RESEARCH REPORT

Advancing The "Light Grey Option": Making Residential Greywater Reuse Happen

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ADVANCING THE

"LIGHT GREY OPTION"

Making Residential Greywater Reuse Happen

Prepared for:

Research Division

Canada Mortgage and Housing Corporation

National Office

Prepared by:

A.R. Townshend, P. Eng.
RR1, Athens, Ontario
K0E 1B0

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Canada Mortgage and Housing Corporation (CMHC), the Federal Government's housing agency, is responsible for administering the National Housing Act.

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ABSTRACT

This report confirms that the "LIGHT GREY OPTION" has the potential of further reducing potable water use in residential buildings by 30 to 40 percent once state-of-the-art conservation devices have been introduced. Actions to be taken to win public acceptance with project evaluation criteria are presented. Anticipated greywater quantity and quality characteristics are established as well as reuse quality criteria.

Various candidate greywatater unit treatment processes are described with comments on their applicability to the "LIGHT GREY OPTION". Based on the information developed, the report outlines the major components of a suitable greywater treatment system and evaluates the use of some commercially available devices. Once the required technology is in place a detailed cost benefit analysis will determine whether the water savings are sufficient to justify the "LIGHT GREY OPTION".

The final Section of the report suggests what further action could be taken to advance the "LIGHT GREY OPTION". This calls for the involvement of all concerned parties from equipment manufacturers to consumers.

Keywords:
- Residential Water Conservation Devices
- Dual Plumbing Systems
- Greywater Characteristics
- Greywater Reuse Criteria
- Greywater Treatment

EXECUTIVE SUMMARY

The "LIGHT GREY OPTION" is a new concept for water conservation in residential housing which has the potential of further reducing potable water use from 30 to 40 percent once state-of-the-art conservation devices are introduced. The concept was originally presented by the CMHC Research Division in collaboration with Health and Welfare Canada at the First National Conference on Water Conservation, Winnipeg, Manitoba, February, 1993.

By means of a dual piping system, the "LIGHT GREY OPTION" proposes to collect used bathing water, clotheswasher rinse water and dishwasher rinse water for treatment. The treated greywater would be reused to: (1) flush toilets; (2) provide washwater for clotheswashers and dishwashers; and (3) irrigate lawns and gardens on a seasonal basis.

The "LIGHT GREY OPTION" requires modification of clotheswashers and dishwashers to accommodate dual water supplies (treated greywater for washing and potable water for rinsing). It also requires the development of acceptable greywater treatment systems. A detailed cost benefit analysis once the technology is in place will determine whether there are sufficient water savings to justify the "LIGHT GREY OPTION".

This report was commissioned by CMHC Research Division to provide a concept review of the feasibility of the "LIGHT GREY OPTION" with respect to (1) greywater treatment requirements; (2) availability of potentially suitable greywater treatment systems, and (3) public acceptance. The aim was to further advance the concept of the "LIGHT GREY OPTION".

An extensive literature search was undertaken and pertinent information was obtained from representative appliance manufacturers and domestic water/wastewater treatment suppliers. Initial contacts were also made with other parties including regulatory agencies and consumer related organizations.

The selection and design of a specific prototype greywater treatment facility was beyond the project terms of reference.

Because of the preliminary nature of the project and because most of the available treatment systems require considerable downsizing for the "LIGHT GREY OPTION" as applied to individual residences no attempt was made to develop cost estimates.

The "Background" reviews the experiences gained from municipal and residential reuse projects in North America and Japan since they first appeared in the 1970's. General project evaluation criteria are presented and actions to win public acceptance are considered.

Based on a typical Canadian four-person house equipped with state-of-the-art conservation devices including European designed clothes and dishwashers, the amount of water generated for treatment by the "LIGHT GREY OPTION" is expected to range between 200 lpd (44 gpd) and 380 lpd (84 gpd). The average amount of water required for reuse would be between 130 lpd (29 gpd) and 240 lpd (53 gpd).

Compared to conventional greywater, the "LIGHT GREY OPTION" greywater is low in total suspended solids and biodegradable organics (BOD_5). These qualities impact negatively on some treatment processes.

The main quality considerations are aesthetic requiring the control of turbidity, colour, odour and staining. Excessive foaming must be avoided. Opportunities must be provided for volatile organics to exit the system under controlled conditions. Effort will have to be made to keep objectionable household cleaning and cosmetic products out of the greywater system. Public health protection will be provided by an appropriate disinfection processes.

In designing a greywater treatment system for the "LIGHT GREY OPTION" particular attention must be made to these and other factors which may impact negatively on the selected treatment processes. Processes which do not contribute significantly to the removal of undesired contaminants should be avoided.

A number of different, suitable greywater treatment facilities can be developed for the "LIGHT GREY OPTION" from present experience and available technology. Each will require the custom design of a prototype which focuses on the findings of this report. Greywater characterization, prototype development, and testing under real residential housing practices are required before the "LIGHT GREY OPTION" can become a reality.

In the concluding Section "Taking Further Action to Advance the "LIGHT GREY OPTION" the report recommends soliciting potential partners to become involved based on the information developed to-date on this innovative concept. Five activities are suggested entailing different participants to:

(1) Modify appliances and plumbing systems
(2) Develop suitable greywater treatment technologies
(3) Test and gain approval of components
(4) Establish demonstration sites
(5) Win public health and consumer acceptance

With respect to demonstration sites it would be advantageous to start with multipe housing units on municipal sewers. This would minimize downsizing requirements and permit gradual introduction of the treated greywater as its acceptability is established.

RÉSUMÉ

Il s'agit d'un nouveau concept d'économie de l'eau dans les habitations qui offre la possibilité de réduire davantage la consommation d'eau potable de 30 à 40 p. 100 grâce à l'installation de dispositifs économiseurs dernier cri. Il a d'ailleurs été présenté à la Division de la recherche de la SCHL en collaboration avec Santé et Bien-être social Canada lors de la première conférence nationale sur l'économie de l'eau, à Winnipeg, en février 1993.

Au moyen d'un double réseau de canalisations, l'option récupération propose de recueillir les eaux usées des baignoires, l'eau de rinçage des lave-linge et du lave-vaisselle en prévision de leur traitement. Les eaux grises ou ménagères traitées seraient réutilisées pour : 1) actionner la chasse des toilettes; 2) alimenter en eau les lave-linge et les lave-vaisselle; et 3) irriguer la pelouse, le jardin et le potager, selon l'usage saisonnier.

L'option récupération requiert de doter les lave-linge et les lave-vaisselle de deux canalisations d'alimentation (en eaux ménagères traitées pour le lavage et en eau potable pour le rinçage). Elle nécessite également la mise au point de dispositifs acceptables de traitement des eaux ménagères. Dès que la technologie sera en place, une analyse coûts-avantages détaillée déterminera si les économies d'eau suffisent pour justifier l'option récupération.

Le présent rapport a été commandé par la Division de la recherche de la SCHL dans le but d'étudier la faisabilité de l'option récupération quant : 1) aux besoins de traitement des eaux ménagères; 2) à la disponibilité de systèmes de traitement convenables; et 3) à son acceptation par la population. L'objectif consiste à promouvoir l'option récupération.

Une recherche documentaire étendue a été entreprise et des informations pertinentes ont été obtenues de fabricants représentatifs d'appareils ménagers et de fournisseurs de systèmes de traitement d'eaux domestiques ou d'eaux usées. Des premiers contacts ont été établis avec les organismes de réglementation et d'organismes de protection des consommateurs.

Le choix et le modèle d'un prototype spécifique d'installation de traitement des eaux ménagères dépassent largement la portée de notre mandat.

En raison du caractère préliminaire du projet et vu que la taille de la plupart des systèmes de traitement disponibles devra être réduite considérablement de manière à cadrer avec l'option récupération pour les maisons individuelles, nous n'avons aucunement tenté d'établir des estimations de coûts.

Le document d'information passe en revue l'expérience acquise des systèmes municipaux et résidentiels de réutilisation des eaux usées en Amérique du Nord et au Japon depuis leur apparition dans les années 1970. Il énonce les critères généraux d'évaluation des systèmes ainsi que les démarches à entreprendre dans l'espoir de gagner la faveur populaire.

Compte tenu d'une maison canadienne type occupée par quatre personnes et équipée de dispositifs économiseurs dernier cri, dont des modèles européens de lave-linge et de lave-vaisselle, la quantité d'eau générée pour le traitement par l'option récupération devrait se situer entre 200 lpj (44 gpj) et 380 lpj (84 gpj). La quantité moyenne d'eau requise pour la réutilisation se situerait entre 120 lpj (29 gpj) et 240 lpj (53 gpj).

Comparativement aux eaux ménagères ordinaires, celles produites grâce à l'option récupération présentent une faible teneur totale en solides en suspension et en matières organiques biodégradables. Ces caractéristiques ont cependant une incidence négative sur certains procédés de traitement.

Les principaux aspects touchant la qualité concernent le contrôle de la turbidité, de la couleur, des odeurs et des taches. Il faut éviter la formation de mousse excessive et trouver des moyens d'évacuer du système les composés organiques volatils dans des conditions contrôlées. Des mesures devront être prises pour tenir les produits de nettoyage ou cosmétiques hors du système de traitement. La protection de l'hygiène publique sera assurée par des procédés de désinfection appropriés.

En concevant le système de traitement des eaux ménagères pour l'option récupération, une attention particulière doit être portée à ces facteurs et à d'autres qui risquent d'exercer une influence négative sur les procédés de traitement retenus. Il faudra éviter de recourir à des procédés dont l'effet ne contribue pas beaucoup à retirer les contaminants indésirables.

Un certain nombre de différentes installations de traitement convenables pourront être mises au point dans le cadre de l'option récupération à partir de la présente expérience et de la technologie disponible. Chacune nécessitera la conception sur mesure d'un prototype qui se concentre sur les résultats du rapport. La caractérisation des eaux ménagères, la mise au point d'un prototype et la mise à l'essai en véritable milieu résidentiel seront requises avant que l'option récupération devienne réalité.

En conclusion, le rapport recommande d'inviter des associés en perspective à prendre part aux travaux d'après les renseignements obtenus à ce jour sur ce concept innovateur. Cinq activités, supposant différents participants, sont proposées :

1) Modifier les appareils ménagers et la plomberie

2) Mettre au point des techniques convenables de traitement des eaux ménagères
3) Tester les composantes et obtenir leur homologation
4) Établir des lieux de démonstration
5) Gagner la faveur des autorités responsables de la santé publique et celle des consommateurs.

En ce qui concerne les lieux de démonstration, il serait avantageux de commencer par des ensembles de logements collectifs raccordés à un réseau d'égouts municipal. Cela éviterait d'avoir à réduire la taille des systèmes et permettrait d'adopter graduellement la notion des eaux ménagères traitées à mesure que son acceptabilité gagnera du terrain.

CMHC SCHL

National Office
700 Montreal Road
Ottawa ON K1A 0P7
Telephone: (613) 748-2000

Bureau national
700 chemin de Montréal
Ottawa ON K1A 0P7
Téléphone : (613) 748-2000

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1.0 INTRODUCTION AND PROCEDURE

The "LIGHT GREY OPTION" is a new concept which has potential of further reducing potable water use in residential buildings by 30 to 40 percent after the introduction of state-of-the-art conservation devices. The concept was originally presented by the CMHC Research Division in collaboration with Health and Welfare Canada at the First National Conference on Water Conservation, Winnipeg, Manitoba, in February 1993.

In the "LIGHT GREY OPTION" (schematic - Appendix A) it is proposed to collect used bath/shower water, dishwasher rinse water and clotheswasher rinse water for treatment so it can be reused for:

- toilet flushing
- clotheswasher wash water
- dishwasher wash water and
- irrigation water (seasonal option)

Kitchen and utility slop sinks would be used to dispose of kitchen wastewaters, household cleaning product solutions, and other manufactured products suitable for discharge with the toilet blackwater to the sewer or septic tank/absorption field system. Kitchen wastewaters are excluded to minimize the presence of oils, fats, greases, detergents and cleansers, which are difficult to treat.

This report was commissioned by the Research Division CMHC to provide a concept review of the feasibility of the "LIGHT GREY OPTION" with respect to public acceptability, greywater treatment requirements, and the availability of potentially suitable greywater treatment systems.

The approach taken in carrying out this assignment was to undertake an extensive literature review, and to obtain pertinant information from representative appliance manufacturers and domestic water/wastewater treatment suppliers. Initial contacts were also made with public/private utility companies; plumbing and mechanical contractors; equipment performance testing laboratories; regulatory agencies; and consumer organizations.

The selection and design of an appropriate greywater treatment prototype was beyond the scope of this project. Without a specific design and because of the extensive downsizing required for most available total household wastewater treatment systems it was not considered meaningful to develop preliminary cost estimates based on off-the-shelf prices of individual components.

The "Background" reviews the experience gained from municipal and residential wastewater reuse projects in North America and Japan. Actions taken to win public acceptance are considered. General project evaluation criteria are presented by which to judge the "LIGHT GREY OPTION".

Anticipated greywater characteristics with respect to quantity and quality are derived from the literature as well as reuse quality requirements. Potential treatability problem areas are also identified.

For the benefit of the reader the various candidate unit treatment processes are described with comments on their applicability to the "LIGHT GREY OPTION". This includes the related experience gained from individual home point-of-entry and point-of-use potable water treatment devices.

Based on the information gained from these sources, the report outlines the major components of a suitable greywater treatment system and evaluates the use of some commercially available treatment devices. The final Section of the report suggests what further action could be taken to advance the "LIGHT GREY OPTION".

2.0 BACKGROUND

As a backgrounder to the "LIGHT GREY OPTION" this Section summarizes municipal, commercial, and residential reuse of treated wastewaters in North America and Japan for non-potable applications. The benefits of water reclamation practices are discussed along with their general acceptance by regulatory agencies and the public. The "LIGHT GREY OPTION" means the introduction of these practices in the home on a widespread basis for the first time. General project evaluation criteria are given based on this experience with wastewater reuse.

2.1 Municipal and Commercial Wastewater Reuse

The technological and engineering concepts of wastewater reuse are becoming increasingly well understood and accepted (51). Direct urban landscape reuse, from municipally operated renovation plants has been fully accepted in California, Texas, Arizona, Florida and Colorado (23) (51). Examples of on-site wastewater treatment and recycling systems for commercial buildings with water conservatioin plumbing fixtures can also be found in the USA (50).

The following three projects incorporate the process train provided by the Thedford Corp. Cycle-Let system described later in Section 7 of the report (22) (44).

In Houston, Texas, sewage discharge limits imposed on a high-growth area curtailed new construction projects because of the high land values involved. As a solution, a construction project of the Alliance Bank and Trust Company included an on-site wastewater treatment and recycling system with water conservation plumbing fixtures.

Similarly, on-site treatment and use of reclaimed water greatly reduced the wastewater discharges of the Squibb Corp. building in Montgomery Township, N.J. The system has enabled the Township to control growth and avoid unwanted sewer infrastructure expenses while maintaining environmental goals.

In conservation-conscious Santa Monica, Calif., a 120 thousand square meter (1.3 mil sq. ft.) complex consisting of four buildings for office and retail space produces only 151,000 lpd (40,000 US gpd) as opposed to an expected 264,000 lpd (70,000 US gpd) without water conservation. The complex uses low flush toilets and other water conserving fixtures, on-site treatment, and reclamation for landscape irrigation.

In Japan (33) (39) (40) (51) water reclamation was first practiced "on-site" in the 1970's by using plants based on reverse osmosis technology to provide toilet flushing water in large commercial buildings. In Tokyo, the use of reclaimed water for toilet flushing is mandated in buildings larger than 10,000 m^2 (100,000 sq. ft.). The many diverse uses of reclaimed water in Japan also include cooling water, landscape irrigation, car washing, cleaning and flow augmentation.

2.2 Residential Greywater Reuse

In Canada during the 1970's CMHC sponsored development of the Canadian Water and Energy Loop (CANWEL) with the aim of reducing the reliance of high-rise residential buildings on community services. Treated combined wastewater was to be recycled for toilet flushing and irrigation purposes and heat energy was to be created from waste garbage.

The prototypes for both systems were developed by the then Ontario Research Foundation and installed in a high-rise rental unit in North York owned by Cadillac Fairview Development Corporation. Following extensive field testing attempts to market CANWEL in Canada and abroad were unsuccessful. The concept was ahead of its time and the technology was not cost effective for its time.

Treated residential greywater reuse for either surface or subsurface urban landscape irrigation is approved in Texas and California (23) (51). Texas has permitted reuse of water from bathtubs, showers, sinks and washers since 1989 for surface or drip irrigation. Treatment required consists of filtration and storage.

California legislation goes into effect 1 July 1993 (31). Greywater from showers, bathtubs, bathroom wash basins, clothes washers and laundry tubs may be used for residential subsurface irrigation. **Wastewaters from kitchen sinks and dishwashers cannot be used.**

In Tucson, Arizona, the "Casa del Agua", a three bedroom, two-bath, conventional house serves as an educational showcase and a facility where researchers from nearby University of Arizona can study new water conservation devices and wastewater treatment systems (31). Here, recycled greywater is treated and used primarily for landscape irrigation.

2.3 Wastewater Reuse Plumbing Systems

There are two types of greywater plumbing systems. The first (Type A) has two water supply and two drainage lines. This dual main system supplies potable water to sinks, showers and bathtubs and non-potable (treated greywater) to toilets. The dual drainage system provides one route for greywater and one route for blackwater from the toilets.

In the second system (Type B) there is a single drainage network which brings all wastewaters to a single point for treatment. Benefits include lower piping costs and the ability to reuse the effluent for a greater number of uses. Wastewater treatment costs are higher because all of the flow must be treated to a higher standard of effluent quality.

The "LIGHT GREY OPTION" utilizes the Type A piping system with variations. Potable water is directed to sinks, showers, bathtubs, dishwasher, clotheswasher and greywater recycle system for make-up water as may be required. Used bath/shower water and rinsewaters from the clotheswasher and dishwasher are directed to the greywater treatment system.

The treated greywater is piped to toilets, dishwasher, clotheswasher, and hosebibs for irrigation purposes. Wastewaters from the toilets and all sinks are directed to the blackwater piping system as well as the used washwater from the clotheswasher and dishwasher for discharge to the sewer or on-site sewage disposal facility.

The possibility of accidental cross-connections and use of the greywater system for potable purposes must be prevented (19) (23) (51) (52). Greywater piping should be of a different material (PVC), and colour (purple) than potable water and blackwater piping in the home.

The potable water supply should be maintained at a minimum of 10 psi higher than the greywater recycle system. The outside hosebibs for irrigation should be marked "NOT FOR DRINKING PURPOSES" and/or locked or placed in secured chambers in the ground.

2.4 Benefits of Wastewater Reclamation

Benefits of wastewater reclamation (23) (51) fall into two categories: (1) supplementing available water resources, and (2) enhancing water pollution abatement. When reclaimed water is considered a resource the potential for cost recovery exits. Cost savings in conventional water supply and wastewater treatment by reduced potable water consumption offset the costs of treating and piping reclaimed water for reuse.

For every reclamation project, including individual home applications, cost benefit and feasibility analyses should be conducted to determine that it is economically desirable and that it brings a net benefit to society. The cost-effectiveness comparison should identify the various beneficiaries, estimate the amount of their benefits and determine when these benefits will be received.

2.5 Acceptance of Waste Water Reclamation Practices

For wastewater reclamation projects there needs to be a clear distinction as to whether the water is to be used for potable or non-potable reuse. <u>"THE LIGHT GREY OPTION" for domestic</u>

water conservation advocates greywater reuse for strictly non-potable uses.

Non-potable reuse has potential to be immediately feasible once the equipment becomes available. It should not have to carry the burden of uncertainties and public resistance that constrain potable reuse.

Close involvement with concerned regulatory agencies is necessary in the development and approval of reuse projects such as the "LIGHT GREY OPTION". Consultation prevents regulation prohibition; encourages development of new, accommodating regulations; and persuades responsible agencies of the benefits and safety of the reuse project.

Public acceptance is generally the most critical element in determining success or failure. "THE LIGHT GREY OPTION" can be technically viable, proven safe by the best scientific procedures available, have regulatory agencies in agreement, yet fail for lack of public acceptance.

Gaining acceptance in the home may not happen without considerable effort by government bodies and other advocates. Distrust of public water supplies is already wide-spread with increased use of bottled water and point-of-use treatment devices.

Reclaimed water projects can end abruptly if health issues are not addressed and if the economies are not clearly justified. It is, therefore, essential that the public perspective be taken into account when developing the "LIGHT GREY OPTION".

2.6 General Evaluation Criteria for the "LIGHT GREY OPTION"

Based on the experience of municipal wastewater reuse projects, the proposed "LIGHT GREY OPTION" to be successful should satisfy the following evaluation criteria:

- product acceptability - meet physical, chemical and microbiological water quality necessary for operation of the appliances involved;
- reliability - produce consistently the required water

quality through the use of multiple containment barriers, process equipment redundancy, and adequate storage;

- operability - be easy to operate based on the equipment provided, time required, and expertise required
- flexibility - be responsive to variations in source water quality and quantity and varying use patterns;
- physical requirements - meet space and location needs;
- waste residual requirement - produce a minimum volume of waste products acceptable for final disposal;
- affordability - have affordable capital, operating and maintenance costs.

2.7 Summary

The experiences gained from municipal and residential reuse practices in North Amarica and Japan have been reviewed with respect to applications, dual plumbing systems, and benefits of wastewater reclamation. The need to actively gain acceptance from regulatory officials and the general public has been identified. Evaluation criteria for judging various aspects of the "LIGHT GREY OPTION" have been derived based on this experience with wastewater reuse.

3.0 GREYWATER CHARACTERISTICS

Residential dwellings exist in a variety of forms. Occupancy by different numbers and ages of people can occur on a seasonal, year-round or mobile basis. Water use and wastewater discharge vary, being influenced by a number of factors including availability of water, plumbing fixtures, appliances, frequency of use, and method of wastewater disposal.

Based on data from the literature and from appliance manufacturers, this Section of the report attempts to determine probable greywater volume, and chemical characteristics from a "typical" Canadian four-person residence equipped with state-of-the-art water conservation devices including low-flush toilets and European-designed, front-loading clotheswashers and dishwashers (15) (29). Unfortunately, most of the available quality data is based on characterization studies conducted in the 1970's (8) (21) (26) (27) (32) (35) (55).

3.1 Residential Indoor Water Use Without Conservation

Figures derived from the Environment Canada Municipal Use Data Base suggest an overall daily per capita domestic use of 425 litres (94 gallons) for communities having serviced populations from 300 to 3000 people (9). In actual practice there is a wide variation in per capita water use by region, community, and individual household. On a national basis, indoor domestic water consumption is considered to be 350 litres (77 gallons) per capita per day (11). In contrast, domestic water use in First Nations communities with piped water systems is 287 lpcd (63 gpcd) (49). This also represents indoor use as irrigation is seldom practiced.

The "LIGHT GREY OPTION" assumes a total indoor use for a family of four of 750 litres or 188 lpcd (41 gpd) (Case A). Based on 350 lpcd (77 gpd), the indoor use for a family of four would be 1400 lpd (308 gpd) (Case B). Both cases of water consumption are used in this Section of the report as a basis for sizing the necessary greywater treatment system.

3.2 Anticipated Water Use With Conservation Devices in the Home

From the referenced literature (2) (8) (11) (21) (23) (25) (27) (32) (35) (41) (42) (44) (54) (55) the following distribution of inside water use in households has been taken based on conventional fixtures and appliances:

Purpose	Percent of Total Water Use
Toilet Flushing	39
Bathroom (showers & baths)	29
Bathroom Lavatory	3
Cooking/Drinking/Kitchen	5
Dishwashing	3
Laundry	18
Miscellaneous	3
	100

Based on reported studies (11) (23), expected savings using low flush toilets 6 lpf (1.6 gpf); showerheads 9.5 lpm (2.5 gpm); and lavatory faucets 7.6 lpm (2 gpm) are:

Fixture	Percent Savings	Assumed for "LIGHT GREY OPTION"
Toilet	60 - 70	65
Showerhead	33 - 53	40
Faucet	15 - 50	30

Tests on front loading clotheswashing machines published in 1991 by the Australian Consumers Association (3) showed there was a great variation in the overall water consumption of the different machines tested. The Thor W1116 RX (Italy) front loader was the most water efficient, using a total of 15 l/kg (1.5 gal/lb) of washing in a complete cycle.

Front loaders generally used 80 to 120 litres (18 to 26 gallons) for a complete cycle while top loaders used from 120 to 180 litres (26 to 40 gallons) of water for each complete cycle. These results suggest that on average front loaders use about one third less water than top loaders. USEPA (53) reports for conventional, top loading clotheswashers actual average use ranges from 87 to 200 L (19 to 44 gal) for each cycle.

Assuming front loading clotheswashing machines use 95 litres (20 gal) per cycle and top loading machines use 150 litres (33 gal) per cycle, conversion to presently available European machines could save 37 percent of present North American water use for clothes washing.

The Miele dishwashers (29) use 20 l (4.4 gal) for a regular wash. The Siemans dishwashers (15) use 22 l (4.8 gal). North American dishwashers use from 23 to 72 l (5 to 16 gal) for a normal cycle. Based on Maytag, the apparent water saving by using the European dishwashers is 42 percent.

For the "LIGHT GREY OPTION", with all of these water conservation devices installed, for a 4-person household the expected water use would be:

PURPOSE	CALCULATION	CASE A (Base Use-750 lpd)	CASE B (Base Use-1400 lpd
Toilet Flushing	A/B x .39 x .35	102.4	191.5
Bathing	A/B x .29 x .60	130.5	244.0
Bathroom Lavatory	A/B x .03 x .70	15.8	29.5
Cooking/Drinking/Kitchen	A/B x .08	60.0	112.2
Dishwashing	A/B x .03 x .58	13.0	24.3
Laundry	A/B x .18 x .63	85.1	159.1
Miscellaneous	A/B x .03	22.5	42.1
	TOTAL	429.3	802.7

The indicated overall gross saving in water use is about 43 percent for both CASE A and CASE B. This does not include residue-bearing waters that must be wasted from the system.

3.3 Greywater Generation/Use in the "LIGHT GREY OPTION"

From the previously developed figures (Section 3.2) the average amount of water available per day for recycle would be:

SOURCE		CASE A 750 lpd		CASE B 1400 lpd
			litres pd	
Bathing		130.5		244.0
Clotheswasher	(77% rinse)	65.5	(73/cycle)	122.5
Dishwasher	(50% rinse)	6.5	(10/cycle)	12.1
	TOTAL	203.3		378.6

The average amount of water required for reuse per day would be:

USE		CASE A		CASE B
Toilet flushing		102.4		191.5
Clotheswasher	(23% wash)	19.6	(22/cycle)	36.6
Dishwasher	(50% wash)	6.5	(10/cycle)	12.1
	SUB-TOTAL	128.5		240.2
Irrigation/Waste		74.8		138.4
	TOTAL	203.3		378.6

On the average, mainly because low-flush toilets are used, the "LIGHT GREY OPTION" will produce more greywater for reuse than is required within the home. Excess will be wasted ahead of greywater treatment or treated for seasonal irrigation purposes. Depending on the treatment process utilized, potable make-up water may be required to prevent an undesired buildup of dissolved solids as a result of recycling.

It must be noted that the volume of greywater from bathing alone appears to be sufficient to meet the indoor reuse volume requirement. These daily figures should be recognized as representative average figures only. To be practical, there must be sufficient water available to accommodate wide variations in use on demand and to provide an adequate safety factor. Further, if only bath water were recycled there would be no water available for summer irrigation.

3.4 "LIGHT GREY OPTION" Greywater Quality

The chemical characteristics of wastewaters are usually expressed as concentrations, ie mg/l. This assumes that the actual flow rate is taken into account. Errors are made in manipulating such data from different studies unless the respective wastewater flows are used. This problem is avoided by expressing concentrations as grams per capita per day.

Available greywater quality expressed in grams per capita per day from the literature (26) (35) (57) is given below:

Parameter	Bath/ Shower	Washing Machine Wash	Washing Machine Rinse	Dishwasher Wash (57)	Dishwasher Rinse (57)	Total (35)
BOD5	3.2	8.0 - 10.8	4 - 8.7	0.5	0	1.3
COD	7.2	21.4	24	0.9	0	-
TS	4.6 - 10.9	24.2 - 37.5	9.1 - 10.9	3.5	0.2	1.8
TVS	0.6 - 3.6	3.8 - 14.7	1.8 - 4.8	0.6	-	1.0
TSS	0.9 - 2.3	2.5 - 7.9	0.9 - 3.0	0.1	0	0.5
VSS	0.9 - 1.6	4.7	1.8	-	-	0.4
PO4	0.0 - .04	0.6 - 1.6	0 - 0.6	0	0	0.08
Total N	0.0 - 0.03	0.2 - .38	.15	0	0	0.05
TOC	1.8	7.7	.26	-	-	0.7
Temp •C	85 29	32	26	-	-	38

Washing machines contribute the most contaminants with dishwashers the least. These values may not be truly representative of greywater from the water conservation appliances assumed in use in the "LIGHT GREY OPTION". Nevertheless, the indicated "LIGHT GREY OPTION" chemical concentrations based on averaging of these data are:

Parameter	Total Contribution grams/day	Greywater Concentration mg/l CASE A	Greywater Concentration mg/l CASE B
BOD_5	37	191	100
COD	62	307	162
TOC	9	46	24
TS	74	364	192
TSS	16	80	42
TKN	17	8	4
TP	5	2	1

3.5 Summary

The indicated additional gross saving in water use with the "LIGHT GREY OPTION" is about 43 percent. It will take detailed cost benefit analysis once the technology is in place to determine whether this is sufficient with residue loss to justify the "LIGHT GREY OPTION".

Assuming the use of 6.0 lpf (1.6 gpf) low flush toilets, 9.5 lpm (2.5 gpm) showerheads, 7.6 lpm (2 gpm) lavatory faucets and presently available European washers with modified plumbing the "LIGHT GREY OPTION" four-person house is expected to use a total of between 430 lpd (95 gpd) and 800 lpd (175 gpd). The amount of greywater generated by the "LIGHT GREY OPTION" is expected to range between 200 lpd (44 gpd) and 380 lpd (84 gpd). The average amount of greywater required for reuse would be between 130 lpd (29 gpd) and 240 lpd (53 gpd) leaving a surplus at all times for irrigation.

Compared to combined household wastewater and conventional greywater, the "LIGHT GREY OPTION" greywater is low in total suspended solids. CASE B with higher water use produces a greywater which is also low in BOD_5 which may make biological treatment difficult.

4.0 GREYWATER REUSE CHEMICAL QUALITY HEALTH CONSIDERATIONS

The level of greywater treatment to be provided depends on the quality required for its intended uses. Determining quality requirements is the task at hand in further advancing the concepts of the "LIGHT GREY OPTION".

In "THE LIGHT GREY OPTION" most health concerns are minimized by using the recycled greywater only for toilet flushing, irrigation (optional) and by direct plumbing to appliances for washing purposes. The recycled greywater is not used for bathing or drinking purposes.

Nevertheless, precautions to prevent cross connections and inadvertent consumption will have to be taken by the designer/contractor and by residents alike. Disinfection is deemed necessary to provide a public health safety factor and to limit biofouling in the greywater treatment system.

Aesthetic considerations include appearance (colour and turbidity) and odour related to toilet flushing and irrigation. Also chemicals causing staining (iron/manganese, dyes) of toilets and washing machines must be kept at acceptable levels.

4.1 Toilet Flushing

The water for reuse for flushing toilets does not require high standards, because it is not to be ingested or to come in contact with the body. The detergents from laundry operations should make the water safer from a health viewpoint since many detergents are bactericidal. Also, any bad taste from soaps and detergents should discourage small children who might accidentally ingest the water.

The use of a coloured dye in the recycled water itself is ruled out for "LIGHT GREY OPTION" because the recycled water is used for other purposes (washing and irrigation). Such a dye could still be added by a toilet tank dispenser.

The main treatment problem is to make the water aesthetically acceptable to the average housewife (42). Reasonable criteria for toilet flushing are minimum odour and minimum staining properties. Manganese, iron, and copper limits may be necessary to prevent staining.

Suggested toilet flushing water standards (42) are:

A. Physical Characteristics

Turbidity	20 units
Colour	30 units
Odour	6 units

B.

Tentative Limits of Staining Agents	Concentration mg/l
Mn	0.5
Cu	1.0
Fe	1.0
Fe + Mn	1.0

4.2 Washing

Limits on the solids concentrations must be maintained because of the requirement for heating the water and the fact that water with high dissolved solids will leave deposits on evaporation. The chemical concentration of other substances can be substantially increased for laundry use without increasing the concentrations above the levels normally found in the water to which cleaning and laundering products have been added.

Some of the substances may linger on cleaned clothes. Any increase in concentration level will be unnoticeable and non-toxic to children who occasionally chew on their clothes.

Suggested quality criteria (42) for general washing are:

Physical Characteristics	
Turbidity	10 units
Colour	15 units
Odour	3 units

Chemical Characteristics	Concentration mg/l
Alkyl Benzene Sulfonate (ABS)	2.0
Arsenic (As)	0.05
Barium (Ba)	1.0
Cadmium (Cd)	0.01
Chloride (Cl)	500.0
Chromium (Cr)	1.5
Copper (Cu)	2.0
Carbon Chloroform Extract (CCE)	0.4
Cyanide (CN)	0.2
Iron (Fe)	1.0
Lead (Pb)	0.05
Manganese (Mn)	.05
Iron and Manganese	1.0
Nitrate (NO_3)	180.0
Phenols	0.01
Sulfates (SO_4)	500.0
Zinc (Zn)	10.0
pH	6.0-8.3

4.3 Lawn and Garden Irrigation

Standards for irrigation are less exacting than for household uses (42). The use of an individual household effluent for irrigation purposes, however, would require closer supervision to prevent possible plant damage. Boron, for example, can cause plant damage in very low concentrations. Tolerance ranges run from 0.5 to 1.0 mg/l for slight to moderate damage for sensitive crops, 1.0 to 2.0 mg/l for semi-tolerant, and 2.0 to 4.0 mg/l for tolerant crops. As borates are frequenty a constituent in household cleaners, it is conceivable that these concentrations could be occasionally exceeded. in greywater.

Surfactants may cause problems. Foams may be produced at low concentrations (0.7 mg/l) and may prove offensive in a sprinkler system. Non-biodegradable detergents could also pollute ground water if applied to a lawn and garden in sufficient quantities. Limits are therefore recommended for surfactant substances for lawn irrigation.

Sulphates in high concentrations are reportedly injurious to plants. It is recommended that 500 mg/l be allowed as a limit for lawn irrigation.

The limit for copper at the 1.0 mg/l level of the Drinking Water Standard (20) should be kept. For irrigation, a level of 0.5 mg/l manganese is permissible.

Chloride must also be limited to a level of 500 mg/l for lawn irrigation. A lower limit would be better, but this level is not infrequent in some areas. Phenol levels of up to 50 mg/l have been found to be acceptable for irrigation but at these levels strong odours exist. A phenol limit of 0.01 mg/l as recommended for washing purposes will avoid such odour problems.

Other compounds, such as nitrates which have fertilizer properties, could be further increased, but the stipulation of water not harmful for accidental ingestion suggests limits for these compounds similar to the values used for wash waters.

The requirements for municipal open space irrigation in Florida (23) are:

General Treatment of Reclaimed Water

USE	Treatment/Service Requirements
Non-potable urban	Secondary effluent 20 mg/l BOD_5 and TSS 1.0 mg/l chlorine residual Total coliforms, 200/l Filtration recommended

St. Petersburg, Florida's Water Reclamation System - Residential irrigation	Chloride - < 600 mg/l Turbidity - < 2.5 nephelometric turbidity units (NTU) Suspended Solids - < 5.0 mg/l Chlorine Residual - > 4.0 mg/l
Altamonte Springs, Florida - - Residential irrigation	City valve box cover square and marked "Reclaimed Water". Customer in-ground hose bib box equipped with a special wrench-type locking device and lid marked "Irrigation - Reclaimed Water, DO NOT DRINK"

4.4 Health Problems From Microorganisms

In the reuse of treated greywater for toilet flushing and irrigation the possibility of exposure to pathogens exists. To provide health protection the treatment train for the "LIGHT GREY OPTION" calls for a disinfection process.

In addition, precautions should be taken by the residents to minimize body contact. For example, an in-ground irrigation system for lawns and gardens would substantially reduce exposure to microorganisms and aerosols (23). Disinfection treatment may have to be provided between uses to produce water of acceptable microbial quality if irrigation is done only periodically.

4.5 Potential Problems Resulting from Household Products (16)

The use of commercial products in the home may present public health problems but certainly have the potential to impact adversely on greywater treatment systems, especially biological processes. The following three categories are of concern: heavy metals, organic chemicals and volatile organics.

4.5.1 Heavy Metals

Estimated daily per capita contributions of heavy metals from household consumer products are:

Metal	Product (Highest two contributors)	Amount (Milligrams per capita per day)
Arsenic	Powder laundry detergents	0.2155
	Powder automatic dish detergent	0.0382
Cadmium	Powder laundry detergents	0.0042
	Powder automatic dish detergent	0.0019
Chromium	Bar soaps	0.03837
	Powdered laundry detergents	0.0151
Copper	Toilet tissue paper	0.0331
	Bar soaps	0.0109
Lead	Automatic toilet bowl cleaner	0.0066
	Powder laundry detergents	0.0034
Mercury	Liquid Bleach	0.00083
	Powder laundry detergents	0.00023
Nickel	Bar soaps	0.0140
	Powder laundry detergents	0.0109
Silver	Powder laundry detergents	0.0050
	Liquid laundry detergents	0.0031
Zinc	Bar soaps	0.2983
	Shampoos	0.1662

Since the recycled greywater is not to be consumed the presence of these metals should not present a hazard to human health. However, for the "LIGHT GREY OPTION" the predominance of metal bearing laundry and dishwasher detergents may have an adverse effect on the greywater treatment system if biological processes are utilized. Body washing greywaters tend to contain metals from shampoos and bar soap thus providing no metal-free dilution water. This threat of toxic metals could be reduced by using products having minimal metal content.

4.5.2 Organic Chemicals

Many hazardous organic chemicals are also found in unseparated residential wastewaters. These include solvents, paint thinners and degreasers, methylene chloride, benzene and toluene, pesticides such as DDT and lindane, incomplete combustion products called PAHs and plastic components. Other organics including acetone, benzoie acid and benzl alcohol come from cosmetics, personal care products, adhesives, and disinfectants. Home improvement and hobby activities also contribute organic chemicals.

For the "LIGHT GREY OPTION" these undesirable chemicals could appear in the greywater from body and clothes-washing. Hand washing of offensive work clothes with discharge to the blackwater piping system would be a good practice.

4.5.3 Volatile Organics

In toilet flushing there will be some release of volatile chemicals into the air by evaporation but the amount will be small. There is also a slight risk of small quantities of non-volatile chemicals being aerosolized.

There is a potential hazard from automatic dishwashers due to inhalation of volatilized chemicals released from the machines. Similarly, an automatic clotheswasher has the potential to release significant quantities of volatile chemicals into residential air.

4.5.4 Surfactants

Surfactants found in dishwashing products may cause undesirable foaming in the greywater treatment system, especially as aeration is a desired process for the release of volatiles. This potential problem can also be minimized by the proper selection of washing products used in the home.

4.6 Summary

The main quality considerations are aesthetic requiring the control of turbidity, colour, odour and staining. It is a given that disinfection will be provided as a public health safeguard and for the control of biofilm development in the greywater system.

Excessive foaming must be avoided. Opportunities must be provided for volatile organics to exit the system under controlled conditions. Dissolved solids built-up through recycling may have to be removed by the use of membrane technology

The introduction of non-sewage chemicals into the greywater treatment system can present problems, both directly to human health and to treatment system operations. Every effort will have to be made to keep the offensive products/chemicals out of the greywater system.

5.0 GREYWATER TREATABILITY CONSIDERATIONS

Previous sections 3 and 4 have developed anticipated greywater flows, discussed greywater characteristics, offered reuse quality criteria, addressed health considerations and pointed out the possible impact of commercial products use on greywater treatment processes. This Section looks further at the implication of these findings on greywater treatment itself.

5.1 Particulate Matter

Because of the nature of the reduced suspended solids sedimentation with accompanying anaerobic treatment is not as effective as for combined wastewaters or blackwaters alone (9). The amount of suspended solids is an important consideration when reuse includes hose nozzles or any other restriction in the line.

For "THE LIGHT GREY OPTION" grease will be minimized as the kitchen sink wastewater is directed to the blackwater system. However, depending on resident habits, grease may still be present from dish and clothes washing operations. Further, because household grease is warm more time is needed for it to harden.

Hypes (21) characterized the undissolved particulates of organic matter, lint, grit and hair in a laboratory-simulated home system. He found the following particle size distribution.

1 - 2 microns	13 percent
3 - 10 microns	75 percent
11 - 19 microns	10 percent
Over 19 microns	2 percent

Generally, little settleable or floatable material is to be expected in the greywater of the "LIGHT GREY OPTION". This means that simple sedimentation or coarse screening will be relatively ineffective in removing this fine particulate matter.

5.2 Organic Loading

The "LIGHT GREY OPTION" as originally proposed results in a relatively weak wastewater to be treated even with reduced flows. Some researchers (26) (42) (56) consider conventional greywater to be more biodegradable than blackwater because of the reduced COD/BOD_5 ratio and because more of the BOD_5 is soluble. Others (10) rationalize that the act of removing toilet wastes and especially kitchen wastes, leaves greywaters less susceptible to biological treatment.

For the "LIGHT GREY OPTION", if a biological process such as extended aeration activated sludge is used in the greywater treatment train, it may be beneficial to install a garbage grinder in the home. Supplied with recycled water the garbage grinder would provide organic food material to the microorganisms involved.

Garbage grinders require about 7.5 l (1.6 gals) per use. Based on 0.58 uses per capita per day the daily use is 4.4 l (0.9 gal) (54) which is not significant.

5.3 Nutrients

Between 50% and 86% of all the phosphorus in combined sewage can be found in greywater. Most originates from the laundry. (41).

The data in Section 3.4 Greywater Quality shows up to 1.6 grams pcd phosphate and 0.6 grams pcd total nitrogen in the washwater from clothes washing machines. If there are not sufficient nutrients in the wash waters for good biological treatment, then as for organic loading, they could be enhanced with the addition of ground kitchen wastes.

5.4 Impact of Household Commercial Products (16) (42)

Greywater contains small but potentially significant amounts of hazardous chemicals from the water supply, plumbing, foods and the many, varied modern consumer products used in homes to-day. Sources and types of Commercial Products affecting

"THE LIGHT GREY OPTION" are listed below:

Source	Type of Product	Metals of Concern
Laundry machine	Detergent	Arsenic, mercury
	Bleach	Cadmium, nickel
	Softener	Chromium, silver
	Soil/household	Lead
	Substances from clothing	
Dishwasher	Dishwashing liquid	Arsenic
	Stain prevention liquid	Cadmium
Bathtub/Shower	Soap	Chromium, nickel
	Shampoo	Copper, Zinc
	Body soil/household	
	Substances on skin	

These commercial products contain important trace elements (heavy metals) and surfactants plus trace organic compounds of concern to biological treatment processes as discussed in Section 4.5.

5.5 Colour, Odour and Volatiles

As discussed previously selected treatment processes must be capable of reducing colour to acceptable levels. Clothes washing requirements are most critical for the "LIGHT GREY OPTION". Colour resulting from staining by trace metals or biofouling must also be kept under control.

Unpleasant odours are a major concern in the reuse of greywaters as are the volatile chemicals which may be given off at the treatment facility or at points of use. Preferably, the treatment process will include aeration to drive off the volatiles and minimize anaerobic, gas-producing conditions.

Adequate covering and venting of the affected treatment process units will have to be provided whether located inside or outside the dwelling. Soil treatment of the vented gases may be deemed necessary in particular cases.

5.6 Summary

In designing a greywater treatment system for the "LIGHT GREY OPTION" particular attention must be paid to those factors which may impact negatively on the selected processes. Further, the designer should avoid processes which do not contribute significantly to the removal of undesired contaminants. These considerations are discussed further in the next Section.

6.0 APPLICABLE TREATMENT PROCESSES FOR GREYWATER

This Section considers the various treatment processes which are available in the individual home wastewater treatment market which could be utilized to make the "LIGHT GREY OPTION" happen. It also looks at the performance of similar processes incorporated into point-of-entry and point-of-use residential potable water treatment devices. (4) (5) (7) (13) (14) (23) (24) (30) (42) (43) (46) (50) (53) (56).

6.1 Unit Processes

Unit processes and their relative capabilities to remove specific contaminants are given below (23).

CONTAMINANT BARRIER

CONTAMINMANT	Biologiocal	Filtration	Activated Carbon	Membrane Demineral-ization	Chemical Oxidation/ Disinfection
Suspended Solids	◘	◘		◘	
Dissolved Solids				◘	
Biological Oxygen Demand	◘	◘	◘	◘	
Total Organic	◘		◘	◘	
Volatile Organic Chemicals	◘		◘	◘	◘
Heavy Metals	◘			◘	
Nutrients				◘	
Radionuclides	◘			◘	
Microbial Factors		◘		◘	◘

Contaminant removal is considered to be a relative measure of unit-process ability to act as a barrier to that contaminant. Unit processes identified as contaminant barriers are expected to remove at least 50% of the contaminant.

6.1.1 Sedimentation

Holding tanks, such as septic tanks, provide for the retention of some solids and scum if the hydraulic detention time and baffling arrangements are adequate. The tanks also provide a location for manual screening devices. As stated previously, the build-up of solids is less for greywater than combined wastewaters.

6.1.2 Biological Processes-Activated Sludge

Activated sludge processes remove gross levels of organic matter from water, thus preparing the water for further processing if required. Although biological treatment removes substantial amounts of suspended matter, its principal function is to reduce the dissolved organic matter to relatively low levels.

Well-operated biological treatment plans produce effluent with soluble 5-day BOD of 1 to 2 mg/L. Additional benefits of biological treatment include reduction of pathogen content; reduction of heavy metals and radionuclides; stripping of volatile organic chemicals; and stripping of radon if it is present in the waste-water.

Biological treatment is subject to shock loading such as from heavy metals and disinfectants. Aeration also tends to generate foam.

6.1.3 Rack Filter

The rack filter is used to pretreat greywater. The primary function of this unit is to remove particulate matter. Greywater is passed through the filter media and collected within the tank. Once the filtered greywater is collected, the solids settle and the grease portion floats. The treated greywater then is discharged through a baffle and is ready for further treatment/reuse or direct reuse.

The rack filter is not a commercial device. It is home built. The construction of this device is relatively simple. Materials consist of a tank (55-gallon drum), home-made rack (coarse mesh screen), piping, and filter media (crushed stone, hay, wood shavings, etc.).

6.1.4 Filtration

Granular-media filtration, as used for swimming pools, removes the majority of suspended matter remaining after biological treatment. Following biological treatment, filtration produces turbidity levels of 1 to 2 NTU. The removal of suspended matter results in a reduction of the microbial contamination of the water.

Filters have been used for greywater treatment directly following screening and sedimentation. Particle removal is by simple mechanical straining. Reportedly these filters can remove particles down to the 10 micrometer range. When pressure drop across the filter reaches a preset point, the unit will automatically backflush. Alternatively, an automatic timer regulates backwash to suit water usage and degree of suspended solids.

6.1.5 Recirculating Filters

Underdrained recirculating sand filters with pump and recirculation tank are used to up-grade conventional wastewater septic tank effluent before soil absorption. Located inground, outdoors, they could be incorporated into a greywater treatment recycle system.

They would provide aeration and suspended solids removal with potential to produce an aesthetically acceptable effluent. The filters are built in place using standard design criteria.

6.1.6 Aeration and Activated Carbon

The processes available for removal of volatile organic compounds are aeration and absorption on granular or powdered activated carbon or a combination of both.

Aeration can be provided in the collection tank or ahead of media filters. Where the activated sludge process is used there is no additional requirement for aeration as it is integral to the process.

Activated carbon filters absorb organic and inorganic compounds that contribute to colour, odour and taste. A potential problem with these devices is that the trapped organic material serves as a nutrient source for bacteria. A disinfection device should be used up/or downstream of these devices to ensure bacteria are killed where organic material concentrations are high.

6.1.7 Membrane Treatment

Demineralization, specifically membrane treatment, is the one method that bars all contaminants, including pathogenic organisms, organic chemicals, heavy metals, radionuclides, nutrients, and dissolved solids. Reverse osmosis and ultrafiltration are the most widely used membrane processes.

Membranes are essentially plastic sieves where the sieve size can vary all the way from the size of the water molecule, or essentially zero, up to micron size. Depending on the pore structure, membranes have different names. The large pore membranes suitable for removing particulates are called microfilters. Membranes that remove dissolved molecules from a fraction of a micron down to ten angstroms or less, are called ultrafilters while membranes that remove very small dissolved molecules from water, are referred to as reverse osmosis membranes.

In reverse osmosis water is forced through a semi-permeable membrane. This permeate or product water transfers through the membrane while the dissolved ionizable solids, particulates and organic matter unable to pass through the membrane, are flushed to drain as the concentrate or wastewater. The science of membrane manufacturing has improved so much in the last few years that it is now possible to operate reverse osmosis devices at tap pressure in homes.

The major disadvantage of these devices is their poor water-use efficiency. Usually only about 10% of the water is purified, the remaining 90% is wasted to a drain after flushing the membrane. Some units do, however, employ a recycling device that increases the efficiency to 20 - 50%. For this reason reverse osmosis technology would not likely be used for the "LIGHT GREY OPTION" unless it were deemed an essential process for dissolved solids removal, or required for system reliability, to be used intermittently only as needed.

6.1.8 Disinfection/Chemical Oxidation

Disinfection is normally the final barrier to microbial organisms. It is most effective at the end of the treatment process where very little suspended matter remains in the water, and oxidant demand has been greatly reduced.

Candidate methods are chlorination, ozonation and ultraviolet light. Ozone can also be used to oxidize organic compounds responsible for colour, odour and taste problems in water into insoluble products that can be removed by filtration.

6.1.8.1 Chlorination

Chlorination requires the addition of a chlorine product in solution, powder or tablet form, which is its major dissadvantage for household use. Its advantage is providing a residual which can be measured by a simple testing kit.

6.1.8.2 Ozonation

In a typical household ozone generator, air passes between two charged electrodes and the resulting high tension voltage discharge converts a small fraction of the oxygen in the air (1% by weight, under optimal conditions) into ozone. It must be immediately bubbled through the water and quickly dispersed for effective disinfection.

Generally, household-type ozonation units consist of a large box with a hose emanating from it that bubbles ozone into a container of water using only a timer as a control. Unlike commercial equipment, household units are normally not equipped with air-driers. Resulting high relative humidities can reduce the production of ozone. Moreover, since ozone has a short half-life and quickly reverts back to oxygen, the oxidation of organic compounds in water is often incomplete causing them to remain unaltered in the water.

6.1.8.3 Ultraviolet Light

Ultraviolet light (UV) devices are potentially effective, reliable, and have the advantage that they do not leave any residual taste or chemicals that can react with other substances in the water. Water is exposed to light from a special lamp at a specific wavelength which is capable of killing bacteria.

Because UV light leaves no residual disinfectant, stored water may become contaminated by photo-reactivation or by subsequent recontamination.

Disinfection is adversely affected by turbidity. Sediment filters are therefore required upstream of the unit if turbidity is a problem. Iron, if present, will coat the lamp and also reduce efficiency.

6.1.9 Solar Aquatics

Solar aquatic technologies based on plants sunlight and natural biota in the form of artificial wetlands and greenhouse systems are being used more and more to solve domestic wastewater treatment problems of rural communites and of on-site buildings. These systems have the potential of being down-sized for residential greywater recycle applications.

6.2 Experience of Point-of-Entry/Point-of Use Potable Water Treatment Devices

A number of companies manufacture and market point-of-entry/point-of-use potable water treatment devices for household application which incorporate the same processes applicable to greywater treatment. Familiar company names include AMF-Cuno, Culligan, Everpure and Trojan. These companies also offer commercial-scale equipment which could be adapted to residential, greywater treatment as required for the "LIGHT GREY OPTION".

It will be expedient to learn from the experience of such products in the treatment of residential water supplies before considering their application to greywater treatment. The following comments on point-of-entry (POE)/point-of-use (POU) potable water treatment devices are taken from a selection of references (6) (17) (18) (36) (37) (47) (48) dealing with their efficacy and efficiency.

6.2.1 Activated Carbon Filters

The removal of total organic carbon (TOC) varies widely. Filter life expectancy varies for different compounds. Few available activated carbon devices incorporate any means of alerting users of when to replace the filters. Users have only the manufacturer's replacement guidelines to follow.

Precoat filters have a finely powdered filter medium of activated carbon, applied to the influent side of the barrier/membrane side of the filter. Tastes and odours can be removed but the capacity for removing total organics is usually less than for granular bed filters of similar size because the amount of activated carbon is less.

6.2.2 Reverse Osmosis

Water supplied to reverse osmosis units must be low in hardness or must be pre-treated as hardness ions will scale the membrane causing it to "foul" or plug. This necessitates frequent replacement. Ideally, hard waters should be pre-softened with a softener before being processed. Alternatively, a special antiscalant polymer can be used in conjunction with reverse osmosis devices to inhibit scaling. This chemical increases the solubility of hardness ions preventing scaling of the membrane. Though effective, this approach adds to the complexity of a reverse osmosis system.

6.2.3 Microbiological Considerations

Both of these treatment devices have the potential of harbouring and growing microorganisms initially removed from the water. The potentialy most serious problems occur with activated carbon filters which contain absorbed organic material. The problem is noticeable after stagnation periods as short as 8 hours.

For greywater recycle systems it is necessary to control microorganisms present not to the high level required for drinking water purposes but to a lower level to prevent objectionable biofouling. Biological accumulations might adversely affect the aesthetic quality of the greywater (colour, odour, staining) and the hydraulic characteristics of the system (head losses, flow distribution).

6.2.4 Ultraviolet Light

Flow rates through ultraviolet light devices must be such to ensure proper disinfection. UV disinfection devices should incorporate a device for monitoring the UV transmission to ensure the unit is delivering the proper dose. They shut off or warn the user when disinfection is less than adequate. A water flow restrictor should be used to ensure the capacity of the unit is not exceeded.

6.3 Summary

This Section focuses on the treatment processes that could be used to constitute a greywater treatment facility for the "GREY WATER TREATMENT OPTION". It describes these processes in general terms pointing out their effectiveness to remove particular contaminants.

Certain advantages and disadvantages based on the experience from point-of-entry/point-of-use residential potable water treatment devices are also included. The only process identified to have limited applicablity is membrane filtration (reverse osmosis) because of its high reject flow).

7.0 GREYWATER TREATMENT OPTIONS

The previous sections of the report have attempted to establish treatment requirements for the "LIGHT GREY OPTION" with respect to chemical, aesthetic and microbiological factors; and to the greywater flow from two typical, four-person residences with different, water-use habits. The report has also reviewed the suitability of selected, potable water and combined domestic wastewater treatment technologies for treatment of the greywater as required by the "LIGHT GREY OPTION".

Included is an assessment of the experiences gained from the use of various residential potable water treatment devices employing the same processes that would be applicable to greywater treatment as required for the "LIGHT GREY OPTION". Section 7 takes this experience together with the availability of domestic, combined wastewater treatment equipment to identify potentially suitable greywater treatment systems for the "LIGHT GREY OPTION".

Treatability of the "LIGHT GREY OPTION" greywater is an unknown at this time. The effectiveness of sedimentation for suspended solids removal and biological treatment for organics removal are in question. It is not known whether activated carbon treatment is necessary for organic, colour, and volatile chemicals removal; and membrane technology for dissolved solids control. The method of disinfection used will depend on the turbidity of the treated effluent.

In considering an appropriate greywater treatment system for the "LIGHT GREY OPTION" with these uncertainties there is a wide range of options from the relatively simple to the most complex, which includes in series all of the unit processes that have been discussed in the report. Addressing all of the possible combinations and considering all available equipment on the market is beyond the scope of this report.

Any greywater treatment process which will satisfy the evaluation criteria given in the Background would consist of some or all of the following components:

1. <u>Storage Before Treatment</u>

   - flow equalization (operating volume of about 182 l (40 gal)
   - prescreening
   - retention of solids
   - vented
   - quality monitoring
   - rejection of supply for quantity or quality reasons
   - aeration (optional)

2. <u>Biological and/or Physical Treatment Processes (Preferably Multibarrier)</u>

   - particlulates
   - organics
   - colour, odour
   - inorganics & heavy metals
   - volatiles
   - microorganisms
   - vented

3. <u>Disinfection</u>

   - before or after treated water storage

4. <u>Treated Water Storage</u>

   - flow equalization for peak/instantaneous demand (operating volume in the order of 182 l (40 gal)
   - contact times for pre-disinfection reactions
   - protected from contamination
   - monitoring and rejection

5. Protection Against Build-Up of Undesirable Constituents

- residue wastage to sewer or on-site blackwater treatment
- makeup water from potable source
- membrane filtration (reverse osmosis) as a last resort

6. Piping Pumps Controls

- colour coded
- automatic operations

7. Process Redundancy

- standby units
- standby spare parts
- alternative discharge in case of power outage or breakdown

The remainder of the Section looks at some commercially available equipment which could be incorporated into a treatment train for the "LIGHT GREY OPTION". In most cases the presently available equipment would have to be downsized for residential use. It is assumed that along with pumps and controls, filtration, and disinfection equipment in the sizes required are available from a number of suppliers already in the home water treatment and swimming pool markets. (See Appendix B for a listing of representative companies).

7.1 Clivus Multrum Rouching Filter and Soil Bed Treatment (12)

7.1.1 Description

Clivus Multrum, in marketing its large type biological toilets, offers a greywater roughing filter for the treatment of residential greywater.

The roughing filter consists of a self-contained tank with twin fabric stretch filters, storage capacity and submersible effluent pump. The filters catch fibers and larger particles allowing water to pass through the fabric even when biofilm develops on the surface. One filter is operated at a time.

Once taken out of service the lead filter is allowed to dry out before being replaced. A manually operated three-way valve is provided for directing the flow to the filters.

The roughing filter effluent, which still contains organic matter in solution and suspension is distributed through subsurface injection irrigation pipes into an underdrained planter tank which contains top soil, sand, gravel and drain system. The filtered water collected at the bottom drain is normally of good enough quality for irrigation purposes. The rich organic soil supports a variety of plantings. Besides mechanical filtration, the greywater is treated biologically under aerobic conditions by the organisms associated with the root zone of the plants.

Greywater soilbed irrigation can take place indoors or outdoors depending on climate. For year-round use in most locations in Canada greenhouse space would be required to utilize this technology.

Clivus Multrum technology including the use of peat moss is being studied at the West Virginia University Technology Education Research and Demonstration House (TERAD) on campus (31 April 1992). The treated greywater is discharged to the sewer so is not being evaluated for reuse applications.

7.1.2 Comments

The roughing filter represents one type of straining device ahead of the collection or flow equalization tank. One standby filter is provided for service when the first filter must be cleaned because of plugging. The underdrained mixed media soil bed filter will aerate the greywater providing biological and physical treatment prior to reuse.

Performance data would have to be obtained on these Clivus Multrum units to determine whether the effluent quality is suitable for the "LIGHT GREY OPTION". A possible limiting factor would be the requirement for greenhouse space to promote plant growth.

7.2 AlasCan Biological Greywater Treatment (21)

7.2.1 Description

AlasCan Inc., Fairbanks, Alaska, markets a three-chambered extended aeration treatment process for treating household greywater. The effluent is usually discharged to a soil absorption system.

The fibreglass rectangular tank is 140 cm (56 in.) high, 90 cm (35 in.) wide and 235 cm (92 in.) long. It is divided into three sections by internal baffles (influent surge chamber, reaction chamber and effluent settling chamber). An air compressor is used to supply air to the first two chambers and to return biological solids from the effluent chamber to the reaction chamber. A pump is used to remove excess accumulated solids from the greywater tank to the accompanying biological toilet..

The working volume is 945 l (200 gal.). The surge tank capacity is 190 l (42 gal.) or 20 percent of the working volume. The minimum design flow for a four occupant home is taken as 613 lpd (135 gpd). Based on 24-hr. retention in the reaction chamber and 4 hours in the settling chamber, which are standard for the extended aeration process, the design flow is 782 lpd (172 gpd).

7.2.2 Comments

The Alascan Biological Greywater Treatment tank is designed and sized for treating residential greywater providing biological treatment using the well-established extended aeration process. When operating properly treating combined wastewaters this process can produce a clear, sparkling effluent.

This unit has yet to be tested by an independent third party, such as the National Sanitation Foundation, against a performance standard. It is not known whether a polishing filter would be required to obtain satisfactory suspended solids and turbidity levels for the recycling purposes of the "LIGHT GREY OPTION".

7.3 Multi-Flo Waste Treatment System

7.3.1 Description

Another example of a biological treatment system is the Multi-Flo sold in Canada by Aer-O-Flo Environmental Inc., Burlington, Ontario. It is one of a number of individual home aerobic extended aeration plants marketed as an alternative to the septic tank for the treatment of combined wastewaters. The Multi-Flo has been listed by the National Sanitation Foundation (NSF) Ann Arbor, Michigan under its Standard 40. It has a number of features which make it attractive for a simplfied greywater treatment system.

The entire process takes place in one tank. A submerged aerator provides oxygen for the growth of aerobic bacteria. Rather than suspended solids removal by clarification, the effluent passes through a series of vertically suspended felted filter tubes. The filters also act as a bacterial support media. The circular motion of the wastewater generated by the aerator assists in cleansing of the filters. All solids are retained in the system for eventual removal by truck haul. The minimum available commercial size is 1893 l (420 gals.). The unit would be buried outdoors. The effluent could then be pumped through pressurized filtering and disinfection units before returning to the house for reuse.

7.3.2 Comments

The Multi-Flo offers a single tank which provides biological treatment and physical separation of the resulting solids by filtration. It would take a demonstration project to determine whether the Multi-Flo alone could reliably function without the need of a post-filtering process as suggested above.

7.4 "CABOS" Wastewater Treatment System (28)

7.4.1 Description

The self-contained "CABOS" wastewater treatment system was first developed by the Ontario Research Foundation in conjunction with Environment Canada in the 1970's for the treatment of black and greywater from commercial vessels to meet expected effluent quality requirements for undiluted discharge into the Great Lakes. The systems installed on vessels of the Misener Transportation Ltd., St Catharines, Ontario fleet were sized to serve crews of 25 to 30 personnel. The prototype had a design flow rate of 7274 lpd (1600 gpd). The CABOS process is marketed by Marsh Engineering Ltd., Nanticoke, Ontario. Its present application is as a portable unit serving from 10 to 200 people for marinas, RV parks, construction projects and isolated on-site developments.

CABOS has a number of features which when modified and downsized could make it suitable for residential grey-water treatment.

- flow equalization
- macerating feed pumps
- plug-flow, extended aeration process with biological support media and optional powdered activated carbon
- conical clarifier with submerged overflow
- gravity ultra-violet light purifier with automatic wiper system and suspended solids monitor
- scum control facilities
- stainless steel tankage for corrosion control
- tank covers and venting system
- positive displacement blower
- tank drain lines
- variable speed sludge recirculation pump
- sludge tank for accumulated waste sludge

7.4.2 Comments

A major downsizing redesign would be required, but the CABOS has a number of desirable features for a residential greywater treatment system. The potentially outstanding feature is that CABOS is licensed to use powdered activated carbon as in the Zimpro PACT™ biological oxidation plus physical absorption process. It is a means of odour, colour and toxic control without having to use an additional activated carbon filter.

7.5 Cycle-Let Wastewater Treatment Recycling System (45)

7.5.1 Description

Examples of commercial applications of this System available from Thetford Systems, Inc., Ann Arbor, Michigan for treating combined wastewaters were given in the "Background". As indicated, the treated water has been used for toilet flushing and landscape irrigation pruposes. The Company is also treating commercial greywater with its System with only small changes in biological tank sizes, depending on waste strength. The Cycle-Let System has been certified by NSF under its Standard N041 for wastewater recycle/reuse and water conservation devices.

The process train consists of a series of processes:

- trash removal;
- flow equalization
- storage;
- biological treatment;
- membrane ultra filtration;
- colour removal (activated carbon)
- UV or ozone disinfection;
- treated water storage; and
- annual sludge removal by truck haul.

Both the flow equalization tank and the treated wastewater tank provide 24 hrs. storage at design flow. This helps to ensure high reliability and allows process equipment to be shut down for servicing.

7.5.2 Comments

For individual home use this System would have to be downsized considerably from 7570 lpd (1660 gpd). It, however, represents a "complete" greywater treatment system utilizing all of the key processes available for producing a high-quality effluent.

7.6 Living Technologies Solar Aquatics Technology (24)

7.6.1 Description

The use of marsh plants and microorganisms growing on surface support materials such as natural stones and gravels has recently gained acceptance for the treatment of municipal wastewaters and is being used more and more for on-site residential combined wastewater treatment. The symbiotic relationship of micro-organisms and plant roots under simulated wetland and aquatic environments contributes to the production of high quality effluents.

Living Technologies Inc., of Burlington, Vermont, with its subcontractor John Todd, Research and Design, of Falmouth, Maine, has been contracted to provide a 454 lpd (100 gpd) wastewater treatment system for the "Codicile", the winning Toronto house of CMHC's Healthy Housing Design Competition. The plan is to build a three-storey dwelling on an area not much larger than would be occupied by a two-car garage. The proposal submitted by Martin Liefhebber Architect Inc. was based on principles of environmental responsibility including the use of water conservation devices. The design of the "Codicile" includes a two-storey solarium and roof garden which lends itself to the use of solar aquatics technology for wastewater treatment.

The house will be free of the water supply and wastewater infrastructure relying on rainwater and recycled wastewater for its water requirements. With the Living Technolgies Inc. proposal there will be no separation of blackwater and greywater. All of the water used in the house by its three occupants [(est 454 lpd (100 gpd)] will be treated using flow equalization, sedimentation, ecological fluidized beds with photosynthetic component, and ultra-violet or ozone disinfection ahead of the non-potable waterholding tank. The four-tank system will have a retention time of at least five days.

7.6.2 Comments

This project is experimental. The components must be downsized from units already developed for commercial and municipal wastewater treatment. Once proven, this system based on solar aquatics principles, will have the potential for direct application to greywater treatment under the "LIGHT GREY OPTION".

7.7 Summary

A number of different, suitable greywater treatment facilities can be developed from present experience and available propriatory equipment to meet the needs of the "LIGHT GREY OPTION". Each will require a custom design taking into account the points raised in this report.

The design must focus on:

(1) actual greywater characteristics;
(2) expected performance of selected treatment processes;
(3) capital, installation and operating costs; and
(4) the evaluation criteria outlines in the "Background". Greywater characterization, prototype development and testing under real residential housing conditions are required before the "LIGHT GREY OPTION" can become a reality.

8.0 TAKING FURTHER ACTION TO ADVANCE THE "LIGHT GREY OPTION"

The "LIGHT GREY OPTION" is a new concept which has potential of further reducing potable water use in residential buildings by 30 to 40 percent after the introduction of state-of-the-art conservation devices.

The concept was originally presented in a CMHC Research Division paper (38) at the First National Conference on Water Conservation, Winnipeg, Manitoba, February, 1993. It has subsequently been edited for publication and wider distribution. Together with this report there is sufficient information for potential partners to become involved in further advancing the "LIGHT GREY OPTION".

During the course of this report contacts have been made with appliance manufacturers, potable and wastewater treatment equipment manufacturers, public/private utility companies, plumbing and mechanical contractors, performance testing laboratories, regulatory agencies and consumer organizations.

This available information, along with an explanatory aims and objectives statement should be sent to these groups for the purpose of soliciting interest and commitment to the "LIGHT GREY OPTION". The following activities need to be undertaken:

(1) Working with appliance manufacturers, and the plumbing industry to deal with the dual plumbing requirements of the "LIGHT GREY OPTION".

(2) Working with the domestic water/wastewater treatment industry and its consultants to develop suitable greywater treatment systems for varying housing configurations.

(3) Working with equipment testing and regulatory agencies for the certification and approval of piping systems, appliance modifications and greywater treatment methods.

(4) Working with the housing industry to establish a variety of demonstration sites for practical, propotype evaluation under actual housing conditions.

With respect to demonstration sites it would be prudent to start with multiple occupancy housing units on municipal sewers. This would minimize the downsizing required for commercially available equipment and permit gradual introduction of the treated greywater as its acceptability is established.

(5) Working with public health officials and consumers to win acceptance of greywater reuse in residential buildings as proposed by the "LIGHT GREY OPTION".

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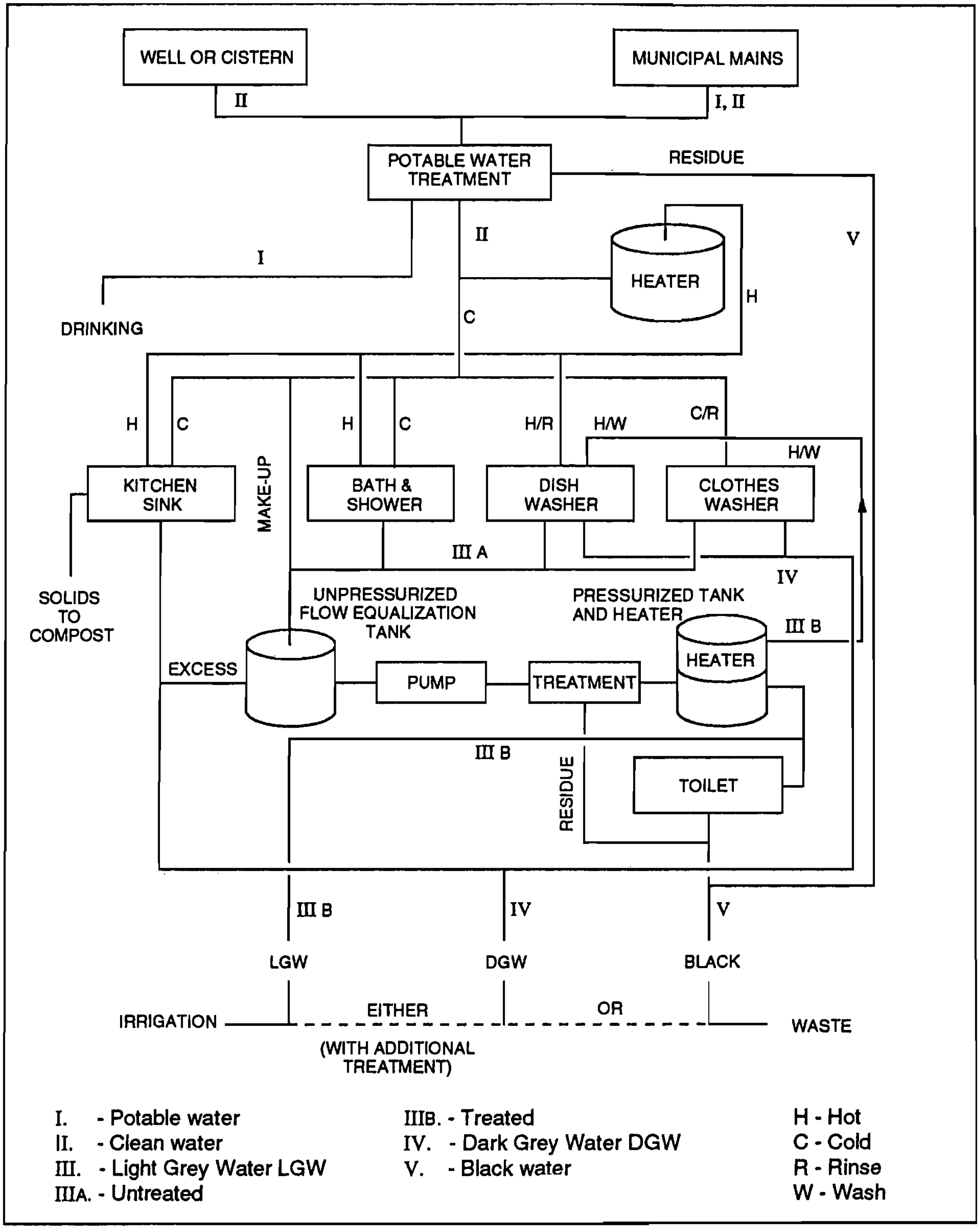

FIGURE 2 Domestic Plumbing Schematic
- one level cascading
- including LGW supply to appliances

APPENDIX A - LIGHT GREY OPTION SCHEMATIC (38)

APPENDIX B

"LIGHT GREY OPTION"
GREYWATER TREATMENT REQUIREMENTS

1.0 Flow

1.1 Volume available for treatment from bathing, clotheswasher and dishwasher: 200 - 380 lpd (44 - 84 gpd).

1.2 Amount required for toilet flushing, clotheswasher and dishwasher: 130 - 240 lpd (29 - 53 gpd).

1.3 Balance available for irrigation use: 70 - 140 lpd (15 - 30 gpd)

2.0 GREYWATER CHEMICAL CHARACTERISTICS

Parameter	Concentration - mg/l
BOD_5	100 - 191
COD	162 - 307
TOC	24 - 46
TSS	42 - 80
TKN	4 - 8
TP	1 - 2

3.0 CONTAMINANTS OF CONCERN

Turbidity
Colour
Odour
Stain causing agents
Unsettleable suspended solids
Foam causing agents
Volatile compounds (aerosols)
Toxic contaminants from commercial products use
high dissolved solids

Some form of disinfection is to be provided to control pathogens and biofilm development in the greywater system.

4.0 TREATABILITY OF THE GREYWATER

Treatability of the "LIGHT GREY OPTION" greywater is an unknown at this time. The effectiveness of sedimentation for suspended solids removal and biological treatment for organic removal are in question. Also, it is not known whether activated carbon treatment is necessary for organic colour/trace organics removal; and membrane technology for dissolved solids control. The method of disinfection used will depend on the turbidity of the treated greywater.

APPENDIX C

REFERENCED COMPANIES WITH RESIDENTIAL POTABLE WATER/WASTEWATER TREATMENT PRODUCTS

AER-O-FLO ENVIRONMENTAL INC.
175 Appleby Line, Unit G-3
Burlington, Ontario L7L 5H9
Tel. (416) 335-8944 FAX (416) 335-8972

ALASCAN INC.
3400 International Way
Fairbanks, Alaska, 99701
Tel. (907) 452-5257 FAX (907) 452-5257

AMF-CUNO/AQUA-PURE
52 Royal Rd.
Guelph, Ontario N1H 7H1
Tel. (519) 822-1576

JACUZZI CANADA
330 Humberline Dr.
Rexdale, Ontario, M9W 1R5
Tel. (416) 675-3333

LIVING TECHNOLOGIES INC.
119 Spruce St.
Burlington, Vermont, 05401
Tel. (802) 860-6821 FAX (802) 860-6821

MARSH ENGINEERING LTD.
Nanticoke, Ontario, NOA 1LO
Tel. (519) 587-4511 FAX (519) 587-2340

THETFORD SYSTEMS INC.
PO Box 1285
Ann Arbor, Michigan, 48106
Tel. (313) 769-6000 FAX (313) 761-7842

APPENDIX C (con't)

TROJAN TECHNOLOGIES INC.
845 Consortium Court
London, Ontario N6E 2S8
(519) 685-6660 FAX (519) 681-8355

ZENON ENVIRONMENTAL INC.
845 Harrington Court
Burlington, Ontario L7N 3P3
Tel. (416) 639-6320 FAX (416) 639-1812