NO

A single-family residence in Tucson, Arizona, was retrofitted with water-conserving fixtures, rainwater harvesting, and graywater reuse systems. During a four-year study, efficient use of water was shown to significantly decrease demand for domestic water at the house without reducing the residents' quality of life. The use of municipal water was reduced by 66 percent to 148 gallons per day (gpd) and total household use was reduced by 27 percent to 245 gpd. Graywater reuse averaged approximately 77 gpd or 32 percent of the total household water use. Evaporative cooling required about 15 gpd. Water use for toilet flushing was only 9 gallons per capita per day (gpcd) or 14 percent of interior water use.

61. Karpiscak, M., R. G. Brittain, C. P. Gerba, K. Foster, and E. Kennith. **"Demonstrating Residential Water Conservation and Reuse in the Sonoran Desert. Casa Del Agua and Desert House".** Water Science and Technology. v24.9 (2000): 323-330.

Peer Reviewed: NO

Single-family homes are being used to demonstrate and research water conserving and reuse techniques and technologies. These facilities can provide real-world data as well as public information and educational programs. The installation of water-conserving fixtures, rainwater harvesting, and graywater reuse systems and storage can reduce the requirements for potable water by 50 percent. Casa del Agua and Desert House show that the science of conserving resources can be balanced with the art of designing quality desert dwellings.

62. Karpiscak, M.M., G.W. France, K.J. Decook, R.G. Brittain, K.E. Foster, and S.B.Hopf. **"Casa del Agua: Water conservation demonstration house 1986 through 1998".** Journal of the American Water Resources Association. v37:5 (2001): 1237-48.

Peer Reviewed: YES

Casa del Agua (Casa) in suburban Tucson, Arizona, was designed as a residential water conservation facility for applied research, demonstration of operational results, and transfer of technology to the general public. Starting in 1983, an existing residence was located, modified and retrofitted to acquire operational data on residential water use. Modifications included retrofitting existing landscapes and enlarging the rooftop to collect and harvest rainwater; separating blackwater and graywater lines; installing meters, low-water-use appliances and fixtures, and underground storage tanks for rainwater and graywater; and creating a public information center. Over the 13-plus years of actual operation, both the interior and exterior water use research results indicate large reductions in water use can be effected using water-saving devices and/or harvesting and reusing rainwater and graywater. Casa achieved over a 24 percent reduction in total water use and a 47 percent reduction in municipal water used compared to the typical Tucson residence. Overall water used was comprised of harvested rainwater (10 percent), recycled graywater (20 percent), and municipal water (70 percent). Casa's Information Center was visited by approximately 13,000 people from September 1985 through April 1999 and the research has been featured in local, national, and international media.

63. Kerkhof, L., M. Santoro, and J. Garland. **"Response of Soybean Rhizosphere Communities to Human Hygiene Water Addition as Determined By Community Level Physiological Profiling (CLPP) and Terminal Restriction Fragment Length Polymorphism (TRFLP) Analysis".** FEMS Microbiology Letters. v1 (March 2000): 95-101.

Peer Reviewed: YES

In this report, we describe an experiment conducted at Kennedy Space Center in the biomass production chamber (BPC) using soybean plants for purification and processing of human hygiene water. Specifically, we tested whether it was possible to detect changes in the root-associated bacterial assemblage of the plants and ultimately to identify the specific microorganism(s) which differed when plants were exposed to hygiene water and other hydroponic media. Plants were grown in hydroponics media corresponding to four different treatments: control (Hoagland's solution), artificial gray water (Hoagland's+surfactant), filtered gray water collected from human subjects on site, and unfiltered gray water. Differences in rhizosphere microbial populations in all experimental treatments were observed when compared to the control treatment using both community level physiological profiles (BIOLOG) and molecular fingerprinting of 16S rRNA genes by terminal restriction fragment length polymorphism analysis (TRFLP). Furthermore, screening of a clonal library of 16S rRNA genes by TRFLP yielded nearly full length SSU genes associated with the various treatments. Most 16S rRNA genes were affiliated with the Klebsiella, Pseudomonas, Variovorax, Burkholderia, Bordetella and Isosphaera groups. This molecular approach demonstrated the ability to rapidly detect and identify microorganisms unique to experimental treatments and provides a means to fingerprint microbial communities in the biosystems being developed at NASA for optimizing advanced life support operations.

64. Knight, M.J., J.S. Tomlin, A.R. Paffard, and R.A. Nicol. **"Potential of Greywater Reuse for Irrigating Household Land in Sydney and Brisbane".** Proceedings from the Tenth World Water Conference. 2000 March 11-17, Australia. Carbondale, IL: International Water Resources. 2000.

Peer Reviewed: NO

Reuse of greywater at the household scale has been identified by water supply authorities as having potential for reducing the demand for reticulated water. Some houses are trialling these ideas in several capital cities of Australia. This research assesses the suitability of different soils, landforms and geologies for potential irrigation savings and limitations, at the household scale, in a range of suburbs in Sydney and Brisbane. The hydraulic conductivities of soil regolith profile beneath various parts of land around houses (eg. lawns, garden beds) have been measured. Slopes greater than 10 degrees appear to be a limiting factor to greywater application due to interflow into other downslope blocks. In Sutherland Shire of Sydney, household land at the lower end of a 5 degree slope with all twelve blocks in series and up slope, using greywater, would take 138 days to reach field saturation. The occurrence of rock at shallow depths (eg. Hawkesbury Sandstone) is another problem in Sutherland Shire. Where slopes of less than 10 degrees occur, some 20-50% of the blocks may not be suitable due to shallow rock. The estimated water use reduction (substituting mains water by greywater for irrigation) in Sutherland Shire is 0.34KL/day/household or 3614 KL/day for the Shire. This equates to a total monetary value of $786,000 per year on 1998 water prices. Sydney-wide savings may reach $70 million. Studies in Brisbane show that some soil types on low slopes such as Red Earths (12% of urbanised Brisbane) are suitable as they have high vertical permeability. On the other hand there are poorly drained humic gleis in the low lying areas (2% of Brisbane) that would present problems. Overall the studies in Brisbane (sampled across the entire city for most soil-slope landscapes) indicate that houses would need about 100 m(super)2 / person to prevent ponding and runoff. Preliminary social surveys in Sydney and Brisbane indicate that, whilst householders like the idea of reusing greywater, most suggest a payback period greater than five years is unacceptable. Payback periods appear to be much greater; 20 to 40 years or so at current prices. Site characteristics at the household scale will determine if greywater is feasible. Economic factors and social desires will determine if people want to install the system.

65. Konopka, A., T. Zakharova, L. Oliver, D. Camp, and R. F. Turco. **"Biodegradation of Organic Wastes Containing Surfactants in a Biomass Recycle Reactor".** Applied and Environmetnal Microbiology. v62.9: (1996): 3292-97.

Peer Reviewed: YES

The microbial biodegradation of simulated graywater, containing 21.5 mg of linear alkylbenzene sulfonate liter21, was investigated with a continuous-flow bioreactor with 100% biomass recycle. Low concentrations of organic matter in the ultrafiltration eluate were achieved at hydraulic residence times as short as 1.6 h and for periods of up to 74 days at a hydraulic residence time of 6 h. Upon a shift from the chemostat to the biomass recycle mode, the increase in biomass with time approximated a linear rather than an exponential function. Biomass densities as high as 6.8 g of cell protein liter21 were reached; this was 50-fold higher than the steady-state biomass level in chemostats fed the same medium. We assessed physiological changes in the microbial community after a switch from the chemostat to the biomass recycle mode. Over 150 h, there was a two- to fourfold decrease in the respiratory potential of the microbes. After this decrease, respiratory potentials were relatively constant up to 74 days of operation. A decline in reactivity was also indicated by increasing lag periods before growth in response to organic nutrient inputs and by a decrease in the proportion of cells able to reduce tetrazolium dye. However, the bioreactor system was still capable of rapidly metabolizing inputs of organic matter, because of the very high biomass concentrations. It appears that <10% of the organic carbon inputs accumulate as biomass.

66. Kourik, R. **"Source reduction for Wastewater".** Biocycle. v31.1 (1990): 35.

Peer Reviewed: YES

It is argued that a well-designed efficient and automatic gray water (i.e. wastewater from kitchen and bathroom sinks, tubs, showers and laundry rooms) system can be a reliable and safe way to reuse such water to irrigate ornamental landscaping, Santa Barbara County in California has permitted gray water reuse for this purpose.

67. Kreysig, D. **"Greywater Recycling: Treatment Techniques and Cost Savings".** Water Conservation and Recycling. v19.3 (1996): 18-19.

Peer Reviewed: NO

This paper argues that greywater recycling incorporating a standard disinfection and electrochemical treatment step can result in significant cost savings for homes and industry.

68. Laak, R., M.A. Parese, and R. Costello **"Denitrification of Blackwater With Greywater".** Journal of the Environmental Engineering Division, Proceedings of the American Societcy of Civil Engineers. v107.EE3 (1981): 581-90.

Peer Reviewed: NO

Nitrogen control techniques used currently in wastewater treatment facilities are expensive. A nitrogen removal technique for on-site systems would be useful for areas where nitrate pollution from septic tank systems may be a potential problem. A biological nitrogen removal technique which is passive, energy free, and requires on more maintenance than a conventional septic tank system called the RUCK system is being developed by the University of Connecticut. This paper describes two studies to determine the applicability of greywater in the denitrificaiton step of the process. Based on the results of this study it can be concluded that: 1. Nitrite did not present a problem. 2. Nitrifying reactors or 1/5 ft (0.5 m) of concrete sand media provided a reliable method for the nitrification of blackwater septic tank effluent. Comparable denitrification efficiencies were obtained using greywater and methanol as a carbon source. 4. Stones loaded at 2.1 gal/ft (super)2 /day (85 L/m (super)2 /day) provided an acceptable anaerobic media which did not clog. 5. Greywater can serve as an acceptable carbon source for denitrificaiton of nitrified blackwater. 6.

By separating part of the greywater an overall nitrogen removal of over 70% can be achieved using a passive system.

69. Lamb, B.E., A.J. Gold, G.W. Loomis, and C.G. McKiel. **"Nitrogen Removal for On-site Sewage Disposal: Field Evaluation of Buried Sand Filter/Greywater Systems".** TRANS ASAE. v34.3 (1991): 883-89.

Peer Reviewed: NO

The nitrogen removal associated with buried sand filter/greywater systems, patterned after RUCK system designs, was assessed in a field laboratory and two fullscale systems in Rhode Island. Specifically, the study tested the ability of buried sand filters to support nitrification and the suitability of household greywater as a carbon source for denitrification. The buried sand filter/greywater systems removed approximately 50% of the total nitrogen in household wastewater before the wastewater entered the soil absorption field. Nitrification within the buried sand filters was a major limiting factor to complete nitrogen removal, with filters generally providing 50-80% nitrification. Denitrification rates of 100% were routinely observed using greywater as a carbon source and a rock tank with a three day retention period as an anaerobic environment. Rock-free tanks with a one day retention period were also assessed as an anaerobic environment, providing an average of 74% denitrification. Buried sand filter/greywater systems show promise as a nitrogen removal system for on-site sewage disposal.

70. Lesikar, B.J., R. Persyn, and M. Garcia. **"Wastewater Reuse and Greywater Systems for Landscape Irrigation".** . 6th Annual Texas On-Site Wastewater Treatment Research Council Conference, May 20-22, Corpus Christi, Texas. 1998.

Peer Reviewed: NO

Demand on fresh water resources is projected to exceed the supply in the next 50 years. Dome areas of the State are already experiencing fresh water shortages. Wastewater is one potential source of water which can be used to replace some of the demand for fresh water. Wastewater reuse is discussed in this paper. Greywater reuse and treated effluent is presented as possible sources for landscape irrigation. The regulations concerning the reuse of effluents are presented as well as treatment and distribution systems. Wastewater is a possible water source for use in the home landscape for preserving our fresh water supplies. This water resource must be used properly to protect public health and the environment.

71. Levine, L. H., J. L. Garland, and J. V. Johnson. **"HPLC/ESI-quadrupole Ion Trap Mass Spectrometry for Characterization and Direct Quantification of Amphoteric and Nonionic Surfactants in Aqueous Samples".** Analytical Chemistry. v74.9 (2001): 2064-71.

Peer Reviewed: YES

An amphoteric (cocamidopropylbetaine, CAPB) and a nonionic (alcohol polyethoxylate, AE) surfactant were characterized by electrospray ionization quadrupole ion trap mass spectrometry (ESI-MS) as to their homologue distribution and ionization/fragmentation chemistry. Quantitative methods involving reversed-phase gradient HPLC and (+)ESI-MSⁿ were developed to directly determine these surfactants in hydroponic plant growth medium that received simulated graywater. The predominant homologues, 12 C alkyl CAPB and 9 EO AE, were monitored to represent the total amount of the respective surfactants. The methods demonstrated dynamic linear ranges of 0.5-250 ng (r² > 0.996) for CAPB and 8-560 ng (r² > 0.998) for AE homologue mixture, corresponding to minimum quantification limits of 25 ppb CAPB and 0.4 ppm AE with 20-μL injections. This translated into an even lower limit for individual components due to the polydispersive nature of the surfactants. The procedure was successfully employed for the assessment of CAPB and AE biodegradation in a hydroponic plant growth system used as a graywater bioreactor.

72. Lim, J., N.W. Jern, K.L. Chew, and V. Kallianpur. **"A Model for Decentralised Grey Wastewater Treatment System in Singapore Public Housing".** Water Science and Technology. v46.9 (2002): 63-69.

Peer Reviewed: NO

Global concerns over the sustainable use of natural resources provided the impetus for research into water reclamation from wastewater within the Singapore context. The objective of the research is to study and develop a water infrastructure system as an integral element of architecture and the urbanscape, thereby reducing the need for large area requirements associated with centralised treatment plants. The decentralised plants were considered so as to break up the large contiguous plot of land otherwise needed, into smaller integrated fragments, which can be incorporated within the housing scheme.

This liberated more usable space on the ground plane of the urban housing master plan, enabling water-edge and waterscape relationships with both the private and public domains of varying scale.

73. Little, V. **"Graywater Guidelines".** . Tucson: Water Conservation Alliance of Southern Arizona, 2000.

Peer Reviewed: NO

Graywater use is the next step for those committed water conservationists who are already practicing good water-saving behavior. Some people, however, are reluctant to take that step, put off by the thought that a graywater system involves the installation of equipment and possible physical alterations. This booklet will provide a boost to those reluctant, well-meaning individuals. Written for the novice or layperson, the publication clarifies graywater issues in a simple and straightforward manner and includes helpful illustrations. The text will help readers decide if graywater is suitable for them and provides guidelines on a variety of appropriate materials and methods of system installation. The booklet also contains a copy of the common-sense rules issued by the Arizona Department of Environmental Quality for the use of residential graywater.

74. Lodge, B, T. Seager, T. Stephenson, P. English, and R. Ford. **"A Water Recycling plant at the Millennium Dome".** <u>Proceedings of the Institution of Civil Engineers:Civil Engineering</u>. v138. 5 (May 2000): 58-64.

Peer Reviewed: YES

The water recycling treatment plant at the Millennium Dome in Greenwich is the largest of its kind in Europe and a showcase for water treatment processes of the future. It is designed to provide 500m super(3)/day to flush all the toilets and urinals in the Dome. The water is 'reclaimed' from three sources - rain water from the Dome roof, greywater from the handbasins in the Dome and groundwater from a borehole on the site. This paper describes the development from the design stage through to construction of this unusual engineering project, and details the Cranfield water treatment processes in use in the plant.

75. Lodge, B.N., S.J. Judd, and A.J. Smith. **"A Statistical Method for Quantifying the Different Fouling Effects of Three Combined**

Water Sources on an Ultrafiltration Membrane". Desalination. v142.2 (February 2002): 143-49.

Peer Reviewed: YES

A simple statistical model has been developed to explain the fouling of an ultrafiltration (UF) membrane treating three mixed feedwater matrices. A tubular UF membrane operating under dead-end conditions, based at the Millennium Dome Water Recycling Plant, was used for this study. The feedwaters comprised surface water, greywater and groundwater, all having distinct quality differences. The analysis utilises the least-squares fit regression technique. Fouling, as manisfested in the diurnal change in trans-membrane pressure (TMP), is related numerically to the volumes of the feedwaters, the mean TMP and the cross product of mean TMP with water volume. It was found that the impact of the recovered greywater on TMP was not statistically significant only due to the low daily volumes of this matrix generated, compared with those of the other sources. The model that best described the data was chosen on the basis of highest R super(2) and lowest residual mean square, and demonstrated the surface water to be more fouling than the ground water by a factor, which is a function of the mean TMP.

76. Lombardo, P. **"Expanding Options for Greywater Treatment".** Biocycle. v23.3 (1982): 45-49.

Peer Reviewed: YES

Compost toilets were first developed in Sweden in the 1930's by Rikard Lindstrom. The Clivus-Multrum, a large capacity unit, evolved from Lindstrom's original research and development activities. The Clivus-Multrum became commercially availabe in Sweden in 1964. During the past 20 years, additional research and development have produced several smaller designs that utilized heating elements to evaporate excess liquid and maintain thermophilic temperatures. American interest in the use of compost toilets as a waste management technique has grown as a result of increased environmental awareness, federal programs to solve household wastewater management problems, excessive costs of conventional treatment, and population growth. The two principle barriers to widespread use of compost toilets in the U.S. are interrelated: user acceptance, and functional performance of the toilet itself. User acceptance, primarily a psychological issue, should be overcome when compost toilets establish a longer track record of success.

77. Lopez-Zavala, M.A., N.Funamizu, and T. Takakuwa. **"Onsite Wastewater Differential Treatment System: Modeling Approach".** Water Science and Technology. v46.6-7 (2001): 317-24.

Peer Reviewed: NO

In this paper, the Onsite Wastewater Differential Treatment System (OWDTS), a new approach for improving treatment systems (OWTS), is proposed based on differential management and treatment of household wastewater effluents. Three fractions of household wastewater have been differentiated, reduced-volume blackwater, higher-load graywater and lower-load graywater. Based on this differentiation, different treatment processes required for each fraction are discussed. The procedure adopted for treatment of toilet wastes (reduced-volume blackwater) is shown. In the case of graywater, a sketch of treatment processes is provided. The OWDTS seems to be anew approach with higher potential for improvement of traditional OWTS, dry ecological sanitation, recycling of resources (toilet wastes and water), conservation of water resources, etc. Aerobic biodegradation of toilet wastes by using sawdust as a matrix is an essential treatment process of the OWDTS. Membrane technology seems to be the most effective process to treat higher-load gray water. Natural biodegradation of lower-load gray water by soil bacteria needs to be deeply studied.

78. Lu, W., and A.Y.T. Leung. **"A Preliminary Study on Potential of Developing Shower/Laundry Wastewater Reclamation and Reuse System".** Chemosphere. v52.9 (2003): 1451-59.

Peer Reviewed: YES

With the ever-increasing urban population and economic activities, water usage and demand are continuously increasing. Hence, finding/re-creating adequate water supply and fully utilizing wastewater become important issues in sustainable urban development and environmental benign aspect. Considering Hong Kong's situation, e.g., lack of natural fresh water, domination of municipal wastewater, etc., developing wastewater reclamation and reuse system is of specific significance to exploit new water resource and save natural fresh water supplied from Mainland China. We propose and have carried out some preliminary studies on the potential of categorizing municipal wastewater, developing grey and storm water recycling system in public housing estate, investigating the feasibility and potential of using reclaimed grey water, etc. Since there is very limited experience in grey water recycling, such initial studies can help to understand and increase knowledge in utilizing grey water, to foresee the feasibility of developing new water resource, to estimate the cost-effectiveness of reclaiming grey water in metropolitan city.

79. Ludwig, A. **"Create an Oasis With Greywater: Choosing, Building, and Using Greywater Systems".** . California: Oasis Design, 1994-2002.

Peer Reviewed: NO

Create an Oasis with Greywater describes how to choose, build, and use twenty different types of greywater systems. It thoroughly covers all greywater basics, and will benefit everyone who is using or contemplating the use of greywater.

80. Ludwig, A. **"Branched Drain Greywater Systems: Reliable, Sanitary, Low Maintenance Distribution of Household Greywater to Downhill Plants Without Filtration or Pumping".** . California: Oasis Design, 2003.

Peer Reviewed: NO

Branched drain systems are the best choice for over half of residential installations. This book describes how to design, build, and use one from off-the-shelf components, in just about any context.

81. Ludwig, A. **"Builder's Greywater Guide: Installation of Greywater Systems in New Construction and Remodeling".** . California: Oasis Design, 1995-2002.

Peer Reviewed: NO

The Builder's Greywater Guide will help building professionals or homeowners work within or around building codes to successfully include greywater systems in new construction or remodeling. Includes information on treatment effectiveness, sample codes, and permit submissions.

82. Mara, D.D., and R.G.A. Feachem. **"Water and Excreta-Related Diseases: Unitary Environmental Classification".** Journal of Environmental Engineering. v125.4 (1999): 334-39.

Peer Reviewed: NO

A unitary environmental classification of water- and excreta-related communicable diseases is presented, which comprises seven categories: Feco-oral waterborne and water-washed diseases; non-feco-oral water-washed (skin and eye) diseases; geohelminthiases; taeniases; water-based diseases (bacterial and fungal, as well as helminthic); insect-vector diseases, and rodent-vector diseases. The global burden of some of theses diseases in 1990 is reviewed. Water- and excreta-related diseases were responsible for 2,700,000 deaths in that year (5.3% of all deaths) and for the loss of 93,200,000 disability-adjusted life years (6.8% of all DALYS). Almost all these deaths and loss of DALYs occurred in developing countries (99.9 and 99.8%, respectively).

83. March, J.G., M.Gual, and B.M. Simonet. **"Determination of Residual Chlorine in Greywater Using O-tolidine".** Talanta. v58 (2002):995-1001.

Peer Reviewed: YES

The determination of chlorine with o-tolidine in greywater has been studied, and a batch method and a sequential injection method have been proposed. It was found that the reaction of 0-tolidine with chlorine was slower in a greywater matrix. Grey water samples must be filtered before analysis, or alternatively, a blank of sample must be measured. The samples are very unstable, and after 2 h of storage in dark conditions at 4 degrees C the chlorine concentration can diminish. The standard addition method, in some samples gave unsatisfactory results as a consequence of matrix effects. It was concluded that samples with a total organic carbon (TOC) higher than 60 mgC 1 (super)-1 can not be accurately analysed using these methods. However, samples with a TOC lower than 60 mgC 1 (super)-1 gave 100 plus or minus 3% recoveries. The linear range of the methods was 0-3.0 and 0-5.0 mgCl (inf)2 1 (super)-1, and the limit of quantification 0.2 and 0.5 mgCl (inf)2 1 (super)-1, for the batch method and the sequential injection method, respectively. This is the first paper devoted to grey water from the analytical chemistry point of view.

84. Mars, R., R. Taplin, G. Ho, and K. Mathew. **"Greywater Treatment With the Submergent Triglochin Huegelii--a Comparison Between Surface and Subsurface Systems".** Ecological Engineering. v20 (2003): 147-56.

Peer Reviewed: NO

Initial studies using Triglochin huegelii, a Western Australian species, in wastewater treatment experiments have shown that Triglochin has consistently removed more nitrogen and phosphorus, in all parts of the plant leaves, tubers and roots, than most other indigenous emergent macrophyte species. Our recent results have again shown that these types of plants do effectively assimilate nutrients from greywater. There was an increase in total N and total P in biomass measurements of T. huegelii leaves, roots and tubers during the course of the investigation. Sixteen percent of the greywater input N and 3% of input phosphorus was incorporated in plant tissue Two further experiments were conducted using different environmental conditions for the plants. A comparison was made between root zone and complete pond conditions, with loading rate and retention times both doubled in some tanks. We found that more nutrients were absorbed by the plants in the pond system, with greater differences in nitrogen levels in the leaves (X2) than in under-ground roots and tubers (X 1.6). Plants in ponds with the highest nutrient loading (10 1 tanks) demonstrated the greatest growth and nitrogen gain, while tanks having the longest retention time (5 1 tanks) had proportionally more N and P retention.

85. Mars, R., K. Mathew, and G. Ho. **"The Role of the Submergent Macrophyte Triglochin Huegelii in Domestic Greywater Treatment".** Ecological Engineering. v12 (1999): 57-66.

Peer Reviewed: YES

Conventional reedbeed systems, which are used in wastewater treatment, are little more than monocultures of Phragmites, Baumea, Water Hyacinth (Eichornia crassipes), Typha or Schoenoplectus. Pond systems, employing a wider range of species, are a means to recycle more nutrients, improve treatment potential and mirror natural ecosystems in ways to sustain the ecosystem. Species of Triglochin, commonly known as water ribbons throughout coastal Australia, are fast-growing submergent macrophytes which seem to be adapted to high nutrient concentrations. In Western Australia, Triglochin huegelii is mainly a submergent plant but its leaves tend to float on the surface in shallow waterways and it has been found seasonally in some ephemeral swamps and lakes. As water recedes, the leaves become emergent. Initial studies using T. huegelii in wastewater treatment experiments has shown that Triglochin has consistently higher concentrations of nitrogen and phosphorus than Schoenoplectus validus, an emergent commonly used for wastewater nutrient stripping, in all parts of the plant -- leaves, tubers and roots. In some cases, such as in the leaves, twice as much nitrogen and one and a half times more phosphorus is assimilated in the Triglochin tissue. It is also likely that T. huegelii will remove nitrogen and phosphorus at a greater rate than many other types of aquatic macrophytes. The implication is that instead of only planting the perimeter of lagoons, artificial wetlands and constructed basins we should be planting the bulk of the waterway with submergent species such as Triglochin spp. which may be far more effective in stripping nutrients than emergents currently used for that purpose.

86. Meyers, C. **"Water Recycling in California".** Water Conservation and Recycling. v19.2 (1996): 14-15.

Peer Reviewed: NO

The reuse of treated wastewater is becoming increasingly accepted and wide spread in arid areas of the souther United States, as a means of reducing dependency on imported water from other areas. This paper reviews some of the options currently being put into practice in California.

87. Mitchell. G., S. Gray, B. Shipton, R. Woolley, J. Erbacher, G. Egerton, and J. McKnoulty. **"Evaluating Integrated Urban Water Systems Alternatives for Brisbane, Australia".** Water Science and Technology. v47.7-8 (2003): 1–9.

Peer Reviewed: YES

The Brazil Development Study investigates the feasibility of alternative approaches to providing sustainable water services to a 226 ha mixed residential and industrial greenfield development within the city of Brisbane, Australia. The alternatives include techniques such as the use of rainwater tanks, water use efficiency, a local wastewater treatment plant for recycling of reclaimed water and composting toilets amongst others. This paper evaluates a series of urban development scenarios against the objectives of the study. The insights gained into the drivers for cost and environmental impact for this particular site are discussed as well as a number of issues of concern and challenges to Council and the community.

88. National Association of Plumbing-Heating-Cooling Contractors. **"Assessment of On-site Graywater and Combined Wastewater Treatment and Recycling Systems".** . National Association of Plumbing-Heating-Cooling Contractors (NAHPCC). 1992.

Peer Reviewed: NO

America is facing a critical water supply shortage because of population and economic growth, persistent drought conditions, and a lack of adequate planning for future water needs. This is evidenced by current efforts in many states, as well as semi-arid and arid areas, to adopt strict standards for water conservation. In addition, an increasing number of communities are imposing sewer moratoriums or sewer capacity restrictions. Historically, public policy, and health codes have mandated centralized collection and treatment of all wastewater. On-site wastewater treatment and recycling systems have been allowed only in very few instances. Some of these systems involve segregation of individual waste sources into dual piping systems -- graywater and blackwater. Graywater generally is defined as used water generated by clothes washing machines, showers, bathtubs, and sinks. Blackwater is water that is flushed down toilets and urinals. Many states and counties currently are reexamining their policies and codes regarding on-site wastewater treatment and recycling due to a variety of factors: persistent drought and water shortages, lack of adequate wastewater treatment and disposal facilities, and growing emphasis on demand-side management strategies. Finding additional water supplies and expanding existing wastewater treatment plant capacity is expensive, sometimes impractical and, at best, involves long range planning. Fortunately, solutions are available which can reduce water consumption and peak demand in environmentally acceptable manner. A number of devices can help water users reduce consumption and demand without any appreciable impact on lifestyles. Typical of these are low-flow toilets, low-flow shower heads, and faucet flow restrictors. Generally speaking, these have been well received and have become steadily more popular as the cost of municipal water has risen. Further reductions can be achieved through the use of on-site wastewater treatment and recycling systems that permit reuse of graywater or combined wastewater for landscape irrigation and toilet and urinal flushing. As an example, in the typical household, approximately 34 percent of the water consumed is used in flushing of toilets. The remaining 66 percent of the water for the most part is available for on-site recovery and reuse. On-site wastewater treatment and recycling systems can be used in all types of residential and commercial buildings and in most types of institutional and industrial buildings. To develop a better understanding of on-site wastewater treatment and recycling technology (including associated costs), regulatory and institutional constraints, and health and safety issues, information was obtained form a variety of sources, including the members of National Association of Plumbing-Heating-Cooling Contractors (NAPHCC), manufacturers, suppliers, and various state and local agencies.

89. Neal, J. **"Wastewater Reuse Studies and Trials in Canberra".** Desalination. v106.1-3 (1996): 399-405.

Peer Reviewed: YES

Reuse of sewage effluent has the potential to both minimize the disposal of water to the environment and reduce the demand on fresh water supplies. In Canberra the Australian national capital city, trials are being undertaken to demonstrate the practicalities of reuse. The first referred to as "water mining" consists of a small treatment plant constructed within the urban environment which extracts flows from an adjacent sewer and uses the treated effluent for the irrigation of nearby playing fields. In the second project, six houses have been disconnected from the city sewerage system and each provided with its own treatment plant. Effluent is stored in tanks on-site and used for garden and lawn irrigation and toilet flushing. The third project also involves a house disconnected from the sewerage system. The blackwater and greywater strains are kept separate. A low-cost process has been devised for the treatment of the greywater stream with effluent again used for irrigation and toilet flushing.

90. Noah, M. **"Graywater Use Still a Gray Area".** Small Flows Quarterly. v 2.1(2001): 20-23.

Peer Reviewed: NO

As clean water resources become more scarce, the concept of separating graywater from a home's waste stream and using it to supplement the family's water demand grows increasingly popular. Graywater is generally defined as all wastewater generated from household activity except that produced from the toilet. Reuse is an integral part of ecosystem management. Reuse and recycling efforts are looked upon with favor these days, and the concept of reusing graywater seems to hold much potential. However, due to the possibility of disease transmission, the actual process of permitting safe, low-maintenance systems can be quite complex. In arid parts of the U.S., the practice of using graywater for irrigation has a long history. To be sure, more than a few pioneer women's chores included marching out into the yard to dump their dishpans of water on some struggling little rosebush. This was graywater use at its most basic. And while graywater use is common in rural areas and has been practiced by many people in urban areas for years, it is technically illegal in many places in the U.S. Water Conservation; Recycling; Water Reuse; Greywater; Domestic Water; Irrigation Water; Diseases; Public Health

91. Nolde, E. **"Greywater Reuse Systems for Toilet Flushing in Multi-story Buildings - Over Ten Years Experience in Berlin".** Urban Water. v1:4 (December 1999): 275-284.

Peer Reviewed: YES

Water reuse in Germany has gained in significance in the last 10 years. Several greywater systems, built according to guidelines introduced in 1995, operate today with no public health risk. Two greywater treatment systems are described in this paper: a rotary biological contactor (RBC) built in 1989 for 70 persons, and a fluidized-bed reactor for a one-family household built in 1995 as the biological stage for the treatment of household greywater for use in toilet flushing. Both systems were optimized in the following years with consideration of a minimal energy and maintenance demand. As numerous investigations have shown, biological treatment of the greywater is indispensable in order to guarantee a risk-free service water for reuse applications other than potable water.

92. Okun, D.A. **"Distributing Reclaimed Water Through Dual Systems".** Resource Management. v89.11 (1997): 52-64.

Peer Reviewed: NO

Growing urbanization has put a heavy demand on limited sources of water for public community water supply systems. A proven conservation measure to help meet increasing demand is the reclamation of wastewater for nonpotable purposes. Reclaimed water can be used for landscape and recreational grounds irrigation, industrial processes, cooling towers, air-conditioning, stack gas scrubbing, toilet flushing, construction, firefighting, and environmental enhancement such as maintaining urban stream flows and wetlands. Urban reuse requires dual distribution systems that use one system for potable water and another for reclaimed water. Dual systems are particularly appropriate for urban developments now being planned, but they can prove cost-effective even for systems that must be retrofitted. The economies arise from savings in the acquisition and development of new water sources and facilities and in wastewater treatment and disposal. Because the public health risk from nonpotable reuse is minimal, public acceptance is high and even enthusiastic. Nonpotable urban reuse is an option worth consideration by municipalities seeking additional water supply to meet future demands.

93. Oldenburg, M., A. Albold, J. Niederste-Hollenberg, and J. Behrendt. **"Experience With separating Wastewater Treatment Systems: The Ecological Housing Estate- Luebeck, Flintenbreite".** Proceedings of the Ninth International Conference on: Urban Drainage. American Society of Civil Engineers (2002): 1-12.

Peer Reviewed: NO

The separation of wastewater treatment system, based on the closing of the water and the nutrient cycle nearly separated from each other, in a ecological housing estate was discussed. The wastewater treatment was separated into blackwater, graywater and stormwater and the emission rates of the graywater treatment was found to be less than conventional plants. The analysis showed that the separation of wastewater system in a housing estate was more cost effective than other systems.

94. Oliver, L, T. Zakharova, A. Konopka, and R.F. Turco. **"Sodium Hypochlorite Perturbation of a Graywater Treatment System".** Journal of Industrial Microbiology & Biotechnology. v24. 3 (Mar 2000): 191-97.

Peer Reviewed: YES

A novel graywater treatment system consisting of an aerated batch reactor and biomass-retaining ultrafiltration unit was evaluated for treatment of shipboard wastes. The focus of this study was to determine the resilience of the biomass recycle reactor to perturbations of sodium hypochlorite, the major component of bleach. A bench-scale reactor was perturbed with 50, 190, and 1000 mg L super(-1) sodium hypochlorite and monitored for changes in respiration, substrate utilization, viable plate counts, fatty acid methyl ester profiles, and Biolog-GN patterns. Following the addition of hypochlorite, respiration and substrate utilization were not detected, and viable biomass decreased. Recovery times following perturbations were longer with higher concentrations of sodium hypochlorite. Community composition (determined by fatty acid methyl ester analysis) changed during the recovery from hypochlorite perturbations. However, more significant differences in community composition were noted between different perturbations and were a function of time. Irrespective of initial community composition, the reactor communities recovered from hypochlorite perturbations. Biolog patterns showed no notable change in the overall metabolic capacity of the community. The biomass recycle reactor's resistance to sodium hypochlorite perturbations contributes to its usefulness in treatment of shipboard wastes.

95. Osburn, R.C., and C.E. Burkhead. **"Irrigating Vegetables With reclaimed Wastewater".** Water Environment and Technology. v4.8 (1992):38-43.

Peer Reviewed: NO

A study was conducted to evaluate the possibility of using the Lawrence, Kans., wastewater treatment plant secondary effluent to irrigate vegetables. The test plot was divided into 16 individual subplots. Each irrigation type and water quality was randomly assigned, with four replicates of each: sprinkle irrigation using tap water, sprinkle irrigation using tap water, sprinkle irrigation of secondary effluent, drip irrigation of tap water, and drip irrigation of secondary effluent. Cucumber and eggplant were selected for the study. Overall, secondary effluent did not affect yields. Sprinkle irrigation of cucumber and eggplant produced larger yields on a lb/row foot basis. Sprinkle irrigation during the heat of the day has a cooling effect on crops and, in this study, rotary sprinkle irrigation improved yields by reducing vegetable heat stress. No significant differences were found in marketable yield between tap water and secondary effluent irrigated cucumber or eggplant. Rotary sprinkle irrigation produced significantly higher marketable yields (lb/ft) of cucumber and eggplant. Marketable yields (lb/gal) were significantly higher for drip irrigation of cucumber. Thus, if irrigation water supplies are scarce or expensive, effluent drip irrigation may be advantageous. There were no significant differences in marketable yields (lb/gal) for eggplant. Rotary sprinkle irrigation using secondary effluent produced significantly higher plant mass of cucumber and eggplant. Both irrigation type and water quality affected plant development. Water quality affected plant mass but not yield. Only slight irrigation use restrictions were found for secondary effluent. Irrigation with secondary effluent increased soil nitrogen and phosphorus levels. Operating the secondary effluent irrigation systems required more maintenance than tap water irrigation systems. Drip irrigated pots could be harvested 1 day after irrigation. The limited soil wetting reduced weed growth between rows and allowed quicker access into the plots for weeding. In addition, drip irrigation did not wash off insecticides and fungicides applied to the vegetables. Rotary sprinkle irrigation required 44% additional water for operation than drip irrigation. Further evaluation of the chemical and biological constituents in the secondary effluent and continued investigation of the ideal crop(s) to irrigate in Kansas is needed.

96. Otterpohl, R., A. Albold, and M. Oldenburg. **"Source Control in Urban Sanitation and Waste Management: Ten Systems With Reuse of Resources".** Water Science and Technology. v39.5 (1999): 153-160.

Peer Reviewed: NO

This paper is a follow up of one presented by Otterpohl et al. (1997) in Water Science & Technology. This extension emphasises the responsibility of the professionals in waste- and wastewater management for future development. It shows a list of 10 technological options for sanitation with source control. The political discussion about future sanitation systems seems to lack input of those working on further development. Even Agenda 21 is a complete failure in this respect -- sadly, in a core subject for survival of future generations. The main task of sanitation besides highest hygienic standards is to keep soil fertile. Sanitation with the mixing up of food and water cycles washes all those substances out to the seas that are extremely harmful there (accumulation) and extremely necessary on the land (depletion of fertility and fossil resources). New integrated sanitation and waste management systems will mostly have to respect different qualities of matter from human settlements: blackwater with biowaste, greywater, stormwater runoff and stormwater runoff and non-biodegradable waste. Based on this distinction, nine differentiating and one mixing system with resources management are presented. Some of them require careful examination in selected pilot projects.

97. Otterpohl, R., M. Grottker, and J. Lange. **"Sustainable Water and Waste Management in Urban Areas".** Water Science and Technology. v35.9 (1997): 121-133.

Peer Reviewed: NO

Sewerage system and centralised aerobic wastewater treatment plants (WTP) should not be considered as the only possible solution for sanitation. Systems with source control can avoid many problems of the end-of pipe technology by respecting different qualities of wastewater and by treating them appropriately for reuse. Different qualities of waste and wastewater in human settlements and appropriate treatment technologies can be 1. low diluted faeces with/without urine and bio waste (composter or anaerobic digester), 2. grey water/aerobic biofilm plant, 3. storm water (usage and infiltration) and 4. non-biodegradable waste (reuse as raw material). In order to perform resource management, the material originating from agriculture should be returned to the soil as fertiliser. Of similar importance is the organic material. This helps maintaining or building up humus and creates a sink for carbon when the C-content in the soil is increased. Energy will be saved too: energy-intensive aerobic with nitrification is obsolete as well as the production of the respective amount of replaced artificial fertiliser. A pilot project for a new settlement for about 300 inhabitants in Lubeck, Germany, shall demonstrate the feasibility of a new integrated system with vacuum toilets and pipes for the collection of black water. This will be mixed with shredded bio waste and fed to a semicentralised biogas plant that produces liquid fertiliser without dewatering. Grey water will be treated in decentralised biofilm systems. Storm water is collected, retained, and infiltrated in a trench system. This way the expensive centralised sewerage system can be avoided for this settlement.

98. Otterpohl, R., M. Oldenburg, and J. Zimmermann. **"Integrated Wastewater Disposal for Rural Settlements".** Wasser und Boden. v11 (1999): 10-13.

Peer Reviewed: YES

Conventional wastewater systems are not designed for re-use of the contents. Evaluation of wastewater characteristics shows a distribution of contents that indicates a good opportunity for source control of toilet wastewater. This requires toilet systems with low dilution: vacuum toilets, compost toilets or separating toilets. The flows produced are blackwater (toilet wastewater), brownwater (blackwater without urine) and yellow water (urine). There are a number of treatment scenarios. One which is especially advantageous for rural areas stores yellow water while brownwater is dewatered and composted in a two chamber tank with a sieve. The latter assures retention times of a year or more until chambers are switched. Water percolating through the compost should be poor in nutrient (soluble nutrients are in the yellow water) and can be treated with greywater (wastewater without blackwater). This concept will be researched in a pilot project and can also be integrated into regional planning.

99. Ottosson, J., and T. Stenstroem. **"Growth and Reduction of Microorganisms in Sediments Collected Froma Greywater Treatment System".** Letters in Applied Microbiology. v36.3 (March 2003): 168-72.

Peer Reviewed: YES

To study the effects of competitive microbiota, temperature and nutrient availability on Salmonella, Enterococcus, Campylobacter spores of sulphite reducing anaerobes and bacteriophages MS2 and Phi X174 in sediments from a greywater treatment system. Standard culture methods were used. Bacteria died off rapidly under normal conditions (20 degree C, competitive microbiota) but remained stable or grew in the other conditions studied. When the sediments became nutrient depleted after 2 weeks, a log-linear die-off was observed for Salmonella, which was higher at 20 degree C than at 4 degree C. Bacteriophage decay was shown to be log-linear from day 0, with T sub(90) values ranging from 9 (Phi X174, 20 degree C) to 55 days (Phi X174, 4 degree C). The MS2 phage had a significantly higher decay rate in tyndallized sediments (T sub(90)=17 days) than in original sediments (T sub(90)=47 days) (P < 0.001), with temperature not shown to affect the decay rate. Spores of sulphite-reducing anaerobes were not significantly reduced during the study period (35 days). Campylobacter died-off rapidly or entered a viable but non-culturable state and subsequently results were not provided. Competition was the most important factor to suppress pathogenic bacterial growth in an eutrophic environment. When nutrient depleted conditions prevailed, temperature was more important and log-linear decay of microorganisms could be observed. These findings suggest that the normally occurring microbiota will suppress pathogenic bacterial growth in nutrient rich sediments. With lower nutrient status, temperature is the more important factor in reducing pathogens

100. Ottosson, J., and T.A. Stenstroem. **"Faecal Contamination of Greywater, and Associated Microbial Risks."**. Water Research. v37 (2003): 645-655.

Peer Reviewed: YES

The faecal contamination of greywater in a local treatment system at Vibyaasen, north of Stockholm, Sweden was quantified using faecal indicator bacteria and chemical biomarkers. Bacterial indicator densities overestimated the faecal load by 100-1000-fold when compared to chemical biomarkers. Based on measured levels of coprostanol, the faecal load was estimated to be 0.04 g person[super]-1 day[super]-1. Prevalence of pathogens in the population and the faecal load were used to form the basis of a screening-level quantitative microbial risk assessment (QMRA) that was undertaken for rotavirus, Salmonella typhimurium, Campylobacter jejuni, Giardia lamblia and Cryptosporidium parvum. The different exposure scenarios simulated--direct contact, irrigation of sport fields and groundwater recharge--gave unacceptably high rotavirus risks (0.04greywater is suggested. Somatic coliphages can under extreme circumstances replicate in the wastewater treatment system and thereby underestimate the virus reduction. An alternative QMRA method based on faecal enterococci densities estimated similar risks as for rotavirus. Growth conditions for Salmonella in greywater sediments were also investigated and risk modelling based on replication in the system increased the probability of infection from Salmonella 1000-fold, but it was still lower than the risk of a rotavirus infection.

101. Parker, L. **"From Pikes Peak to Mars".** Civil Engineering (New York). v 70.4 (April 2000): 44-45,69.

Peer Reviewed: NO

To keep pace with swelling global population and shrinking water supply, water conservation and reuse projects are being implemented at an ever-increasing rate. One such project is designing a water reuse system to serve a visitors' center and a nearby laboratory atop Pikes Peak, Colorado. The system will use an immobilized cell bioreactor, reverse osmosis membranes and other disinfection units to treat graywater.

102. Prillwitz, M. **"Making Graywater Profitable for You: New Business Opportunities for Irrigation Professionals".** Fifteenth International Irrigation Exposition & Technical Conference Proceedings; Where Technology Gets Down to Business. Atlanta, GA . November 5-8, 1994

Peer Reviewed: NO

The use of graywater is now legal everywhere in California. This paper discusses the evolution of the graywater Standards, how the standards affect the use of graywater, the benefits of graywater use, the future of graywater in California and the country, and how irrigation professionals can benefit from this new business opportunity.

103. Prillwitz, M., and L. Farwell. **"Graywater Guide: Using Graywater in Your Home Landscape".** California Department of Water Resources.

Peer Reviewed: NO

California's graywater Standards are now part of the State Plumbing Code, making it legal to use graywater everywhere in California. These standards were developed and adopted in response to Assembly Bill 3518, the graywater Systems for Single Family Residences Act of 1992. This Guide was prepared to help homeowners and landscape and plumbing contractors understand the graywater Standards and to help them design, install and maintain graywater systems.

104. Prillwitz, M., and L. Farwell. **"Graywater: It's Legal Not Lethal".** Proceedings of Conserv 96: Responsible Water Stewardship. Orlando, FL . January 4-8, 1996.

Peer Reviewed: NO

This paper describes the legalization of gray water in California and the steps that the community went through to develop a gray water standard and a gray water guide. After the community recognized that thousands of bootleg gray water systems were in use, there was a need to provide guidance and legal avenues for use to better protect public health and provide a means to augment the current water supply. A committee adopted gray water standards, based on public comments and extensive data collection and several public meetings. The California Gray Water Standards were published in the California Plumbing Code, May 9, 1994, making them effective statewide November 9, 1994. The Department of Water Resources has also developed a Gray Water Guide. This guide is designed to help people understand the Gray Water Standards and to make the design, installation, and maintenance process as simple as possible. The primary audience for this guide is the homeowner. Seven steps for using gray water are given in the guide including: permitting process, information sources, system design, installation, inspection, and maintenance.

105. Rababah, A.A., and N.J. Ashbolt. **"Innovative Production Treatment Hydroponic Farm for Primary Municipal Sewage Utilisation".** Water Resources. v34.3 (2000): 825-834.

Peer Reviewed: YES

The objectives of this work were to investigate a conceptual layout for an inexpensive and simple system that would treat primary municipal wastewater to discharge standards. Furthermore, the system may provide an increased supply of safe water for irrigation with low operational costs and produce commercially valuable plants for small communities in arid and semi-arid areas. A commercial hydroponic system was adapted for this study and consisted of five gullies, 3 m long by 100 mm wide. Primary treated effluent was used to irrigate lettuce in one series and a commercial nutrient solution was used to irrigate the same type of lettuce in another series as a control, both by nutrient film technique (NFT). Nutrient and suspended solids were efficiently removed by the NFT plant system. While no uptake of F-RNA bacteriophages were detected within lettuce leaves, uptake was apparent from spiked virus-sized particles (fluorescent 0.1 micrometer microspheres) and equivocal from spores of the faecal bacterium, Clostridium perfringens. Microbial data was used in a Beta-Poisson dose response model and indicated that the probability of infection for a single ingestion event of NFT grown lettuce grown on primary treated municipal effluent was about 1.7% for viruses. Moreover, plants accumulated heavy metals in leaf tissues at concentrations higher than the maximum recommended levels for Australian and new Zealand food (As=6.5, Cd=3.8, Pb=20 mg kg(super)-1). Hence, it is recommended to evaluate ornamental or non-edible crops, such as essential oils, pyrethrum or flowers for sewage treatment. A conceptual layout for a full-scale production treatment hydroponic farm (PTHF) for small communities was based on modelling phosphorus removal with the hydroponic NFT experimental pilot plant. With NFT culture of lettuces, roots and other surfaces accounted for 67-72% of total phosphorous (TP_ removal (by adsorption mechanisms). Based on empirical modelling, an influent TP 2-6 mg 1(super)-1. PTHF would be expected to be economical for small communities (<400 people) and produce effluent with TP <0.15 mg 1(super)-1, SS <2.5 mg 1(super)-1 and BOD <55 mg 1(super)-1. Lower values would be expected if the effluent was polished through a humus filter.

106. Rockefeller, A., and C. Lindstrom. **"Greywater for the Greenhouse".** Compost Science. v18.5 (1977): 22-25.

Peer Reviewed: NO

This paper describes how a greenhouse can close the cycle of organic waste conversion/water purification/food production. The description is based on an arrangement consisting of a Clivus Multrum, a Lindstrom roughing filter and a lean-to greenhouse. The critical aspects for this paper are deep soil boxes in the greenhouse, an irrigation/purification interaction between the greywater and soil boxes, and a rock storage under the greenhouse floor for heating and cooling. The Clivus converts kitchen and soil wastes to humus soil for use in growing beds. Wastewater passes through a stone roughing filter and then is pumped into the greenhouse soil boxes through leach pipes that lie 2-3" under the soil. The soil mix consists of 1/2 homemade leafmold and 1/2 commercial topsoil. At the bottom there is a 2"layer of crushed rocks, topped by 1/4" mesh, which is topped by 1"of 1/2" stones. The soil boxes have drains at the low end of a slightly sloping bottom. This system provides a water purification system and a method to irrigate and fertilize plants.

107. Rose, J.B., Sun, Gwo-Shing; C.P. Gerba, and N.A. Sinclair. **"Microbial Quality and Persistence of Enteric Pathogens in Graywater**

FromVarious Household Sources". Water Research. v25.1 (1991): 37-42.

Peer Reviewed: YES

This study is on - graywater microbial quality, safety and chemical composition. - Reuse application. - Sample sources from shower/bath, wash and rinse cycles of laundry units over a period of 2-3 months time period. - Dealt with families with children (1 ½ - 9 years) and without. - Analysis yielded standard plate count bacteria (SPC) for shower/bath as10 super(5) to 10 super(10) colony forming units (cfu) per 100ml, and averaged 10 super(4) to 10 super(6) cfu/100ml for total coliforms. Only wash cycle from families with children gave 10 super(6)cfu/100ml of fecal coliforms.

108. Rudolph, K.U., and D. Schaefer. **"Alternative Water Systems (AWS) With Examples From Japan".** KA - Wasserwirtschaft, Abwasser, Abfall. v49.12 (2002): 1667-73.

Peer Reviewed: YES

Alternative Water Systems" (AWS) is not a new topic. Of growing importance are membrane technologies and water saving installations. Modifications of the conventional water system (= centralised pressurised pipe supply with disposal via gravity sewers), leading to semi-centralised or fully decentralised schemes, often focused on triple wastewater collection and dual water supply with grey water recycling, rainwater harvesting and the utilisation of sewage as fertilisers and biogas production - up to multi utility schemes (water + wastewater + solid waste + power supply). Japan, Australia, Germany and Canada are some of the countries, where many AWS activities and high-tech innovations were found. The paper presents among other examples the Ohtemachi Financial Centre, Tokyo, where greywater is reused. Low-tech concepts, able to serve the poor, are emerging in developing countries and rural areas. In future, it is necessary to further improve and demonstrate the economic sustainability and technical reliability of holistic AWS concepts.Original Abstract: Das Thema "Alternative Wassersysteme" (AWS) ist keineswegs neu. Zunehmend diskutiert werden sowohl neue Technologien (z. B. Membrantechnologie), wassersparende Installationen als auch Veraenderungen des bestehenden zentralen Systems mit Schwemmkanalisation hin zu semizentralen oder dezentralen Loesungen mit der Abtrennung und dem Recycling von Teilstroemen (Grauwasserrecycling, Naehrstoffrecycling, Energiegewinnung etc.). Die am haeufigsten verfolgten Grundideen betreffen die Wasserverwendung und Abwasserproduktion (z. B. Trenntoiletten, die eine getrennte

Behandlung und Verwertung von Faekalien und Grauwasser ermoeglichen), die weitergehende Abwasserbehandlung zwecks Recycling und den Querverbund von Wasser/Abfall/Energie in einem integrierten System. Neben Australien, Deutschland und Kanada ist insbesondere Japan ein Land, aus dem viele Innovationen zu "High-Tech"-Ansaetzen kommen. Hier wird u.a. die Recyclinganlage des Ohtemachi Financial Centers in Tokio vorgestellt. "Low-Tech"-Konzepte entstehen vor allem in Entwicklungslaendern und dem laendlichen Bereich. Fuer die Zukunftsentwicklung geht es um die Demonstration der Wirtschaftlichkeit und Betriebssicherheit von Konzepten, welche den langfristig orientierten, oekologischen Notwendigkeiten genuegen.

109. Sadovski, Fattal, Goldberg, Katzenelson, and Shuval. **"High Levels of Microbial Contamination of Vegetables Irrigated With Wastewater By the Drip Method".** Applied and Environmental Microbiology. v36.6 (1978): 824-830.

Peer Reviewed: YES

The public health aspects of the use of wastewater in agriculture and the effects of the drip irrigation method on the contamination of vegetables were studied. The method used was to simulate enteric microorganisms' dissemination by contaminated irrigation water in the field. The vegetables were irrigated with an effluent inoculated with a high titer of traceable microorganisms: poliovirus vaccine and a drug-resistant Escherichia coli. The dissemination of the marker organisms in the field was followed, and the effects of certain manipulations of the drip irrigation method on the contamination of the crops by the effluent were examined. It was shown that drip irrigation under plastic sheet cover with the drip lines placed either on the soil surface or buried at a depth of 10 cm significantly reduced crop contamination from inoculated irrigation water even when massive doses of bacteria and viruses were used. The microbial contamination was found to persist in the irrigation pipes and in the soil for at least 8 and18 days, respectively. The data indicate that the recovery of the marker organisms was affected by soil texture and environmental conditions.

110. Schaub, S.A., H.T. Bausum, and G.W. Taylor. **"Fate of Virus in Wastewater Applied to Slow-infiltration Land Treatment Systems".** Applied and Environmental Microbiology. v44.2 (1982): 383-394.

Peer Reviewed: YES

The removal of seeded coliphage f2 and indigenous enteroviruses from primary and secondary wastewaters applied by spray irrigation to sandy loam and silt loam soils in field test cells was examined. The amount of f2 recovered from 170-cm deep soil percolate samples taken over a 53 day period never exceeded 0.1% of applied virus levels and was usually below detection limits. Indigenous enterovirus levels in percolate waters also constituted only a small portion of those found in the wastewaters. At 10 days after seeding. f2 virus was present throughout the soil column but tended to accumulate around the soil core middepths. Coliphage f2 disappeared from the soil surface regions at a high rate, and by 53 days very little virus could be detected within the length of the soil columns. Sterilized soil core segments from different depths were studied to determine their virus adsorption capabilities when suspended in either wastewater, test cell percolate water, or distilled water containing divalent cations. The adsorptive capacity of Windsor and Charlton soils for poliovirus 1 and coliphage f2 increased greatly with the soil sample depth until leveling off at the midcore depths. Soil suspended in wastewater had the least virus adsorption capability for all depths studied.

111. Schonborn, A., B. Zust, and E. Underwood. **"Long term performance of the sand-plant-filter schattweid (Switzerland)".** Water Science and Technology. v 35.5 (1997):307-314.

Peer Reviewed: NO

The human waste concept of the Centre for Applied Ecology Schattweid, Switzerland combines treatment of feces in compost toilets and a constructed wetland for the liquid wastes. The wastewater of 5.1 population equivalents (greywater and urine) is treated in a two chambered settling tank followed by an underground vertical flow sand filter and a horizontal flow constructed wetland. The wastewater system has been in operation since 1985. Its performance has been monitored on COD, NH4-N, NO2-N, Total P and Total-N almost monthly since then, and on other parameters (Total-Fe, Cl) occasionally. COD elimination (91.4%) and Total-P removal (90.6%) were stable over the years, whereas NH4-N and Total-N elimination have improved markedly from around 55% to 93.0% (NH4-N) carbon source to the plant filter in summer 1991 led to a markedly decreased phosphorus retention and a washout of iron during the experiment.

112. Shin, H.S., S.M. Lee, I.S. Seok, G.O. Kim, K.H. Lim, and J.S. Song. **"Pilot-scale SBR and MF Operation for the Removal of Organic and Nitrogen Compounds From Greywater".** Water Science and Technology. v38.6 (1998): 79–88.

Peer Reviewed: YES

A pilot plant of SBR (Sequencing Batch Reactor) and MF (microfiltration) process was operated in order to treat and reuse the greywater produced from an office building. The performance of SBR for greywater was satisfactory as the effluent had 20 mg/l, 5 mg/l, and 0.5 mg/l of SCOD, BOD, and ammonia, respectively. The cyclic operation of SBR used in this study proved more effective in nitrification and denitrification than the conventional SBR operation. However, the most effective mode was step-feed SBR for denitrification. The decanting system of this SBR discharged the effluent fairly well without sludge washout. However, it was difficult to maintain constant concentration of suspended solid from the SBR process. Thus, additional filtration was needed to get adequate water quality for water reuse. MF could remove residual suspended solids and pathogens as well from the SBR effluent. The suspended solids of final effluent were around 1 mg/l and allowed using the treated water for some purposes.

113. Shrestha, R.R, R. Haberl, and J. Laber. **"Constructed Wetland technology transfer to Nepal".** Water Science and Technology. v43.11 (2001): 345-350.

Peer Reviewed: YES

Constructed Wetland (CW) technology is still not wide spread in developing countries despite having great potential. This paper describes an approach carried out in Nepal to transfer CW technology for wastewater treatment. Three CWs (hospital wastewater treatment - 20 m super(3)/d, greywater treatment of a single household, septage treatment - 40 m super(3)/d) were built and two have been investigated so far. All systems are subsurface flow systems with at least one vertical flow stage. Their treatment efficiency turned out to be very high. Median load elimination rates of the hospital wastewater and greywater treatment plants were for TSS: 97 to 99%; BOD sub(5): 97 to 99%; COD: 94 to 97%; NH sub(4)-N 80 to 99%; PO sub(4)-P: 5 to 69%; Total Coliforms: 99.87 to 99.999% (3-5 log steps). Beside the treatment task the plants play an important role as demonstration sites to make common people and especially decision makers aware of the existing environmental problems and one possible solution. Several recommendations are pointed out to promote the technology in developing countries.

114. Shrestha, R.R., R. Haberl, J. Laber, R. Manandhar, and J. Mader. **"Application of constructed wetlands for Wastewater Treatment in Nepal."**. Water Science and Technology. v44.11-12 (2001) 381-386.

Peer Reviewed: YES

Surface water pollution is one of the serious environmental problems in urban centers in Nepal due to the discharge of untreated wastewater into the river-system, turning them into open sewers. Wastewater treatment plants are almost non-existent in the country except for a few in the Kathmandu Valley and even these are not functioning well. Successful implementation of a few constructed wetland systems within the past three years has attracted attention to this promising technology. A two-staged subsurface flow constructed wetland for hospital wastewater treatment and constructed wetlands for treatment of greywater and septage is now becoming a demonstration site of constructed wetland systems in Nepal. Beside these systems, five constructed wetlands have already been designed and some are under construction for the treatment of leachate and septage in Pokhara municipality, wastewater in Kathmandu University, two hospitals and a school. This paper discusses the present condition and treatment performance of constructed wetlands that are now in operation. Furthermore, the concept of the treatment wetlands under construction is also described here. With the present experience, several recommendations are pointed out for the promotion of this technology in the developing countries.

115. Siegrist, R., M. Witt, and W. C. Boyle. **"The Characteristics of Rural Household Wastewater".** Journal of the Environmental Engineering Division. v102.EE3 (1976) :533-548.

Peer Reviewed: YES

The characteristics of waste flows from individual households can have a profound effect on the performance of individual household treatment and final disposal methods. Various water use events within a home create an intermittent flow pattern of wastes that vary widely in strength and volume. In order to study and improve individual treatment and disposal alternatives effectively, quantitative and qualitative characterization of household wastewater is necessary. The field analyses on wastewater characteristics were accomplished in two phases: (1) Water use (wastewater production) characterization; and (2) wastewater quality characterization. Conclusions: 1. The water usage in 11 rural homes was monitored for a total of 434 days yielding an average flow of 42.6 gal/capita/day (161.0 1/capita/day) with a 90% confidence interval of 40.8 gal/dapita/day-44.4 gal/capita/day

(154.2 1/capita/day--167.81 1/capita/day). 2. Monday was found to have the highest average flow with 49.7 gal/capita/day (187.8 1/capita/day), while Friday had the lowest with an average of 37.5 gal/capita/day (141/81 1/capita/day). 3. Of the 42.6 gal/capita/day measured, the individual events contributed the following : (a). Laundry--10.5 gal/capita/day--24.7%; (b) bath/shower--10.0 gal/capita/day--23.5%; (c) dishwashing--4.9 gal/capita/day--11.4%; (e) water softeners--2.6 gal/capita/day--6.2%; and (f) Others--5/4 gal/capita/day--12.7%. 4. The average size of the events in these households was found to be: (a) Clothes washer--33.5 gal; (b) bath/shower--21/4 gal; (c) toilet--4.0 gal; (d) dishwashing 12.5 gal; and (e) water softeners--81.1 gal. 5. The quality of eight major household events was characterized by obtaining individual samples of each over a 35-day period from four Wisconsin families. 6. Some of the household events were found to contribute a majority of certain pollutants. 77% of the total daily BOD (inf)5 was produced by three events: (a) The total toilet output (21.7%); (b) the automatic dishwasher (25.5%) and (c) the total clothes washer output (29.8%). 54% of the daily total phosphorus was produced by the automatic clothes washer. 7. The average daily contributions of BOD (inf)5, suspended solids, total nitrogen, and total phosphorus were determined to be 0/109 lb BOD (inf)5 /capita/day and 0.009 lb Phosphorus/capita/day. 8. The vast majority of pollutant mass produced by an average household was found to be generated between the hours of 6 a.m. and 9 p.m. with distinct peaks occurring at 9 a.m., 1 p.m., and 7 p.m. 9. Bacteriological analyses indicated wide variation in indicator organisms and the possibility of pathogenic organisms in the bath and laundry wastewaters. Therefore, disinfection prior to reuse is recommended

116. Smith, D.W., and V. Christensen. **"Innovative Approaches to Sewage Collection, Treatment, and Disposal: Practices in Northern Canada".** Canadian Journal of Civil Engineering. v 9 (1982): 653-662.

Peer Reviewed: YES

Some components of the wastewater management systems used in northern Canada have undergone significant changes within the last ten years. The natural and imposed constraints are reviewed with special emphasis on the wastewater characteristics. Wastewater collection through the use of butt-welded polyethylene pipe, individual line service connections, and truck collection are discussed. Improvements in the disposal of undiluted and moderately, conventionally, and greatly diluted wastewater are outlined. The problems and improvements underway wit greywater treatment and disposal are important for the improvement of living conditions. Also, current efforts to increase water conservation are noted

117. Stamper, D.M., M. Walch, and R.N. Jacobs. **"Bacterial Population Changes in a Membrane Bioreactor for Graywater Treatment Monitored By Denaturing Gradient Gel Electrophoretic Analysis of 16S rRNA Gene Fragments".** Applied and Environmental Microbiology. v69.2 (January 2003): 852-860.

Peer Reviewed: YES

The bacterial population of a graywater treatment system was monitored over the course of 100 days, along with several wastewater biochemical parameters. The graywater treatment system employed an 1,800-liter membrane bioreactor (MBR) to process the waste, with essentially 100% recycling of the biomass. Graywater feed consisting of 10% galley water and 90% laundry water, selected to approximate the graywater composition on board U.S. Navy ships, was collected offsite. Five-day biological oxygen demand (BOD sub(5)), oils and greases (O/G), nitrogen, and phosphorus were monitored in the feed and were found to vary greatly day to day. Changes in the bacterial population were monitored by PCR amplification of region 332 to 518 (Escherichia coli numbering) of the 16S rRNA gene and denaturing gradient gel electrophoresis (DGGE) analysis of the resultant PCR products. DGGE analysis indicated a diverse and unstable bacterial population throughout the 100-day period, with spikes in feed strength causing significant changes in community structure. Long-term similarity between the communities was 0 to 25%, depending on the method of analysis. In spite of the unstable bacterial population, the MBR system was able to meet effluent quality parameters approximately 90% of the time.

118. Stone, R. **"Water efficiency program for Perth".** Desalination. v106 (1996): 377-390.

Peer Reviewed: YES

Water efficiency gains have been incorporated as an integral component of the long-term water supply strategy for Perth, Western Australia. This paper describes the development of the proposed water efficiency program for Perth which would reduce the need for additional water supplies by about 23%. The principles and approach used to develop the program are outlined and the economic evaluation of program options presented. The elements of the proposed program and associated research and development are described. Features of the program are an emphasis on water industry participation and structural changes to water use patterns.

119. Surendran, S., A.D. Wheatley. **"Grey-Water Reclamation for Non-potable Re-use".** Water Science and Technology. v133.10-11 (1996):451-462

Peer Reviewed: NO

Direct water recycling has become an important part of water conservation in the dry areas of the world and is now being seriously considered for the UK. This paper reviews current demands in large buildings and balances these against non-potable re-use. Work is also described on the development of a sustainable low running cost treatment unit. Results are presented from a 751/day prototype biological process operated with a synthetic sewage, which achieved a near potable standard at a cost of 25 p/m(super)3. The design performance and costings of a 40 "population equivalent" demonstration unit are also given.

120. Tleimat, B., M. Tleimat, M.A. Friedman, MA; and L. Styczynski. **"The Use of Vapor Compression Distillation for Recycling Graywater as an Early Application in the Antarctic Planetary Analog.".** Desalination. v87 (1992): 97-107.

Peer Reviewed: YES

Gray water is a major fraction of the waste water from small isolated outposts such as Antarctic bases and planned Lunar and Martian bases. Recycling of this water is a key element in a reliable and efficient life support system. This paper describes the design and test of a gray water recycling system based on vapor compression distillation. The Exploration Program group at LMSC funded WRT to test and obtain data on the use of vapor compression distillation for the recovery of distilled water from gray waters.

121. Tleimat, B.W., and M.C. Tleimat. **"Water Recovery From and Volume Reduction of Gray Water Using an Energy Efficient Evaporator".** Desalination. v107. 2 (1996): 111-19.

Peer Reviewed: NO

Tests were made under a contract with VEDA Inc. of Alexandria, Virginia, for the United States Navy, Environmental Protection Branch, Annapolis, Maryland. The objectives of the tests were to demonstrate the use of vapor compression distillation to greatly reduce the storage volume of wastewater on US Navy ships during extended missions, examine the quality of the produced distilled water for reuse, and determine energy requirements for the process. Three 55 gal drums of gray wastewater, shipped from Annapolis, were used in the tests at The Water Reuse Technology (WRT) test facility, Alamo, California. The tests were made in a 3 gal/h vapor compression distillation unit using the energy efficient wiped film rotating disk (WFRD) evaporator. Data were collected to determine recovery, evaporator performance, and distilled water and blowdown qualities. The tests were run at an average temperature of 122 degree F in the evaporator. The results show that recoveries as high as 98.6% are possible. Measured energy consumption by the compressor and rotor (for this small unit) varied from 75 to 90 Wh/gal. Samples of the wastewater, distilled water, and blowdown were collected for analysis. The results of the analysis of the distilled water samples indicate that total suspended solids, fecal coliform, and biological oxygen demand were below the detection limits of the instruments used in the analysis. The chemical oxygen demand varied from below 10 mg/L (detection limit) to 30 mg/L.

122. Truijillo, S., A. Hanson, W. Zachritz, and R. Chancy. **"Potential for Greywater Recycle and Reuse in New Mexico".** New Mexico Journal of Science. v838 (1998): 293-313.

Peer Reviewed: YES

One relatively new on-site, natural alternative to wastewater disposal technique involves segregating the wastes produced in a household into tow types of waste to be treated separately: blackwater and greywater. Blackwater is defined as the wastewater from the toilet and garbage disposal, and greywater includes all the remaining wastewater in the home. Separating the waste allows for more efficient treatment. Treated greywater can supply landscape irrigation for a home. Unfortunately, in most cities around the U.S. greywater recycling is illegal because of outdated state regulations. Due to the decrease in water quality and quantity, many states have been forced to evaluate water conservation alternatives such as greywater recycling. Most current state regulations do not include the alternative of greywater reuse. However, as of March 11, 1995, thirteen states have incorporated greywater reuse into their regulations (NSFC, 1995). This increase shows that progress is being made toward acknowledging greywater as a resource. The State of New Mexico is currently developing regulations for the use of greywater, and interim guidelines are currently available

123. Van Der Hoek, J. P., B. J. Dijkman, G. J. Terpstra, M. J. Uitzinger, and M. R. van Dillen. **"Selection and Evaluation of a New Concept of Water Supply for "IJburg" Amsterdam".** Water Science and Technology. v39.5 (1999): 33–40.

Peer Reviewed: NO

124. Whitney, A., and R. Bennett. **"Monitoring Graywater Use: Three Case Studies in California".** Conserv 99 Water Efficiency: Making Cents in the Next Century. Monterey, CA . January 31-February 3, 1999

Peer Reviewed: YES

California Department of Water Resources (DWR) assisted and cooperated with the City of Santa Barbara and East Bay Municipal Utility District in conducting a two-year study of graywater use for three single family residences from November 1996 to November 1998. DWR's purpose in sponsoring the study was to collect data at single-family sites to determine the benefits, costs, and impacts of graywater use. Data on graywater use, soil quality and water quality were anlyzed in the three case studies. Potential water savings and the impact of graywater on plants and soil was documented. The two local agencies were interested in determining how practical it is to install graywater systems, including capital cost, customer acceptance, and necessary permits, and how graywater would affect soils and landscape quality.

125. Zeeman, G., and G. Lettinga. **"The Role of Anaerobic Digestion of Domestic Sewage in Closing the Water and Nutrient Cycle at Community Level".** Water Science and Technology. v39.5 (1999): 187–94.

Peer Reviewed: YES

Decentralised sewage treatment is more and more considered to be a sustainable way of waste(water) treatment. Three different options for the on-site treatment of sewage in combination with VFY (Vegetable, Fruit and Yard waste) with anaerobic treatment as a central technique are presented. The collection system and therewith the composition and concentration of the sewage will determine the type of anaerobic technology and the process conditions to be applied. Model calculations are made for determining the HRT to be applied in a UASB system at an obliged SRT at a certain temperature.

Section IV

Recommendations for Future Research

Recommendations for Future Research

Examine graywater quality and characteristics.

Factors that influence the quality of graywater dictate the type of treatment technology required and determine the appropriate end use of graywater. These factors need to be defined more clearly in order to develop appropriate guidelines for graywater collection systems and use.

- *Examine the correlation between different types of household compositions activities and graywater quality.*

  Perform a risk analysis to determine how the age and number of occupants of a household influence graywater. Identify those characteristics or activities that would preclude individual households from using graywater.

- *Evaluate the types of detergents that are available for use in both the dishwasher and clothes washing machine*.

  Most modern detergents seem to be safe components of graywater discharge, but some varieties may contain large amounts of salts used as filler or other undesirable additives. Detergents that introduce minimal or no impact on soil quality and plant life should be identified.

- *Determine the appropriate microbial indicators in graywater.*

  How effective are coliform bacteria for indicating pathogen presence? Is there a more effective method?
  What influence do nutrient-rich versus nutrient-poor environments have on organism growth in the systems?
  What are the effective microbial controls for the systems (UV, ozone, minimal radiation)?

- *Determine the optimal storage time for graywater.*

  Holding times should be long enough to allow for some treatment to take place, but not so long that anaerobic degradation starts to take place producing undesirable products and odors.

What are the minimal treatment requirements necessary to extend the storage time of graywater? Can graywater be stored in amounts that will allow for the irrigation of large turf areas?

What is the aeration need, if any, for stored graywater?

Graywater systems are subject to temperature extremes introduced by graywater sources such as bathtub/showers and clothes washing machines. What are the effects of temperature on the system as a whole? How do these temperature extremes influence microbial growth and storage time?

How much does graywater storage influence the establishment/presence of biofilms, especially in toilet flushing reuse/application?

Survey the implementation methods for graywater reuse.

It is important to determine what methods of graywater collection and reuse have been successful and under what conditions. An inventory of collection/treatment methods is necessary for the range of conditions for which graywater use may be applied. Comparative and evaluative research is needed for each protocol. Variables, costs and benefits need to be identified and measured for effectiveness.

- *What are the benefits for individual graywater collection systems versus integrated community systems?*

  Should preference be given to a community system that would allow for residents to travel without the system going idle?

  What is the efficiency of each of these types of systems for removing various constituents, particularly microbial?

  What are the energy requirements of both types systems and how can they be minimized?

  How effective is retrofitting existing residences, businesses, apartments, schools? Is there existing technology that would make retrofits feasible to do on a large scale?

  Is it better to use an active or a passive system? For a given use, what should the treatment process entail?

- *Develop a comparison between graywater systems and on-site wastewater treatment systems.*

  Clear delineation of how both systems utilize reclaimed water is needed to prevent confusion by consumers and decision makers. Appropriateness, advantages, and disadvantages for each option needs to be studied Contributions of the graywater systems to the decentralization of water treatment should be examined.

Examine public awareness and education issues.

The public perception of graywater reuse and its level of acceptability among communities need to be evaluated. It has long been recognized that public perception regarding water quality is a barrier to the adoption and use of not only graywater, but reclaimed water and treated effluent as well. The literature has mostly identified perception as a problem but has not explored the magnitude of opposition nor the means to overcome this negative perception. Research is needed to explore the strength and intensity of opposition and the remedial measures necessary to overcome each.

- *Determine what tools can be used to demonstrate the potential applications of graywater reuse to the public.*

  Beyond printed media, what public education measures will be necessary to insure that homeowners reuse graywater in a safe and appropriate manner? Should local governments take the lead in educating their community about graywater, or rely on the State for public education efforts?

- *Identify the necessary efforts that will need to be made to influence policy and legislation with respect to graywater use.*

  The 78th Legislature has directed TCEQ to develop guidelines for graywater use. How receptive will local governments be to these new graywater regulations. What are the potential conflicts between the different levels of government in regards to administrating these rules? What will be necessary to streamline the regulation of graywater use?

- *Develop a distinction between the definitions of graywater and recycled water.*

Recycled water refers to wastewater treated to specific standards and distributed to customers through a municipal distribution system. Wastewater (excluding toilet, kitchen sink, and dishwashing machine flows) that is generated and reused onsite with minimal treatment is generally referred to as graywater. There is confusion in the literature regarding a distinction between both categories. In order to encourage both, a clearer demarcation is needed. Other categories, such as reclaimed, reuse and treated effluent should also be identified and defined.

Evaluate the cost effectiveness of various graywater reuse scenarios.

Costs vary depending on regional conditions, regulations and intended use of graywater. Identification of variables that affect costs and baseline data is needed. There is little information in this area.

- *Develop suggestions for appropriate technologies in new construction.*

  Can graywater systems be incorporation into design codes in a cost effective manner? Is graywater a valuable enough resource that ordinances requiring dual plumbing for graywater should be considered?

- *What is the feasibility of treating graywater for other applications beyond landscape irrigation?*

  Graywater has been used for toilet flushing and laundry rinsing in some instances, but what other applications does it have? Some uses would require a higher level of treatment (e.g., membrane technologies and aggressive disinfection). Are there any end uses that would justify the higher cost of such treatment?

- *How would large-scale graywater reuse by individuals impact municipal sewer systems and water recycling programs?*

  What are the effects of graywater systems on the quality and concentration of wastewater (blackwater) entering the sewer collection system and subsequently the wastewater treatment facility? This would not be as much of an issue with new constructions/installations, but would it affect considerations for retrofitting?

For communities with an active water recycling program, would graywater use be a counter productive or complimentary effort? At what point would municipal water recycling programs be affected by individual reuse of graywater?

- ***Evaluate the cost effectiveness of graywater reuse verses other options for water conservation.***

  There are a variety of means to manage and provide water. One obvious way is to conserve or use less water as a means of extending the reliability of a given water supply. Graywater reuse is one option that should be compared with other conservation techniques in order to optimize water use. Decision makers must be able to select options based, in part on, cost, reliability and effectiveness.

Evaluate alternate non-potable water sources to combine with graywater.

Additions to the graywater systems from sources such as water softeners, reverse-osmosis systems, ice-machines, condensate and rainwater can put added demands on the quantity being treated and contaminates into the system. What is the quality of these waters, how long can they be stored, what level of treatment would be needed, and how appropriate would it be to incorporate or blend them into graywater systems?

Section V

Protocol for Evaluating Existing Systems

Protocol for Evaluating Existing Graywater Systems

General Objective

Graywater systems have the potential to alleviate demands on residential water treatment and supply systems by providing an alternate source of water that can replace potable water for the purpose of landscape irrigation. However, a significant barrier to the use of graywater for landscaping is the potential of bacterial and chemical contamination. This should be the principle consideration when designing a method to evaluate the effectiveness of existing graywater systems. A graywater system evaluation must be structured to identify the factors that control graywater quality, determine how they will influence the final discharge product, and assess the effectiveness of the systems treatment and dispersal methods in relation to the end use of the graywater.

The evaluation process must take into account the sources of water prior to entering appliances, the possible contaminants added while the appliance is in use, the condition of water leaving the appliances, the loading on the system, the treatment of the water and the location of the dispersal.

This protocol assumes that every graywater system has a source, collection, pretreatment and dispersal component.

Sources

Identify the characteristics of the household. Determine the size of the residence, number of people in household, ages of the residents, and any other factors that would influence graywater quality.

Evaluate the water supply to determine the initial water quality.

Identify the fixtures/appliances plumbed into the graywater system.

Estimate fixture/appliance usage based on the number of people in the household.

Collection

Evaluate the method used to collect the graywater. Is the house dual plumbed for graywater collection, has it been retrofitted, or is there separate piping exiting exterior walls?

Measure volume of graywater generated on a daily basis.

Based on the number of appliances attached to the system and the number of residents living in the house (which affects the number of times an appliance is used).

Verify that the system includes a diversion valve that will allow graywater to be diverted to the sanitary sewer or onsite septic system. Determine if an overflow line is connected to the discharge from the washing machine for use when there is too much graywater for the system, or when contaminate clothes are washed.

Determine if the system is adequately vented to prevent the buildup of noxious gases.

Pretreatment

Identify the type and capacity of the pretreatment system being used.

Determine if a hopper is in place to direct solids toward the scour outlet. The scour should remove solids to the house drain.

Test quality of graywater influent and effluent going to the dispersal system. Parameters that should be evaluated include:

- ***pH*** – Too high or too low would indicate an unusable water
- ***dissolved oxygen*** – Is aeration necessary?
- ***chemical oxygen demand (COD)*** – Potency of the water
- ***total suspended solids (TSS)*** – Sediment load in the water
- ***electrical conductivity (EC)*** – Indicates the presence of minerals.
- ***temperature*** – Should be within reason for application.
- ***fecal coliforms*** - Are they consistently within the accepted levels?
- ***total phosphorous and total nitrogen*** – Nutrient loading must be at appropriate levels to discharge.

Determine if the system is properly maintained according to manufacturer's guidelines.

Determine if the system has an overflow line for the pretreatment system to automatically discharge excess water to the sewer or septic system.

Dispersal

Identify the type of dispersal system being used to distribute graywater, the type and amount of vegetation being irrigated, the soil type, slope and water features.

Evaluate the hydraulic loading rate to the dispersal system.

Determine if the system is adequate for the hydraulic loading into the system.
Systems can include: soil absorption fields, evapotranspiration systems, low-pressure dosing system, bubbler distribution, ponding (not recommended) and spray.

Collect soil samples to evaluate the soil health.

Verify that all parts of the graywater conveyance system are properly identified. Pipes, outlets, storage tanks, etc. should be clearly marked and color-coded. A graywater storage tanks should have signage indicating that it contains nonpotable water and must be secured in a manner that will not allow accidental access.

If limited pretreatment is used, verify that the pump has the capability to completely empty the storage tank to prevent extended storage of graywater.

Section VI

Quick Reference Bibliography

Quick Reference Bibliography

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3. Anda, M., K. Mathew , and G. Ho. **"Evapotranspiration for Domestic Wastewater Reuse in Remote Indigenous Communities of Australia"**. Water Science and Technology. v44.6 (2001): 1-10.

   Peer Reviewed: NO

4. Benson, J., I. Caplan, and R. Jacobs. **"BlackWater and Graywater on U.S. Navy Ships: Technical Challenges and Solutions"**. Naval Engineers Journal. v111.3 (May 1999).

   Peer Reviewed: YES

5. Bouhabila, E.H., R. B. Aim , and H. Buisson. **"Fouling Characterisation in Membrane Bioreactors"**. Separation and Purification Technology. v22-23 (2001): 123-132.

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6. Brown, S.H., E.B. White, M. Pechulis, and R. Garman. **"Integrated Liquid Discharge System for Waste Disposal on Future Surface Combatants"**. Naval Engineers Journal. v111.3 (May 1999): 285-291.

   Peer Reviewed: YES

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Peer Reviewed: NO

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Peer Reviewed: YES

10. Dixon, A., D. Butler, and A. Fewkes. **"Water Saving Potential of Domestic Water Reuse Systems Using Greywater and Rainwater in Combination"**. Water Science and Technology. v39.5 (1999): 25-32.

Peer Reviewed: NO

11. Folke, Gunther. **"Wastewater Treatment By Greywater seperation: Outline for a Biologically Based Greywater Purification Plant in Sweden"**. Ecological Engineering. v15 (2000): 139-146.

Peer Reviewed: YES

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Peer Reviewed: YES

13. Gander, M., B. Jefferson, and S. Judd. **"Aerobic MBRs for Domestic Wastewater Treatment: A Review With Cost Considerations"**. Separation and Purificaiton Technology. v18-19 (2000): 119-130.

Peer Reviewed: YES

14. Gray, S., and N. Booker. **"Wastewater Services for Small Communities"**. Water Science and Technology. v47.7-8 (2003): 65–71.

Peer Reviewed: YES

15. Gunter, F. **"Wastewater Treatment By Greywater Separation: Outline for a Biologically Based Greywater Purification Plant in Sweden"**. Ecological Engineering. v15 (2000): 139-146.

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16. Hills, S., A.Smith, P. Hardy, and R. Birks. **"Water Recycling at the Millennium Dome"**. Water Science and Technology. v43.10 (2001): 287-94.

Peer Reviewed: NO

17. Ho, G., S. Dallas, M. Anda, and K. Mathew. **"On-site Wastewater Technologies in Australia"**. Water Science and Technology. v44.6 (2001): 81-88.

Peer Reviewed: NO

18. Karpiscak, M. M., R.G. Brittain, and M. A. Emelity. **"Residential Water Conservation and Reuse Demonstration: Casa del Agua and Desert House"**. Water Resources Planning and Management and Urban Water Resources. (1993): 694-97.

Peer Reviewed: NO

19. Karpiscak, M. M., K.E. Foster, and N. Schmidt. **"Residential Water Conservation: Casa del Agua"**. University of Arizona: Water Resources Bulletin. v26:6 (1990): 939-948.

Peer Reviewed: NO

20. Karpiscak, M., R. G. Brittain, C. P. Gerba, K. Foster, and E. Kennith. **"Demonstrating Residential Water Conservation and Reuse in the Sonoran Desert. Casa Del Agua and Desert House"**. Water Science and Technology. v24.9 (2000): 323-330.

Peer Reviewed: NO

21. Karpiscak, M.M., G.W. France, K.J. Decook, R.G. Brittain, K.E. Foster, and S.B.Hopf. **"Casa del Agua: Water conservation demonstration house 1986 through 1998"**. Journal of the American Water Resources Association. v37:5 (2001): 1237-48.

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Peer Reviewed: NO

25. Lodge, B, T. Seager, T. Stephenson, P. English, and R. Ford. **"A Water Recycling plant at the Millennium Dome"**. Proceedings of the Institution of Civil Engineers:Civil Engineering. v138. 5 (May 2000): 58-64.

Peer Reviewed: YES

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Peer Reviewed: NO

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Peer Reviewed: NO

28. Ludwig, A. **"Branched Drain Greywater Systems: Reliable, Sanitary, Low Maintenance Distribution of Household Greywater to Downhill Plants Without Filtration or Pumping"**. . California: Oasis Design, 2003.

Peer Reviewed: NO

29. Ludwig, A. **"Builder's Greywater Guide: Installation of Greywater Systems in New Construction and Remodeling"**. . California: Oasis Design, 1995-2002.

Peer Reviewed: NO

30. Mars, R., R. Taplin, G. Ho, and K. Mathew. **"Greywater Treatment With the Submergent Triglochin Huegelii--a Comparison Between Surface and Subsurface Systems"**. <u>Ecological Engineering</u>. v20 (2003): 147-56.

Peer Reviewed: NO

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Peer Reviewed: YES

32. National Association of Plumbing-Heating-Cooling Contractors. **“Assessment of On-site Graywater and Combined Wastewater Treatment and Recycling Systems”**. . National Association of Plumbing-Heating-Cooling Contractors (NAHPCC). 1992.

    Peer Reviewed: NO

33. Neal, J. **“Wastewater Reuse Studies and Trials in Canberra”**. Desalination. v106.1-3 (1996): 399-405.

    Peer Reviewed: YES

34. Okun, D.A. **“Distributing Reclaimed Water Through Dual Systems”**. Resource Management. v89.11 (1997): 52-64.

    Peer Reviewed: NO

35. Oldenburg, M., A. Albold, J. Niederste-Hollenberg, and J. Behrendt. **“Experience With separating Wastewater Treatment Systems: The Ecological Housing Estate- Luebeck, Flintenbreite”**. Proceedings of the Ninth International Conference on: Urban Drainage. American Society of Civil Engineers (2002): 1-12.

    Peer Reviewed: NO

36. Osburn, R.C., and C.E. Burkhead. **“Irrigating Vegetables With reclaimed Wastewater”**. Water Environment and Technology. v4.8 (1992):38-43.

    Peer Reviewed: NO

37. Otterpohl, R., A. Albold, and M. Oldenburg. **“Source Control in Urban Sanitation and Waste Management: Ten Systems With Reuse of Resources”**. Water Science and Technology. v39.5 (1999): 153-160.

    Peer Reviewed: NO

38. Otterpohl, R., M. Grottker, and J. Lange. **“Sustainable Water and Waste Management in Urban Areas”**. Water Science and Technology. v35.9 (1997): 121-133.

Peer Reviewed: NO

39. Otterpohl, R., M. Oldenburg, and J. Zimmermann. **"Integrated Wastewater Disposal for Rural Settlements"**. Wasser und Boden. v11 (1999): 10-13.

Peer Reviewed: YES

40. Parker, L. **"From Pikes Peak to Mars"**. Civil Engineering (New York). v 70.4 (April 2000): 44-45,69.

Peer Reviewed: NO

41. Prillwitz, M. **"Making Graywater Profitable for You: New Business Opportunities for Irrigation Professionals"**. Fifteenth International Irrigation Exposition & Technical Conference Proceedings; Where Technology Gets Down to Business. Atlanta, GA . November 5-8, 1994

Peer Reviewed: NO

42. Rababah, A.A., and N.J. Ashbolt. **"Innovative Production Treatment Hydroponic Farm for Primary Municipal Sewage Utilisation"**. Water Resources. v34.3 (2000): 825-834.

Peer Reviewed: YES

43. Rockefeller, A., and C. Lindstrom. **"Greywater for the Greenhouse"**. Compost Science. v18.5 (1977): 22-25.

Peer Reviewed: NO

44. Sadovski, Fattal, Goldberg, Katzenelson, and Shuval. **"High Levels of Microbial Contamination of Vegetables Irrigated With Wastewater By the Drip Method"**. Applied and Environmental Microbiology. v36.6 (1978): 824-830.

Peer Reviewed: YES

45. Schaub, S.A., H.T. Bausum, and G.W. Taylor. **"Fate of Virus in Wastewater Applied to Slow-infiltration Land Treatment**

Systems". Applied and Environmental Microbiology. v44.2 (1982): 383-394.

Peer Reviewed: YES

46. Schonborn, A., B. Zust, and E. Underwood. **"Long term performance of the sand-plant-filter schattweid (Switzerland)"**. Water Science and Technology. v 35.5 (1997):307-314.

Peer Reviewed: NO

47. Smith, D.W., and V. Christensen. **"Innovative Approaches to Sewage Collection, Treatment, and Disposal: Practices in Northern Canada"**. Canadian Journal of Civil Engineering. v 9 (1982): 653-662.

Peer Reviewed: YES

48. Surendran, S., A.D. Wheatley. **"Grey-Water Reclamation for Non-potable Re-use"**. Water Science and Technology. v133.10-11 (1996):451-462

Peer Reviewed: NO

49. Tleimat, B., M. Tleimat, M.A. Friedman, MA; and L. Styczynski. **"The Use of Vapor Compression Distillation for Recycling Graywater as an Early Application in the Antarctic Planetary Analog."**. Desalination. v87 (1992): 97-107.

Peer Reviewed: YES

50. Whitney, A., and R. Bennett. **"Monitoring Graywater Use: Three Case Studies in California"**. Conserv 99 Water Efficiency: Making Cents in the Next Century. Monterey, CA . January 31-February 3, 1999

Peer Reviewed: YES

51. Hammes, F., Y. Kalogo, and W. Verstraete. **"Anaerobic Digestion Technologies for Closing the Domestic Water, Carbon and Nutrient Cycles"**. Water Science and Technology. v41.3 (2000): 203-211.

Peer Reviewed: NO

Wastewater Quality and Characteristics

1. Albrechtsen, H.J. **"Microbiological Investigations of Rainwater and Graywater Collected for Toilet Flushing"**. Water Science and Technology. v46.6-7 (2002): 311–16.

   Peer Reviewed: YES

2. Almeida, M.C., D. Butler, and E. Friedler. **"At-Source Domestic Wastewater Quality"**. Urban Water. v1(1999): 49-55.

   Peer Reviewed: YES

3. Badawy, A.S., J.B. Rose , and C. P. Gerba. **"Comparative Survival of Enteric Viruses and Coliphage on Sewage Irrigated Grass"**. Comparative Journal of Environmental Science and Health. vA25.8 (1990): 937-52.

   Peer Reviewed: YES

4. Bouwer, H., P. Fox , and P. Westerhoff. **"Irrigating With Treated Effluent"**. Water Environment and Technology. v10.9 (1998): 115-120.

   Peer Reviewed: NO

5. Burrows, W.D., M.O. Schmidt, R.M. Carnevale , and S.A. Schaub. **"Nonpotable Reuse: Development of Health Criteria and Technologies For Shower Water Recycle"**. Water Science and Technology. v24.9 (1991):81-88.

   Peer Reviewed: NO

6. Casanova, L.M., C.P. Gerba, and M. Karpiscak. **"Chemical and Microbial Characterization of Household Graywater"**. Journal of

Environmental Science and Health, Part A: Toxic/Hazardous Substances & Environmental Engineering. vA36.4 (2001): 395-401.

Peer Reviewed: YES

7. Casanova, L.M., V. Little, R.J. Frye, and C.P.Gerba. **"A Survey of the Microbial Quality of Recycled Household Graywater"**. Journal of the American Water Resources Association. v37.5 (2001): 1313-20.

Peer Reviewed: YES

8. Dixon, A., D. Butler, A. Fewkes, and M. Robinson. **"Measurement and Modelling of Quality changes in Stored Untreated Grey Water"**. Urban Water. v1.4 (2000): 293-306.

Peer Reviewed: YES

9. Dixon, D., J. Daly, H. Dorr, and R. Peterson. **"Enhanced MARPOL IV Sewage and Graywater Pollution Prevention - Holland America Line Westours Case Study"**. Transactions - Society of Naval Architects and Marine Engineers. v110 (2003): 453-472.

Peer Reviewed: YES

10. Eriksson, E., K. Auffarth, M. Henze, and A. Ledin. **"Characteristics of Grey Wastewater"**. Urban Water. v4.1 (March 2002): 85-104.

Peer Reviewed: YES

11. Gerba, C.P., T.M. Straub, J.B. Rose, M.M. Karpiscak, K.E. Foster, and R.G. Brittain. **"Water Quality Study of Graywater Treatment Systems"**. Water Resources Bulletin. University of Arizona v 31:1 (1995): 109-16.

Peer Reviewed: NO

12. Kourik, R. **"Source reduction for Wastewater"**. Biocycle. v31.1 (1990): 35.

Peer Reviewed: YES

13. Laak, R., M.A. Parese, and R. Costello **“Denitrification of Blackwater With Greywater”**. Journal of the Environmental Engineering Division, Proceedings of the American Societcy of Civil Engineers. v107.EE3 (1981): 581-90.

Peer Reviewed: NO

14. Levine, L. H., J. L. Garland, and J. V. Johnson. **“HPLC/ESI-quadrupole Ion Trap Mass Spectrometry for Characterization and Direct Quantification of Amphoteric and Nonionic Surfactants in Aqueous Samples”**. Analytical Chemistry. v74.9 (2001): 2064-71.

Peer Reviewed: YES

15. Lodge, B.N., S.J. Judd, and A.J. Smith. **“A Statistical Method for Quantifying the Different Fouling Effects of Three Combined Water Sources on an Ultrafiltration Membrane”**. Desalination. v142.2 (February 2002): 143-49.

Peer Reviewed: YES

1. Mara, D.D., and R.G.A. Feachem. **“Water and Excreta-Related Diseases: Unitary Environmental Classification”**. Journal of Environmental Engineering. v125.4 (1999): 334-39.

Peer Reviewed: NO

2. March, J.G., M.Gual, and B.M. Simonet. **“Determination of Residual Chlorine in Greywater Using O-tolidine”**. Talanta. v58 (2002):995-1001.

Peer Reviewed: YES

3. Ottosson, J., and T. Stenstroem. **“Growth and Reduction of Microorganisms in Sediments Collected Froma Greywater Treatment System”**. Letters in Applied Microbiology. v36.3 (March 2003): 168-72.

Peer Reviewed: YES

4. Ottosson, J., and T.A. Stenstroem. **"Faecal Contamination of Greywater, and Associated Microbial Risks."**. Water Research. v37 (2003): 645-655.

Peer Reviewed: YES

5. Rose, J.B., Sun, Gwo-Shing; C.P. Gerba, and N.A. Sinclair. **"Microbial Quality and Persistence of Enteric Pathogens in Graywater FromVarious Household Sources"**. Water Research. v25.1 (1991): 37-42.

Peer Reviewed: YES

6. Siegrist, R., M. Witt, and W. C. Boyle. **"The Characteristics of Rural Household Wastewater"**. Journal of the Environmental Engineering Division. v102.EE3 (1976) :533-548.

Peer Reviewed: YES

7. Stamper, D.M., M. Walch, and R.N. Jacobs. **"Bacterial Population Changes in a Membrane Bioreactor for Graywater Treatment Monitored By Denaturing Gradient Gel Electrophoretic Analysis of 16S rRNA Gene Fragments"**. Applied and Environmental Microbiology. v69.2 (January 2003): 852-860.

Peer Reviewed: YES

Section VII

Internet Resources

Internet Resources

1. Anon. Water Efficiency Case Study: The Society for the Protection of New Hampshire Forests, Concord. Posted: 5/21/02. New Hampshire Department of Environmental Services.

http://www.des.state.nh.us/studies/spnhf.htm
Date accessed: 8/19/2003

Web article discussing the water reuse technology incorporated into the construction of the SPNHF's headquarters located in East Concord, New Hampshire. Graywater is collected from kitchen and bathroom sinks, and showers and used to irrigated indoor planter boxes. At the time the article was written, the SPNHF headquarters uses 45% of the graywater generated, but plans are being made to add outdoor planter boxes to utilize the remaining graywater. The article discusses the graywater system design, problems encountered, and solutions to overcome them.

2. Anon. Reuse: Graywater for Irrigation. Posted: N/A. Santa Monica Green Building Program.

http://greenbuildings.santa-monica.org/watersystems/waterreuse.html
Date accessed: 8/19/2003

Aimed at building designers/managers. Gives general instruction on how to collect and use graywater. Recommends simple gravity fed system if maintenance staff are available to observe and perform regular maintenance. Recommends a more complex system (automatically backwashed filters, pumps, etc.) if no maintenance staff available.

3. Anon. Graywater Systems, Compost Toilets, and Rain Collection. Posted: N/A. The Rocky Mountain Institute.

http://www.rmi.org/sitepages/pid287.php
Date accessed: 8/19/2003

Brief discussion on three different water reuse strategies. Estimates that the average family can generate between 50 to 100 gallons of graywater per day. Gives links to other information sources.

4. Anon. Graywater. Posted: 6/18/01. Office of Arid land Studies, Desert Research Unit.

http://ag.arizona.edu/OALS/oals/dru/graywater.html
Date accessed: 8/19/2003

Defines graywater and legitimate sources, and distinguishes between graywater and blackwater. Estimates that individual households produce 10,000 gallons of graywater annually. Includes a list of "DO'S" and "DON'TS" for graywater use. Recommends subsurface leachfield or drip dispersal of graywater.

5. Anon. Wasser Recycling. Posted: N/A. Lokus CmbH.

http://www.graywater.com
Date accessed: 8/19/2003

German based company that installs graywater reuse systems in commercial and residential buildings.

6. Anon. Graywater. Posted: 3/29/99. Desert Botanical Garden.

http://www.dbg.org/center_dl/graywater.html
Date accessed: 8/19/2003

General discussion of graywater sources and uses. Discussion of graywater use at "The Desert House".

7. Anon. Greywater Recycling Filter Basins and Graywater Irrigation Systems. Posted: N/A. The Natural Home Building Source.

http://www.thenaturalhome.com/greywater.html
Date accessed: 8/19/2003

Website for a company that sales residential graywater systems. Article includes general discussion of graywater sources and uses.

8. Anon. Preliminary Guidelines for Using Graywater for Irrigation. Posted: 1/1/03. Center for the Study of the Built Environment (CSBE).

http://www.csbe.org/graywater/guide1.htm
Date accessed: 8/19/2003

Guidelines for using graywater presented by the CSBE in Jordan. Guidelines seem to be based on the "Graywater Guidelines" brochure produced by the Water Conservation Alliance of Southern Arizona.

9. Anon. Greywater Recycling and Irrigation Systems. Posted: N/A. ECO Design.

http://www.greywater.com.au/
Date accessed: 8/25/2003

Website for Australian company that sells graywater systems.

10. Anon. Graywater: Safe Reuse and Recycling. Posted: Winter 2002 Vol.13, no.1. Pipeline.

http://www.nesc.wvu.edu/nsfc/Articles/PL/PL_w02_web/pl_w02_GraywaterMain.htm
Date accessed: 8/29/2003

11. Bennet, D. Graywater: An Option for Household Water Reuse. Posted: July/August 1995. Home Energy Magazine Online.

http://hem.dis.anl.gov/eehem/95/950712.html
Date accessed: 8/19/2003

Extensive article that defined graywater and explores system design, plant water needs, costs of new and retrofit systems, and appropriate cleansers to use in a graywater system.

12. Bilson, S. How Greywater Systems Work. Posted: 8/29/00. PM Engineer.

http://www.pmengineer.com/CDA/ArticleInformation/features/BNP__Features__Item/0,2732,9484,00.html
Date accessed: 8/29/2003

Examines the Uniform Plumbing Code, International Plumbing Code and California Plumbing Code (CPC), Appendix G definitions of graywater. In-depth discussion of the CPC requirements for graywater use. Also discusses leach field and subsurface drip dispersal methods.

13. City of Abilene Building Inspection Division Hands Out Guidelines for Graywater Systems. Posted: N/A. City of Abilene.

http://www.abilenetx.com/building_insp/b20.htm
Date accessed: 8/29/2003

Outlines guidelines for graywater use in the City of Abilene. These guidelines pertain only to graywater systems for residential laundry washing machine drains for surface irrigation. Only the wastewater from residential laundry washing machines shall be utilized for the graywater system. All other waste must drain to the public sewer in accordance with the City of Abilene plumbing code.

14. Coder, K. Using Graywater on the Landscape. Posted: N/A. University of Georgia, College of Agricultural and Environmental Sciences.

http://interests.caes.uga.edu/drought/articles/gwlands.htm
Date accessed: 8/30/2003

Site maintained by the University of Georgia that posts information relating to the state's drought. This article discusses the use of graywater to conserve potable water by maintaining landscaping. Includes sections on the definiton of graywater, contents of graywater, substances to avoid when using graywater, health concerns, and methods of collecting, treating and dispersing graywater. Also includes criteria for using graywater on trees and shrubs.

15. County of San Diego Department of Environmental Health Guideline for the Installation of Graywater Systems. Posted: N/A. County of San Diego.

http://www.sdcounty.ca.gov/deh/lwq/land_use/pdf/gray_water.pdf
Date accessed: 8/29/2003

Summarizes the development of graywater regulations in California and describes requirements for using graywater in San Diego County, California.

16. Demboski, D.J., et al. Evolutions in U.S. Navy Shipboard Sewage and Graywater Programs. Posted: N/A. Navy Shipboard Environmental Information Clearinghouse (Navy SEIC).

http://navyseic.dt.navy.mil/liquid/html/paper.htm
Date accessed: 8/25/2003

A discussion of regulations governing discharge of graywater from Navy ships. Outlines reliability and maintenance issues with current shipboard graywater systems. Examines current graywater treatment technology and discusses future goals and research.

17. Goforth, D. Using Graywater on Plants. Posted: N/A. North Carolina Cooperative Extension Service.

http://www.ces.ncsu.edu/cabarrus/staff/dgoforth/newsart/drought2.html
Date accessed: 8/29/2003

A brief discussion of graywater use in North Carolina. Article states that graywater is currently considered as the same as blackwater and must be treated accordingly.

18. Hildebrand, R. Greywater the Easy Way. Posted: N/A. Reiner Hildebrand.

http ://www.reinerhildebrand.de/website-grauwasser-recycling/grey.com
Date accessed: 8/30/2003

Website maintained by German graywater enthusiast. Sections include importance of graywater use, system set-up, operating costs, hygiene, reliability and maintenance issues, water savings and economics, and photos of graywater systems.

19. Jenkins, J., T. Griffin The Humanure Handbook: A Guide to Composting Human Manure. Posted: N/A. The Permacult Project.

http://www.permacult.com.au/shelter/poop.html
Date accessed: 8/27/2003

Description of a book about various ways to recycle human waste. The book includes a review of the historical, cultural, and environmental issues pertaining to "human waste," as well as an in depth look at the potential health risks related to humanure recycling, with instructions on how to eliminate those dangers in order to safely convert humanure into garden soil. Includes a chapter on alternative graywater systems; color photos of humanure compost gardens; a review of U.S. state regulations pertaining to compost toilets, graywater systems, and constructed wetlands; and a list of compost toilets sources worldwide.

20. Jett, J. . Posted: 7/1/00. West Virginia University Extension Service, Center for.

http://www.wvu.edu/~agexten/hortcult/homegard/graywate.htm
Date accessed: 8/30/2003

Brief article written by WVU Extension Service Agent. Includes a short list of precautions for graywater use.

21. Kourik, R. Graywater For Gardens. Posted: N/A. Do It Yourself.com (reprinted with permission from the National Gardening Association.

http://doityourself.com/garden/graywater.htm
Date accessed: 8/19/2003

Provides a brief history of graywater use in California. References California Plumbing Code Appendix J and Appendix W of the Uniform Plumbing Code. Recommends subsurface irrigation for safety and discusses benefits and limitations of drip emitter systems.

22. Lehr, V. Graywater Systems. Posted: N/A. American Society of Septic Engineers.

http://www.asse-plumbing.org/greywatersystems.html
Date accessed: 8/30/2003

Reprint of a 1986 article that discusses graywater system design and reuse. Details graywater reuse in hotels and examines the economic feasibility of installing graywater systems under different scenarios. Includes schematics for different graywater systems.

23. Lindstrom, C. Greywater: What It Is, How to Treat It, How to Use It. Posted: 1/1/00. Carl Lindstrom.

http://www.greywater.com
Date accessed: 8/29/2003

Fairly detailed web posting about graywater. Section include a synopsis of graywater, summary of scientific data, planning a graywater system, treatment options, samples of different installations, links to companies that sell graywater systems, and a list of references on which the information was based. Discusses the differences in BOD between graywater an blackwater and compares decomposition rates between the two. References a well-accepted Swedish study that compares different characteristics of gray- and blackwater. Samples of installations include location, photos, and a brief narrative for each site.

24. Little, V. Graywater Guidelines. Posted: N/A. Water CASA.

http://www.watercasa.org/pubs/Graywater%20Guidelines.pdf
Date accessed: 8/29/2003

A 28 page manual written for graywater users in Arizona. The manual is presented in a non-technical format and contains a summary of the State's graywater rules as well as the 15 best management practices that must be followed when using graywater in the Arizona. The pamphlet also includes examples of system designs and cost considerations for system construction.

25. Ludwig, A. Greywater Central. Posted: N/A. Oasis Design.

http://greywater.net http://www.oasisdesign.net
Date accessed: 8/30/2003

One of the most extensively developed websites about graywater. Site content was developed and is maintained by Art Ludwig, author of "Create an Oasis With Greywater", "Branched Drain Greywater Systems", and "The Builder's Greywater Guide". The website contains information and links about a wide spectrum of graywater related topics. Discussions include how to choose and build graywater systems, information on graywater regulations, summaries of documented graywater studies, methods of graywater treatment and irrigation, and indoor graywater reuse. One page on the website details common system design mistakes and how to correct them. Also include a page devoted to current graywater regulations (specifically the California rules) and ho they can be improved.

26. Office of Water Use Efficiency, California Water Resources Division. Revised Graywater Standards. Posted: N/A. California Department of Water Resources, Office of Water Use Efficiency.

http://www.owue.water.ca.gov/docs/Revised_Graywater_Standards.pdf
Date accessed: 8/19/2003

A 12 page summary of the changes and revisions to Appendix G: California Graywater Standards. Regulations were revised in 1997 to include provisions for graywater use in commercial, industrial, and multifamily projects.

27. Santa Clara County Department of Environmental Health Use of Graywater. Posted: N/A. Santa Clara County Government Homepage.

http://www.sccgov.org/content/0,4745,chid%253D15175%2526ccid%253D121950,00.html
Date accessed: 8/29/2003

Lists 8 best management practices for using graywater in Santa Clara County, California.

28. Schalau, J. Using Household Gray Water. Posted: 7/11/01. Backyard Gardener.

http://ag.arizona.edu/yavapai/anr/hort/byg/archive/usinghouseholdgraywater.html
Date accessed: 8/30/2003

Article written by the director of the Arizona Cooperative Extension, Yavapai County. Discusses Arizona's recently passed graywater regulations and give guidelines for safe reuse of graywater.

29. Sustainable Building Sourcebook Graywater. Posted: N/A. The City of Austin Green Building Program.

http://www.greenbuilder.com/sourcebook/greywater.html
Date accessed: 8/29/2003

A section from the "Green Building Sourcebook" that discusses graywater systems and uses. Includes a brief synopsis of graywater use in Travis County, Texas. Discusses 4 types of graywater systems: ET system, shallow trench, shallow mound, and pressure effluent dosing and drip irrigation. Links to system installers and/or system component suppliers.

30. Washington State Department of Health, Wastewater Management Program. Water Conservation Using Greywater. Posted: N/A. Washington State Department of Health.

http://www.doh.wa.gov/ehp/ts/WW/GreywaterFact.PDF
Date accessed: 8/30/2003

Defines graywater for Washington State citizens, summarizes constituents present in graywater and provides guidance on installing a system based on Washington State's regulations.

31. Waskom, R. Graywater Reuse and Rainwater Harvesting (publication No. 6.702). Posted: 14-Apr-03. Colorado State University Cooperative Extension.

http://www.ext.colostate.edu/PUBS/natres/06702.html
Date accessed: 8/19/2003

Discusses graywater and rainwater uses as permitted by the State of Colorado. Summarizes Colorado's graywater regulations and cites agencies and rules that govern graywater use. Lists specific design requirements for graywater systems.

32. Water Conservation Association of Southern Arizona Can I Use My Graywater? Posted: 1/1/00. Water CASA.

http://www.watercasa.org/pubs/greywater.pdf
Date accessed: 8/29/2003

A two-page pamphlet created for the citizens of Arizona. The pamphlet describes in non-technical format the 15 best management practices that homeowners must adhere to in order to utilize graywater in manner that will be consistent with the state's newly enacted graywater laws (effective January 2001).

33. Water Conservation Association of Southern Arizona Residential Graywater Reuse Study. Posted: N/A. Water CASA.

www.watercasa.org/research/residential/resindex.htm
Date accessed: 8/30/2003

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

34. Wilson, A. Greening Federal Facilities: An Energy, Environmental, and Economic Resource Guide for Federal Facility Managers and Designers, Second Edition. Posted: 5/1/01. Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy.

http://www.eere.energy.gov/femp/techassist/pdf/29267-0.pdf
Date accessed: 8/19/2003

A resource guide designed to increase energy and resource efficiency, cut waste, and improve the performance of Federal buildings and facilities. It is intended primarily for Federal facility managers, and describes a wide range of effective actions that include selecting nonpolluting materials, recycling, conserving energy and water, improving landscaping, and purchasing energy-efficient lighting, heating, and cooling equipment. The discussion on graywater is a brief, one-page synopsis of potential uses for graywater in large buildings. Includes limited discussion of California graywater regulations.