PROTOCOLS FOR PRE-DESIGN ASSESSMENT OF GREYWATER REUSE RETROFIT IN URBAN REDEVELOPMENT: AN OPPORTUNITY/CONSTRAINT ANALYSIS METHOD FOR EXISTING BUILDINGS

BY

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A Practicum
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF CITY PLANNING

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ABSTRACT

Two general types of wastewater are generated within buildings: greywater, which is produced from baths, showers, clothes washers and bathroom sinks, and blackwater, which is produced from toilets, kitchen sinks and dishwashers. In conventional plumbing systems, greywater and blackwater are combined to form a common waste stream which is disposed of via sewer systems to central treatment plants. Greywater reuse represents a break from this traditional method of wastewater disposal and proposes keeping greywater and blackwater streams separate and reusing greywater for a purpose other than that for which it was originally used. (For example, reusing greywater for toilet flushing or landscape irrigation.) Retrofit of existing buildings with greywater reuse systems could provide an effective strategy for urban redevelopment resulting in a more efficient urban form in terms of both individual building efficiencies and municipal water costs. In Winnipeg, greywater reuse, if applied broadly, could become a water conservation alternative having the potential to delay or eliminate the need for a supplemental water supply source and reduce future water treatment costs.

Before a greywater reuse system can be designed for a particular building, it is necessary to determine whether the building is appropriate for retrofit with a greywater reuse system. To facilitate this, a decision-support system is required which provides a defined method or planning tool for identifying opportunities and constraints to greywater reuse retrofit for existing buildings. Through a review of literature and contact with local professionals, this

practicum identified protocols or important criteria for pre-design assessment of greywater reuse retrofit. From this, a process was developed for relevant data collection necessary for a pre-design assessment of feasibility for greywater reuse retrofit. This process was titled an *Opportunity/Constraint Analysis Method* for greywater reuse retrofit of existing buildings.

The Opportunity/Constraint Analysis Method is comprised of three levels of information which must be considered in a preliminary assessment of feasibility for greywater reuse retrofit. These are: (i) planning issues related to the institutional or regulatory/policy environment (focusing on public health, environment, building/plumbing codes, sewer utility by-laws, infrastructure/public works and zoning); (ii) site specific information related to the building environment in question (focusing on general facility information, current water usage and existing equipment/infrastructure); and (iii) solution generation related to possible reuse options (focusing on appropriate reuse possibilities, pre-design considerations related to public health protection and operating and maintenance requirements and preliminary costing). Specific areas of concern or protocols were identified for each of the focus areas listed under the three levels of information. Presented as a three-part checklist, each part of the Opportunity/Constraint Analysis Method corresponds to the three levels of information and lists the related focus areas and specific protocol related to each. This format provides a convenient planning tool for addressing the issues and considerations necessary in a preliminary assessment of feasibility for greywater reuse retrofit.

I would like to express my sincere gratitude to my Committee for their guidance and commitment throughout this practicum.

Advisor: Mary-Ellen Tyler, B. Sc., M.E.Des., PhD.

Readers: Daryl McCartney, M. Sc., PhD., P. Eng.

Arnold Permut, M. Sc., P. Eng.

Also, special thanks to Curtis and my family for their encouragement and support.

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1. INTRODUCTION

The design and construction of cities has historically lacked a strategy for the efficient use of water and energy resources. Consequently, the built environment of modern cities is not "sustainable" in an environmental economic sense. In a recent Worldwatch Institute publication, Malin Roodman & Lenssen (1995) estimated that "buildings consume at least 40% of the world's energy." Among the resources wasted by modern buildings, the waste of potable (i.e., drinking quality) water is the highest throughout the building life cycle. As a result, "buildings account for one-sixth of the world's fresh water withdrawals" (Malin Roodman & Lenssen, 1995). The United States Environmental Protection Agency (USEPA, 1992) has declared that "few cities now enjoy a surplus of high quality water; [and] if they do, this surplus can be expected soon to be exhausted." Furthermore, Environment Canada has indicated that "Canada's water supply is not endless. Population growth, rising pollution and global warming are shrinking the usable supply." Despite these assessments, building design and urban development standards and codes continue to be approved with little regard to the value and limitations of the water supply.

1.1 Water Use in Winnipeg

Typical of urban centres today, all of Winnipeg's water supply is of potable quality. There are three categories of water use in Winnipeg: residential, commercial and industrial. Residential uses account for 60% of the City's total water use (The City of Winnipeg, 1994a). Of this, only 1% is used for drinking, 20% is used for showers and 10% is used for baths. Toilet flushing accounts for the largest percentage of indoor residential water use (32% for normal operation and 6% for leaks). Outdoor residential use is seasonal and dependant upon the weather, normally accounting for 3% to 13% of annual water use but as high as 50% of the demand during peak days. Commercial water use is increasing at a rate of 0.5% per year while industrial water usage has been declining at a rate of approximately 3% per year (The City of Winnipeg, 1994a).

Winnipeg has been fortunate in that its water supply source, Shoal Lake, is of a high quality such that treatment is not necessary (other than the addition of chlorine for disinfection and fluoride for the prevention of tooth decay). However, due to the possibility of future changes in water quality at the source, increasing aesthetic concerns about water quality, trends towards higher water quality standards established by regulatory bodies, and increased public health protection, it is expected that the City will eventually be faced with treating its water source (The City of Winnipeg, 1994a). Additionally, due to Winnipeg's growing population and a growing per capita water consumption, it has been suggested that at some point, Winnipeg's water demand will exceed the ability of the Shoal Lake Aqueduct to convey water to the city resulting in the need to find supplemental supply sources. These supplemental sources may not have as high a quality as Shoal Lake and treatment may be necessary (City of Winnipeg, 1994a).

A water treatment system would result in a significant expenditure for the City in terms of both capital costs for developing a treatment facility and annual costs for water treatment. The City's *Regional Water Supply Conceptual Planning Study* (1994a) indicates that the projected cost for a treatment plant for the existing water supply is approximately $185 million and annual operating and maintenance costs would be in the order of $7 million. In addition, significant costs would be involved with providing a supplemental water source to meet rising demands.

Because only a small fraction of Winnipeg's water supply is used for drinking and washing, purposes that demand a potable quality, a significant waste is seen from an economic and urban management standpoint in using potable water for all uses. If a lesser quality water were used for such purposes as toilet flushing and perhaps landscape irrigation, savings in future water supply and treatment costs could be realized.

1.2 Water Use in Buildings

Water use within buildings can be divided into two categories: those uses that produce *blackwater* and those that produce *greywater* . Generally, blackwater is the wastewater generated by toilets, kitchen sinks and dishwashers while greywater is produced from baths, showers, clothes washers and lavatories (Austin, City of, 1995). In addition, blackwater may contain industrial waste streams. In conventional buildings, blackwater and greywater streams are combined to form one waste stream and then disposed of via sewers to central treatment plants.

By keeping blackwater and greywater streams separate within buildings, the opportunity for reusing greywater on-site is introduced. Depending on the particular building, possible reuses for greywater include toilet flushing and landscape irrigation.

1.3 Greywater Reuse: A Strategy For a More Efficient Built Environment

From an urban planning and management standpoint, the reuse of greywater within buildings has many advantages including increased building efficiencies, water conservation and a reduction in municipal water treatment and supply costs (California, State of, 1994b). For the City of Winnipeg, greywater reuse, if applied broadly, has the potential to delay or eliminate the need for a supplemental supply source and to reduce future water treatment costs. Additionally, the potential exists for a reduction in wastewater treatment and disposal costs due to a smaller overall volume of wastewater generated. Ultimately, the introduction of greywater reuse into the built environment could create more efficient urban centres in the context of both economics and resource management.

Retrofit of existing buildings also has the potential to create more efficient urban centres and to provide an effective strategy for urban redevelopment. Cities have huge investments in their existing building stocks. Through renovation and retrofit, older buildings can become more efficient and more economically viable while maintaining their historical and cultural role within the fabric of the city. The advantage of retrofit as an urban redevelopment strategy is that it improves upon the existing built environment rather than abandoning or demolishing older buildings.

Great potential exists for improving the efficiency of the existing built environment. Through retrofit with greywater reuse systems, existing buildings can be made to use water more efficiently and responsibly, resulting in water conservation and decreased municipal water treatment and supply costs. In addition, by investing in and making improvements to existing buildings, their useful life is extended. Ultimately, this reduces the need for construction of new buildings and represents a further conservation of resources and even greater effectiveness in urban management.

2. PURPOSE AND OBJECTIVES

Planners play an instrumental role in any urban redevelopment scheme. They must assess the opportunities and constraints of a given redevelopment possibility to enable informed decision-making with respect to whether redevelopment is feasible and what type of redevelopment is needed.

Planners make use of various tools in order to provide effective planning. Traditional planning tools include zoning by-laws, development plans and building codes. However, the complexity of urban redevelopment demands that planners be versatile and able to apply their skills outside the domain of traditional planning.

Planning tools are needed to enable planners to deal with specific issues and opportunities for urban redevelopment. A planning tool could be created to facilitate the evaluation of existing building environments with respect to their suitability for retrofit with greywater reuse systems. Such a tool is needed because before a greywater reuse system can be designed for a particular building, it is first necessary to determine whether the building is appropriate for retrofit with a greywater reuse system. An exploratory tool which identifies protocols for pre-design assessment would provide a defined method for assessing specific opportunities and constraints to greywater reuse retrofit and a decision-support system for assessing the feasibility of greywater reuse retrofit of existing buildings.

The purpose of this project is to provide a concise background to greywater reuse technology and develop an opportunity/constraint analysis method consisting of protocols for pre-design assessment of feasibility of greywater reuse retrofit for particular buildings. To be used as a tool in the planning stages of a greywater reuse scheme, this analysis method will consist of a set of assessment criteria for determining the appropriateness of this type of water conservation strategy to existing building environments.

The objectives of this study are as follows:

(i) to examine the current "state-of-the-art" in greywater reuse technologies;

(ii) to identify protocols for pre-design assessment of feasibility of greywater reuse retrofit in urban redevelopment; and

(iii) to develop an opportunity/constraint analysis method in a format which presents the protocol identified as a convenient tool for planners considering the retrofit of existing buildings with greywater reuse systems.

3. OVERVIEW AND BACKGROUND TO GREYWATER TECHNOLOGY

This chapter provides a summary of the literature review conducted on greywater technology including definitions of greywater and greywater reuse, reasons for separating and reusing greywater, necessary precautions, treatment options and possible reuse alternatives.

3.1 Greywater

Conventional plumbing systems within cities combine all of the wastewater streams within a building into one common stream. This combined wastewater stream is then disposed of via sewer systems to central treatment plants. Although combining all wastewater streams into one common stream has been the dominant practice for the plumbing of modern buildings, this method of dealing with wastewaters generated within buildings does not consider the varying levels of contamination and the different constituents which make up the various wastewater flows which originate inside buildings.

Wastewaters originating from within buildings can be divided into two general categories: *blackwater* and *greywater* . Generally, blackwater is the wastewater generated by toilets, kitchen sinks, and dishwashers while greywater is the wastewater produced from baths, showers, clothes washers, and bathroom sinks or lavatories (Austin, City of, 1995). In cases in which industrial wastewaters are generated within a building, these wastewaters are considered as part of the blackwater.

It should be noted that within the literature, *greywater* is spelled differently by different authors. Some use the English "grey" while others use the American "gray". Additionally, it may be presented as either one word or two words. Furthermore, in the definition of greywater, some authors include water from kitchen sinks. However, most authors indicate that wastewater from kitchen sinks should be excluded from greywater due to the presence of microorganisms which cause food-borne and water-borne diseases. For the purposes of this report, the definition of greywater will be taken as presented earlier and will not include wastewater originating from kitchen sinks.

3.1.1 Differences Between Greywater and Blackwater

Greywater differs from blackwater in several ways which suggest that the two types of wastewaters be treated separately rather than combined in the manner of conventional wastewater treatment systems. First, greywater and blackwater differ in the relative rate of decomposition of pollutants observed for each. The pollutants in greywater decay very rapidly in comparison to the pollutants in blackwater. This is due to the differences in composition of greywater and blackwater. The major constituents of greywater are typically sugars, starch, proteins, and fats. These are more readily available to decomposing microorganisms than the organics in blackwater and thus, greywater decomposes more rapidly than blackwater (Rockefeller, 1994).

A second difference between greywater and blackwater is the relative sources of nitrogen for each. The nitrogen in greywater tends to exist in more complex and less soluble forms than those found in blackwater and is therefore, less polluting than blackwater (Rockefeller, 1994).

Third, greywater and blackwater differ in their relative potential for pathogen concentrations. "Greywater does have the potential to contain pathogenic organisms, but to a considerably lesser extent than combined wastewater" (i.e., greywater and blackwater) (Fogel, 1979).

3.1.2 Constituents of Greywater

"The chemical and biological composition of greywater varies greatly, based on numerous factors including the original quality of the water coming into [the building], the personal habits of the [building's occupants], which plumbing fixtures are connected to the system, and the soaps used" (California, State of, 1994b). "The primary constituent of greywater, of course, is water. Other components including soaps, detergents, oils, and flecks of dead skin, give greywater its biological and chemical characteristics" (Wilson, 1995). The main components of greywater, as described in Wilson's *Using Graywater For Landscape Irrigation* , are as follows:

(i) Microorganisms and Pathogens. Pathogenic organisms include bacteria, viruses, and protozoa. The risk of contamination in water systems is measured using indicator organisms which generally exist in similar conditions as the more dangerous pathogens. Fecal coliform and enterococci bacteria are the most commonly used indicator organisms. The primary source of these microorganisms is human feces, but they can be found in greywater as well.

(ii) Biochemical Oxygen Demand (BOD). This is a measure of the concentration of decomposable organic matter in water based on the quantity of oxygen that would be used up as the organic matter is decomposed by microorganisms. The BOD of greywater is often higher than that of blackwater because the organic matter in greywater is more readily decomposed (Lindstrom, 1992).

(iii) Suspended Solids. These are any solids that are suspended in the wastewater. Greywater usually contains less suspended solids than blackwater.

(iv) Nutrients. The two primary nutrients are nitrogen and phosphorus. Nitrogen levels are usually higher in blackwater than greywater while phosphorus is found in higher levels in greywater (due to the presence of detergents containing phosphorus).

(v) Salts and Other Chemicals. These are usually present in greywater due to soaps and detergents.

3.1.3 Sources of Greywater

As previously identified, the primary sources of greywater are washing machines, showers, tubs, and bathroom sinks. (However, this may vary depending on the particular uses of water for the building in question.)

Greywater produced from washing machines can be expected to contain a medium concentration of soaps and lint. However, laundering diapers will dramatically increase pathogen levels. With respect to greywater produced from showers and tubs, consideration must be given to the accumulation of hair as it can cause problems for pumps. Generally, concentrations of soap are minimal and shampoo is of little concern. Greywater originating from bathroom sinks can have high concentrations of soap, shaving cream, and toothpaste. Pathogen levels in greywater originating from bathroom sinks should be considered.

The amount of greywater typically produced from washing machines, showers, tubs and bathroom sinks can be estimated by using the figures shown in Appendix A.

3.2 Greywater Reuse

Greywater reuse refers to reusing greywater for a purpose other than that for which it was originally used. For example, greywater may be collected from bathroom sinks, baths, showers, and clothes washers and then reused for toilet flushing or landscape irrigation. Greywater reuse is not the same as *greywater recycling* in which greywater is used over and over for the same purpose. "While water reuse would refer to the reclamation of a wastewater and its subsequent use for a different purpose, water recycle would involve using reclaimed wastewater for the same purpose" (National Research Council, 1986).

Reusing greywater is not a new concept. Rather, greywater reuse systems have been used informally for a long time (Austin, City of, 1995; Lindstrom, 1992). The French were among the first to recognize the benefits of separating greywater from blackwater. They utilized separate collection systems and different types of treatment for greywater and blackwater (Winneberger, 1974).

3.3 Reasons For Separation and Reuse of Greywater

In the early stages of conventional sewer and septic system design, "lavatory drains were plumbed in [to sewage disposal systems] as an afterthought because it was quite handy to do so" (Clivus New England, 1994). Since then, this method of combining all wastewater flows originating within buildings has become the standard for the design of plumbing systems and for the handling of all wastewaters generated within buildings. Despite this, however, there are many reasons for keeping greywater and blackwater separate and for reusing greywater on-site.

Reason #1: *Water is a Reusable Substance*

The first and perhaps most basic reason for reusing greywater relates to the reusable nature of water. "Among [water's] critical properties is that it is an inert solvent and does not undergo chemical change from the effect of the substances it dissolves. It can, as a consequence, be reused repeatedly" (Todd & Josephson, 1994).

Reason #2: *Differences in the Composition of Greywater and Blackwater*

Because of the differences in their physical, chemical and biological properties, greywater and blackwater should be kept separate and treated and/or reused according to the individual characteristics of each. For example, because the BOD of greywater degrades much more readily than the BOD of blackwater, one would expect greywater and blackwater to respond differently to different treatment alternatives. In addition, because the nitrogen found in greywater tends to be in a less polluting form than blackwater and because greywater typically contains fewer pathogenic microorganisms than blackwater, it would seem that greywater would have more reuse potential than blackwater.

Reason #3: *Water Conservation*

Although water conservation presently may not be seen as an issue in some communities, water supply shortages are expected in the near future (USEPA, 1992). Through pollution and waste, clean water is growing scarce the world over (Clivus Multrum Canada). Meanwhile, demands for water continue to grow as trends towards urbanization persist (USEPA, 1992). "Water reclamation and reuse has become an attractive option for conserving and extending available water supplies. ...The use of reclaimed water for nonpotable purposes offers the potential for exploiting a 'new' resource that can be substituted for existing sources" (USEPA, 1992).

Reason #4: *Cost Savings*

When greywater is reused in a building, less water is drawn from outside sources to meet the demands of the building. Similarly, less wastewater is produced and disposed of externally when greywater reuse systems are in place. By reusing greywater on-site, savings can be realized in water and sewer bills. (However, it is noted that savings must be balanced against capital and operating and maintenance costs.)

Reason #5: *Reduced Strain on Septic Fields and Treatment Plants*

When greywater from a building is reused, the only wastewater disposed of externally is blackwater. This results in a reduction in the quantity of wastewater to be dealt with and therefore, less strain is placed on septic fields and treatment plants. In addition, operating costs associated with wastewater treatment and disposal are reduced and the need for building new treatment and disposal infrastructure is lessened.

Reason #6: *More Efficient Building Environments/Systematic Functioning*

By reusing greywater within buildings, better use can be made of the water entering the building, thereby increasing the overall efficiency of the building environment. In addition, like in natural systems, buildings can begin to operate in a systematic and efficient manner. "In natural ecosystems, materials cascade endlessly through an intricate web of interrelated cycles ...the waste products from one step are the raw materials for the subsequent steps" (Ludwig, 1989). By reusing greywater on-site, a cyclical process can be established within the building environment in which the wastewater from one source (such as bathroom sinks) can become the influent for another water use (such as toilet flushing). In this way, buildings can begin to function more like natural systems.

Reasons Specific To The Reuse Application

In addition to the seven reasons identified above, there may be reasons specific to the particular uses to be made of the greywater. For example, in the case of reusing greywater for landscape irrigation, additional reasons would include making use of the nutrients which are contained within greywater and drought-proofing the landscape (Ludwig, 1994).

For a particular building environment, the relative importance of the reasons identified above for reusing greywater is a factor of the economic, environmental, and political climate within which the building exists. However, most of the issues that are imbedded within these reasons (such as water conservation, cost savings, improved efficiencies and sensitivity to natural cycles) are becoming increasingly valued within society. "Today and in the future, legislative requirements and internal cost-reduction policies will promote conservation/ recycling projects and wastewater minimization. Limited freshwater supply, more stringent environmental regulations and spiralling costs drive conservation and reuse trends" (Goldblatt, 1993).

3.4 Precautionary Measures To Ensure Safe Reuse of Greywater

Various precautionary measures can be taken to minimize the possibility of creating a hazard with the reuse of greywater. The following is a summary of precautionary measures which should be taken to ensure the safe reuse of greywater:

Measure #1: *System Identification*

All components of a greywater system should be clearly marked with warning labels indicating the presence of dangerous water (California: State of, 1994b). The purpose of this is to avoid cross-connections between greywater pipes and fresh water supply lines.

Measure #2: *Backflow Prevention Devices*

The system should be installed with appropriate backflow prevention devices (Tchobanoglous & Burton, 1991).

Measure #3: *No Storage of Untreated Greywater*

Because greywater contains a high reaction rate, it will quickly use up all of its oxygen and become anaerobic if stored in a tank (Lindstrom, 1992). As a result, untreated greywater should not be stored for any length of time.

Measure #4: *Routine System Monitoring and Maintenance*

As a precautionary measure against system malfunctioning, routine monitoring and surveillance of the system should be provided for (USEPA, 1992). An appropriate quality control program should be established at the onset of implementation of the greywater reuse system.

Measure #5: *Proper Staff Training*

Staff should be properly trained to ensure the operations, maintenance and inspection of the system (USEPA, 1992).

Measure #6: *Basic Common Sense*

Finally, basic common sense should be used where greywater reuse systems are in place. For example, the State of California (1994b) suggests the following common sense guidelines:

- do not drink greywater
- do not allow playing in greywater

- do not mix greywater with potable water
- do not allow anything that may be eaten to come into contact with greywater
- do not allow greywater to pond on the surface or run off the property

"The quality of greywater and its reuse application will define the appropriate guidelines to reduce health risks associated with potential exposure" (Rose et al, 1991). Thus, again, a site-by-site approach is necessary to determine and prevent any potential risks that may be associated with the reuse of greywater.

3.5 Treatment Options

Prior to reuse, the greywater will have to be subjected to a suitable treatment process. Additionally, if the greywater is to be stored for any length of time, it should be treated to prevent the occurrence of anaerobic conditions. Possible treatment options include aeration, sedimentation, activated sludge, filtering, reverse osmosis, disinfection and solar aquatics.

3.5.1 Aeration

Aeration involves introducing oxygen into the greywater. Increasing the oxygen content of greywater is favourable because it prevents or delays the onset of anaerobic conditions. This would enable the greywater to be stored in a tank without the occurrence of anaerobic conditions.

3.5.2 Sedimentation

Sedimentation involves the use of holding tanks in which suspended particles are allowed to settle out. In conventional wastewater treatment, when particles are too small to settle out in a reasonable length of time, chemicals are added to the wastewater to promote coagulation of the particles into larger masses that will settle out more quickly. Sedimentation tanks also provide an ideal location for manual screening devices.

3.5.3 Filtering

The purpose of filtering is to remove large particles, hair, lint, grease, etc. Generally, two types of filters may be used: screen filters and sand or gravel filters. Typically, a screen filter is used before allowing greywater to enter a holding tank. Gravel filters can be used prior to sub-surface disposal of greywater and prior to irrigating a greenhouse (Fogel, 1979).

An example of a sand/gravel filter for treatment of greywater is the "soilbox" manufactured by Clivus Multrum. The bottom layer of the soilbox contains a layer of polyethylene actifill or pea gravel to provide effective drainage. A layer of plastic mosquito-netting on top of the actifill prevents the next layer of coarse sand from falling through. On top of the coarse sand is a layer of normal concrete-mix sand. The top two feet consist of humus-rich top soil (Lindstrom, 1992). These soilboxes are planted with suitable plants and may be used in greenhouses.

3.5.4 Reverse Osmosis

Reverse osmosis is a water treatment alternative which is capable of filtering out extremely small particles (0.0001 mm) and dissolved salts. It has been used for purifying and treating liquids from industry as well as producing drinking quality water from brackish or salt water in developing countries. It is noted that at the present time, cost may present an obstacle for an on-site application of reverse osmosis for treatment of greywater. However, research of reverse osmosis is continuing to evolve and its use for different types of water treatment applications is likely (Archambault, 1997).

3.5.5 Activated Sludge

Activated sludge uses biological processes to remove suspended matter and reduce the dissolved organic content. In addition, these processes reduce pathogen content, heavy metals and radionuclides and strip volatile organic chemicals and radon if present. Basically, activated sludge makes use of microorganisms which use the wastewater's organic content as a food supply, converting them into biological cells. However, activated sludge may not be an appropriate treatment option on an individual building basis due to issues of scale and operating complexities. Activated sludge may be a more appropriate alternative in the case of treating greywater generated from several buildings.

3.5.6 Disinfection

Disinfection involves destroying the harmful bacteria and viruses within a substance and is necessary as a public health safety factor and to limit biofouling in the system. "The disinfection of wastewater is usually required where portions of the effluent may come into contact with humans" (Peavy et al., 1985). In evaluating disinfection alternatives, the following factors should be taken into consideration:

- effectiveness and reliability;
- capital, operating, and maintenance costs;
- ease of application and control;
- safety; and
- potential adverse effects such as toxicity to aquatic life or formation of toxic or carcinogenic substances (USEPA, 1992).

Common wastewater disinfectants include chlorine, ozone and ultraviolet light. Chlorine is currently the most common disinfectant for both water and wastewater. The major advantages of chlorine are its "cost-effectiveness, its reliability, and its efficacy against a host of pathogenic organisms" (National Small Flows, Fact Sheet). Common applications include disinfection of pathogens and prevention of waterborne disease as well as control of odors, algae, flies, sludge bulking and foaming; prevention of septicity and filter ponding; improving grease and scum removal; and destruction of cyanides and phenols (in industrial wastewaters). Hazards associated with the use of chlorine include its toxicity to aquatic, estuarine and marine organisms; its potential toxicity when inhaled; risks associated with its transport; and the highly corrosive nature of chlorine gas and hypochlorites.

Ozone is a highly effective alternative to chlorine disinfection. Ozone has been considered to be "more effective as a bactericide and virucide than chlorine" (Small Flows...Fact Sheet). The process does not result in a residual being left in the water and by-products are considered minimal and much less detrimental than those generated through chlorination (National Small Flows... Fact Sheet). Ozonation contributes dissolved oxygen to the water and can reduce BOD, COD, color and odor. The effectiveness of ozone is enhanced with filtration.

Ultraviolet (UV) light disinfection is another alternative to chlorine disinfection. UV disinfection "... is a physical process, relying on the absorbance of UV energy by the genetic material of the cell (DNA and RNA). The damage it causes results in the inability of the cell to replicate" (Small Flows...Fact Sheet). UV disinfection typically involves the use of a standard low pressure mercury arc germicidal lamp and is comparatively inexpensive, safe (i.e., it does not form chlorinated hydrocarbons) and well established method of disinfection (USEPA, 1992). The performance of UV disinfection is further enhanced with filtration (Darby et al., 1993). UV disinfection has been proven to be a highly effective means of disinfection, consistently achieving, for example, disinfection criteria set out in the California Wastewater Reclamation Criteria (Darby et al., 1993). These criteria are considered to be typical of health-related standards in industrialized countries (Smith & Walker, 1992).

3.5.7 Solar Aquatics

Solar aquatic technologies make use of plants, sunlight and natural biota in the form of artificial wetlands and greenhouse systems (CMHC, 1993).

An artificial or constructed wetland is "a man-made, engineered, marsh-like area designed and constructed to treat wastewater by attempting to optimize physical, chemical and biological processes of natural wetland ecosystems" (Choate in Fischer, 1993). The advantages of constructed wetland treatment of wastewaters are "relatively low capital and operating costs, more consistent compliance with permit requirements and greatly reduced operational and maintenance costs" (Fischer, 1993).

Constructed wetlands use aquatic plants and organisms to process wastewater. "Aquatic plants possess an outstanding ability for assimilating nutrients and creating favorable conditions for microbial decomposition of organic matter" (Brix & Schierup, 1989). In addition to the complex variety of biological, physical and chemical processes associated with aquatic plants and organisms, constructed wetlands also make use of the processes of sedimentation, absorption and precipitation.

There are two types of constructed wetlands: free-water systems and subsurface flow systems. Free-water systems are similar to natural marshes. These systems contain a sub-surface water barrier such as clay to prevent groundwater infiltration and consist of shallow depths in which the water surface is exposed to the atmosphere, low flow velocities and emergent vegetation (Fischer, 1993 and Reed & Brown: 1992). Subsurface flow systems are also referred to as the root zone method, vegetated submerged beds (VSB), rock reed filters, microbial rock filters and hydrobotanical systems. A subsurface flow system or rootzone treatment is typically achieved with a one metre deep basin which is sealed with clay or a synthetic lining to prevent percolation to groundwater. The basin is filled with a suitable soil and then planted with reeds. Wastewater is run through the root zone soil. Biological activity in the soil is enhanced by the high oxygen content provided by the plants. The microorganisms in the soil eliminate the organic compounds and other impurities contained within the wastewater while heavy metals and phosphates are eliminated by means of chemical precipitation (Dansk Rodzone Teknik).

Both types of constructed wetland systems have demonstrated effective removal of biochemical oxygen demand, total dissolved solids and fecal coliforms (Reed & Brown, 1992). In addition, both have been reported to be reliable and cost-effective methods for wastewater treatment with subsurface flow systems being considered particularly well-suited for small systems and those in relatively close proximity to the public. Criticisms of constructed wetlands tend to focus on their performance with respect to ammonia levels, a limited capacity for phosphorus removal in subsurface flow systems and their performance in cold climates (Reed & Brown, 1992). Land requirements may present an obstacle, particularly for treatment on an individual building basis. It is noted that the performance of a treatment method in cold climates is very important in Winnipeg.

The use of constructed wetlands for treatment of municipal and industrial wastewaters has grown rapidly since 1980, with most of this growth having occurred since 1988. It was estimated that 150 constructed wetland systems were in operation in the United States in 1992 (Reed & Brown, 1992).

3.6 Possible Reuses of Greywater

"Many urban residential, commercial, and industrial (water) uses can be satisfied with water of less than potable water quality" (USEPA, 1992). The possible uses for reclaimed greywater will depend on the particular building for which the system is being considered and the quality of the greywater produced on site. As a result, the uses to be made of greywater must be determined on a site-by-site basis. However, the possibilities for reusing greywater include such purposes as landscape irrigation, toilet flushing, heating/cooling, and various industrial uses. Each type of use will have its own set of requirements relating to performance, health, and environmental considerations and will have to comply with various regulatory measures.

3.6.1 Landscape Irrigation

When used for irrigation, greywater helps to promote plant growth. This is due to minute amounts of nutrients within greywater including phosphates from detergents, dirt from laundry and protein from the cells of dead skin and rinsed-off body oil (Kourik, 1988).

Greywater is naturally purified by biological activity in top soil. "Soil microorganisms break down organic contaminants (including bacteria, viruses, and biocompatible cleaners) into water soluble plant nutrients. Plant roots take up these nutrients and most of the water" (Enviro-Management & Research, Inc. in Los Angeles, City of, 1992).

"Most authors recommend subsurface irrigation with gray water and advise against surface application. This is due to the potential presence of viruses and pathogens in gray water. Also, it is generally recommended that gray water should not come into contact with the edible portion of fruits and vegetables, be allowed to collect on the surface of the ground, or to run off the property" (Los Angeles, City of, 1992). In addition, greywater should be applied at a shallow depth so that it is available to plant roots and soil microorganisms and it should be applied at a low rate so that the soil does not become saturated (Austin, City of, 1990).

3.6.1.1 Components of a Greywater System For Landscape Irrigation

Before using greywater for irrigation, it is generally recommended that it be filtered to remove large fibers and hair. In addition to a suitable filtering device, a greywater system for landscape irrigation should consist of a plumbing system made up of pipes and valves to bring the greywater out of the building, a surge tank to temporarily hold large drain flows, a pump to move the water from the surge tank to where it will be used, and an irrigation system to move the water to the plants (California, State of, 1994b).

3.6.1.2 Maintaining Healthy Soil and Plants When Irrigating With Greywater

In order to maintain healthy soils and plants when irrigating with greywater, careful consideration must be given to the types of substances allowed to come into contact with the sources of greywater in the building. For example, it is recommended that liquid detergents be used rather than powders because most powders are very high in sodium and salts. It is also recommended that chlorine bleach, cleaning products containing boron, and caustic drain cleaners be avoided (Wilson, 1995). Additionally, it is suggested that detergents which advertise whitening, softening, and enzymatic powers and cleaning products containing peroxygen, sodium perborate, petroleum distillate, alkylbenzene, or sodium trypochlorite be avoided if greywater is to be used for landscape irrigation (California, State of, 1994b).

Appendix B identifies elements often found in common household products which should be limited when irrigating with greywater.

3.6.1.3 Plants Unsuitable For Irrigation With Greywater

Some plants are better suited to irrigation with greywater than others. Generally, shade-loving and acid-loving plants do not respond well to irrigation with greywater" (California, State of, 1994b). Appendix C contains a list of plants that are not suitable for the alkaline conditions associated with greywater irrigation.

3.6.1.4 Plants Suitable For Irrigation With Greywater

Fruit trees, groundcovers, and ornamental trees and shrubs can safely be irrigated with greywater. A list of plant species that should respond well to greywater irrigation are included in Appendix C.

3.6.2 Toilet Flushing

Traditionally, toilets have been flushed with potable water. However, toilet flushing does not require water of potable quality (i.e., water safe for drinking). As a result, large quantities of drinking-quality water are continuously wasted by the flush toilet. By using greywater to flush toilets, the quality of water is more adequately matched to the purpose of the use and valuable drinking-quality water is conserved.

Before greywater is used for flushing toilets, filtering may be necessary to remove particles such as hair, lint, grease, etc. The purpose of this is to ensure adequate flushing action and guard against undue wear on the toilet's flushing mechanisms. The addition of a colored dye to greywater which is to be reused for toilet flushing is suggested as a means of identifying that it is greywater and indicating that the water may be unsafe (CMHC, 1993).

Water to be used for toilet flushing is typically subjected to minimum odour and staining requirements. This suggests that manganese, iron and copper limits may be necessary. In Advancing the Light Grey Option: Making Residential Greywater Reuse Happen, CMHC (1993) recommends that the limits shown in Appendix D be followed for toilet flushing.

4. A REVIEW OF GREYWATER REUSE IN PRACTICE

This chapter provides a review of the practical side of greywater reuse as identified from the review of literature. Implementation issues associated with greywater reuse technology are identified and examples of practical applications of wastewater and greywater reuse are provided.

4.1 Implementation Issues

Though greywater reuse may offer many advantages including water conservation, savings in water supply and treatment costs, more efficient building environments, and reduced strain on septic systems and wastewater treatment plants, there are several important issues which must be considered before implementing such a system. In particular, concern must be given to public health protection, prevention of environmental degradation, avoiding public nuisance, meeting user requirements, regulatory compliance, cost and public acceptance. It is noted that these issues apply to wastewater reuse in general as well as the specific case of reusing greywater.

4.1.1 Public Health Protection

"One of the most critical objectives in any reuse program is to assure that health protection is not compromised through the use of reclaimed water" (USEPA, 1992).

Even though greywater does not contain sewage and "typically contains only one percent or less of the microorganisms found in total wastewater" (Austin, City of, 1990), it can contain potentially dangerous microorganisms and thus, concern must be given to the possible health effects associated with reusing greywater.

Indicator organisms are used to determine whether water or wastewater is contaminated with organisms which could be dangerous from a public health standpoint. "The presence of Escherichia coli and other enteric organisms in water indicates fecal contamination and the possible presence of intestinal pathogens such as Salmonella or enteric viruses. Fecal coliforms are a pollution indicator and may be used to assess the relative safety of greywater. Generally, a high fecal coliform count is undesirable and implies a greater chance for human illness to develop as a result of contact during greywater reuse" (Rose et al., 1991).

To monitor a water reuse system for pathogen levels, the USEPA (1992) suggests continuous monitoring of the following factors:

- the sources contributing to the wastewater;
- the general health of the contributing population;
- the existence of "disease carriers" in the population; and

- the ability of infectious agents to survive outside their hosts under a variety of environmental conditions.

"In practice, the health risk of greywater reuse has proven to be minimal" (Ludwig, 1994). However, protection of public health is ensured through the following precautionary measures recommended by the USEPA (1992) for safe reuse of reclaimed water:

- reduce concentrations of pathogenic bacteria, parasites, and enteric viruses in reclaimed water;
- control chemical constituents in reclaimed water;
- limit public exposure to the reclaimed water; and
- treat the reclaimed water to a high degree where human exposure (through contact, inhalation or ingestion) is likely.

4.1.2 Preventing Environmental Degradation

With respect to environmental degradation, the main risks associated with a greywater reuse system would involve untreated greywater ponding on the surface of the ground or infiltrating into groundwater reservoirs. However, if the system has been designed such that a minimal risk exists with respect to public health (as identified above), the occurrence of either of these situations should be unlikely.

4.1.3 Avoiding Public Nuisance

A public nuisance could occur if untreated greywater was allowed to pond on the surface and then run off the property into a neighbouring property. This would be of concern if the greywater was being reused for landscape irrigation. Again, however, if the greywater reuse system is designed such that a minimal risk exists with respect to public health, the creation of a public nuisance should also be unlikely.

4.1.4 Meeting User Requirements

Most users will require the greywater to meet acceptable odour levels. However, user requirements must be established individually for each site. For example, the performance of a building's various operating systems (i.e., those involving water use) must be assessed with respect to their operation with a greywater reuse system. For example, an important consideration to be made is whether the reuse of greywater within the building and the consequential reduction in wastewater flows out of the building would affect the flow through municipal sewers.

Another concern with respect to meeting user requirements is the quality of the greywater produced within the building environment. In particular, the quality of the greywater must be sufficient for its intended reuse. For example, if the greywater is to be used for landscape irrigation, suitable treatment may be necessary to improve the quality of the reclaimed water. Additionally, if the greywater is to be reused for flushing toilets, an important consideration to be made is the effect of greywater on the toilet's flushing mechanisms and thus, the quality of the reclaimed water may need to be improved through filtering or some other means of purification.

4.1.5 Regulatory Compliance

The following sources of law could raise issues for a water reuse plan: federal statutes, federal case law, state or provincial statutes, state or provincial case law and local ordinances (USEPA, 1992). In particular, however, a greywater reuse plan for a building must conform with health, sewer utility by-laws and plumbing codes.

Recent articles in prominent publications have suggested that regulatory policies which encourage water reuse are needed and that policy-makers should not create hardships for those using reclaimed water (Smith & Walker, 1994). Currently, however, most jurisdictions contain plumbing and other regulations which prevent the reuse of greywater. For example, the City of Winnipeg's Sewer By-law (By-law No. 7070/97) which was passed on July 24, 1997, contains no special provision for greywater. Greywater is considered wastewater and according to Section 11 of the By-law,

> For any building and/or land used or designed for human habitation, employment, or recreation, or any building used for commercial or industrial purposes:
>
> (a) Wherein wastewater is generated, shall be connected to the wastewater sewer where available. If no wastewater sewer is available, wastewater shall be connected to a private wastewater disposal system subject to conditions as herein provided.

However, Section 56 of the By-law states the following:

> No person shall construct, install, excavate, have or use any system of receiving, treating, or disposing of wastewater on any property located in the City without a Private Wastewater Disposal System Permit from the Sewer Utility.

This suggests that in order to develop an on-site system for reusing greywater, it would be necessary to apply to the Sewer Utility for a Private Wastewater Disposal System Permit. Section 62 of the By-law contains a provision which enables an applicant who is refused a Private Wastewater Disposal System Permit by the Sewer Utility to appeal the refusal to the City's Committee on Works and Operations. The Committee may grant the permit if the proposed system is "compatible with the area, has no impact on adjoining property and adjacent area, has no potential for adverse public health consequences, has no adverse effect on the environment and complies with City health and zoning regulations."

In some jurisdictions, the regulatory climate with respect to greywater reuse appears to be changing. On November 9, 1994, the State of California amended its plumbing code to include *Appendix J - Graywater Systems For Single Family Dwellings* . A copy of this regulation is included as Appendix E. This amendment legalizes the reuse of household greywater for landscape irrigation in California. In addition, many other states, including Arizona, Colorado, Connecticut, Florida, Hawaii, Kentucky, Minnesota, Montana, New Jersey, New York, Oregon, South Dakota, Texas, and Wyoming, have regulations specifying design criteria for separate disposal of greywater (National Small Flows Clearinghouse, 1995).

Arizona's regulations allow greywater from single and multi-family residences to be used for surface irrigation. Hawaii's regulations permit disposal of greywater via sand filters, absorption trenches and beds, mounds or seepage pits or when disinfected, as irrigation water. Kentucky's regulations focus on laundry greywater and its disposal in lateral beds or trenches. South Dakota's regulations specify design criteria for greywater systems in homes, cabins and other facilities and permit the reuse of greywater for toilet flushing, irrigation of lawns and areas not intended for food production or disposal in absorption fields, mounds or seepage pits. Texas' regulations permit subsurface disposal of greywater (National Small Flows Clearinghouse, 1995).

National policies have also been introduced in Japan which encourage the reuse of wastewater and rainwater in large buildings (Smith & Walker, 1992).

The International Plumbing Code contains provisions which deal explicitly with greywater. It states that only greywater from bathtubs, showers and lavatories be reused and that the reuse purpose be restricted to flushing water closets and urinals. Greywater must be collected in a closed and gas-tight reservoir and coloured with a vegetable dye (blue or green) before being supplied to fixtures. Greywater entering the reservoir is to be filtered through a media, sand or diatomaceous earth filter and disinfected by one or more disinfectants such as chlorine, iodine or ozone. The collection reservoir must be equipped with an overflow pipe, vent and drain which connects to the sanitary sewer. Potable water must be available as a source of make-up water. Suitable backflow prevention devices must be in place. The reservoir and all piping must be identified as containing nonpotable water.

A proposed amendment to the British Columbia Plumbing Code would add a section entitled *Recycled Waste Water Systems* in which recycled wastewater is defined as water recovered from black and greywater sources that has been treated and disinfected. Included in this amendment are specifications with respect to testing, materials, piping and system identification, location of system components and contamination prevention.

4.1.6 Public Acceptance

Public acceptance is identified as a potential issue because people tend to oppose changes to the established way of doing things. However, the USEPA (1992) has reported that "...surveys over the last two decades indicate a surprisingly large measure of public support for water reuse programs." Additionally, Kasperson and Kasperson (1977) suggest that "...the prevailing levels of public acceptance of reclaimed water in American cities reveal widespread acceptance of lower-order (non-bodily contact) uses."

Acceptance of greywater reuse can be promoted through appropriate public awareness and education strategies such as distributing informative material and holding public meetings with respect to the proposed greywater reuse plan.

4.1.7 Cost

Cost is perhaps the most important issue to be considered in the retrofit of an existing building with a greywater reuse system. In some cases, because of the magnitude of necessary changes to the building's operating systems, the capital cost of the retrofit may be prohibitive. In addition to capital costs, there are annual operating and maintenance costs to be considered. Specific items of capital and operating and maintenance costs as well as other issues related to developing a preliminary costing estimate will be presented in Chapter 5. However, an in-depth examination of the costs associated with retrofitting an existing building for the reuse of greywater is beyond the scope of this study.

4.2 Examples of Water Reuse Applications

There are many examples of successful wastewater reuse applications. "Water reclamation and reuse are widely practised ...both in industrialized and developing countries" (USEPA, 1992). "Throughout the world, wastewaters have been reclaimed for irrigation purposes for many years. There also have been instances of reclaiming wastewaters as a source for recreational ponds and for ground water recharge. Industries frequently use reclaimed wastewaters for cooling, quenching and washing operations. Further, reclamation of wastewater for potable reuse in arid countries or areas where a water shortage exists has been investigated in the United States and elsewhere in the world" (National Research Council, 1986).

The frequency and variety of successful wastewater reuse applications found in the review of literature suggests that the implementation issues identified above (i.e., public health concerns, preventing environmental degradation, avoiding public nuisance, meeting user requirements, regulatory compliance, public acceptance and cost) can be overcome. The following sub-sections provide examples of various water reuse applications.

4.2.1 Examples of Combined Wastewater Reuse

Reusing combined wastewater has often involved transporting the wastewater to a central treatment plant and then redistributing the reclaimed water to selected non-potable uses after it has been submitted to a suitable treatment process. Below is a sample of combined wastewater reuse projects that make use of a central treatment plant.

- In the Las Virgenes Metropolitan Water District in western Los Angeles, California, combined wastewater has been treated at a near-by treatment plant and then redistributed for various non-potable uses including landscape irrigation, highway greenbelts and landfills since the early 1970s. The system reuses approximately 50% of the wastewater produced and meets about 20% of annual water needs (Schorr & Dewling, 1988).
- A dual distribution system was constructed in St. Petersburg, Florida to provide potable water and filtered secondary effluent for fire protection and landscape and turf irrigation. The system's construction was valued at a total cost of

approximately $104 million — $60 million for treatment up-grading, $37 million for distribution and $7 million for an alternative discharge system to deep wells (Schorr & Dewling, 1988).

- In Riyadh, Saudi Arabia, the Petromin Oil Refinery uses 20,000 m^3 per day of treated wastewater effluent from the Riyadh Wastewater Treatment Plant (RWWTP). Approximately 75% is treated to produce high-quality boiler feed water. The rest is treated and used for crude oil desalting and cooling water and is available for fire fighting. The RWWTP pumps the largest portion of its effluent to the communities of Dirab and Dariyah for agricultural irrigation. (The pumping station has a capacity of 120,000 m^3 per day and on-line storage of 300,000 m^3 per day.) In addition, the RWWTP uses approximately 3,600 m^3 per day of effluent for landscape irrigation (J.M. Chansler, *Water Reuse in Riyadh, Saudi Arabia*, USEPA, 1991).
- The Central Basin Municipal Water District implemented a water reclamation project which involves landscape irrigation and industrial applications. The ultimate goal of the project is for 100,000 acre-foot of recycled water use (Smith & Walker, 1994).
- At Walt Disney World in Florida, reclaimed water is used for golf course and landscape irrigation in order to reduce demands on potable groundwater sources (Smith & Walker, 1994).

- The City of Sarasota, Florida has a wastewater reuse program consisting of agricultural irrigation of a 12,000 acre ranch and three golf courses with future plans for irrigation of two citrus groves and an 850-acre cattle ranch (Smith & Walker, 1994).
- From 1932 until 1985, wastewater treated at a nearby facility was used for watering lawns and supplying ornamental lakes at Golden Gate Park in San Francisco, California (Tchobanoglous & Burton, 1991).
- In Colorado Springs, Colorado, reclaimed municipal wastewater has been used for landscape irrigation of golf courses, parks, cemeteries, and along freeways since 1960 (Tchobanoglous & Burton, 1991).

On-site treatment and reuse of combined wastewaters has also been achieved. Some examples of on-site wastewater reuse are identified below.

- The Body Shop Canada's new Home Office in Toronto contains an on-site wastewater treatment system using natural biological activities to treat and clean the wastewater produced within the facility. Constructed at a cost of $58 per square foot ($624 per square metre), the office was built "... for no more than the traditional way of building and operating office and manufacturing space" (The Body Shop Canada, 1995). Using John Todd's "Living Machine" system housed in a 4,000 square foot greenhouse, a huge variety of organisms from bacteria and algae to higher plants, snails and fish reduce the nutrient and pathogen concentrations within the wastewater by breaking down and digesting them in a continuous food chain (Living Technologies).

- As a result of a sewer moratorium which restricted wastewater discharges from new developments to no more than 1,600 gallons per day per acre, the Alliance Bank and Trust Company in southwest Houston, Texas developed an on-site wastewater treatment and recycling system which provides reclaimed water for toilet flushing throughout the a 200,000 square foot, 12-story structure. With the system, sewer discharge is kept to a maximum of 1,000 gallons per day with full building occupancy (J. Irwin, *On-Site Wastewater Reclamation and Recycling* , USEPA, 1991).
- Due to a lack of sewer capacity, the Headquarters Park Office Complex near Princeton, New Jersey which consists of four separate buildings totalling 366,500 square feet has a wastewater treatment and recycling system which uses treated wastewater effluent as flush water for toilets and urinals. Wastewater volume was reduced by approximately 94%. A capital cost savings of over $250,000 was achieved and water use cost savings are estimated at $15,000 per year (Zenon Municipal Systems, Inc., 1995).

- A study by the Irvine Water Ranch District in California investigated the costs of using reclaimed wastewater for toilet flushing in high-rise office buildings. For the Koll Center, an 11-story, 249,000 square foot office building, it was concluded that 68% of the 24,000 gallons of water used daily for toilet flushing could be substituted by reclaimed water at a lower cost than buying potable water for the same purpose (Schorr & Dewling, 1988).
- In 1985, the Squibb Corporation developed a 366,000 square foot office and research and development complex in Montgomery Township which incorporated a system for on-site wastewater treatment and recycling of reclaimed water for toilet flushing (J. Irwin, *On-Site Wastewater Reclamation and Recycling*, USEPA, 1991).
- In Japan, reclaimed water has been used for toilet flushing, cooling water, landscape irrigation, car washing, cleaning and flow augmentation since the 1970s. The reuse of reclaimed water for toilet flushing is mandated for buildings over 10,000 m^2 (CMHC, 1993).
- A Canadian example of a combined wastewater reuse project is the CMHC sponsored Canadian Water and Energy Loop (CANWEL) of the 1970s. The aim of this project was to reduce the reliance of high-rise residential buildings on community services. As part of the project, combined wastewater generated within a building was to be treated and reused for toilet flushing and

landscape irrigation. Prototypes were developed by the then Ontario Research Foundation; however, field testing attempts to market CANWEL were unsuccessful (CMHC, 1993).

4.2.2 Examples of Greywater Reuse

The following is a sample of several applications of greywater reuse technology.

- At the University of British Columbia, the C.K. Choi Building, a 30,000 square foot office complex which houses the Insitute of Asian Studies, is not connected to the city's sewer system. Instead, it uses compost toilets and incorporates a subsurface wetland to cleanse greywater from the building using phragmite (tall grass) plants and reuse it for on-site irrigation (Schooley, 1994, City Farmer, 1997).
- In 1992, the City of Los Angeles' Office of Water Reclamation completed its *Gray Water Pilot Project* to investigate residential greywater systems used for landscape irrigation. The study concluded that greywater irrigation did not elevate health risks as long as sanitary practices were followed. It also found that the cost for a residential greywater system ranged from approximately $400 to $5,000 depending on system complexity and capabilities (Los Angeles, City of, 1992).

- A system for treating all wastewater from washing machines and recycling the processed water for wash water was installed in 1994 at the Cape Cod Laundry Center in South Yarmouth, Massachusetts. The system processes 12,000 gallons per day (Zenon Municipal Systems, Inc.).
- The Blue Spruce Park Visitor's Center in Indiana is an example of an indoor greywater purification system which uses a lean-to greenhouse (Como).
- The public washroom facilities at Peggy's Cove utilize a greywater reuse system in which the greywater is piped into the rootzone of planter beds where it is purified. The effluent from the planter beds is then drained by gravity to an old holding tank which overflows to a septic field on the site (John K. Dobbs & Associates, 1994).
- A system which combines both greywater and rain cistern water for irrigation of the entire yard was installed at the Arizona Public Service Environmental Showcase Home in Phoenix, Arizona in 1994 (Agwa Systems).
- In Big Sur, California, a greywater reuse system which collects 2,500 gallons of water per day and irrigates 3.5 acres of surrounding landscape was installed in a 50-room hotel in 1993 (Agwa Systems).
- The United States Army has experimented with the reuse of shower and laundry water in order to reduce the burden of supplying water for military operations in desert areas (National Research Council, 1986).

- Ecolonia, a residential district in Alphen aan den Rign, Holland, consists of approximately 100 single-family dwellings which were built to achieve energy-savings and to promote an awareness of the environment. Part of this design ethic included recycling of bath and shower water (Novem Sittard, 1992).

5. DEVELOPMENT OF AN OPPORTUNITY/CONSTRAINT ANALYSIS METHOD FOR GREYWATER REUSE RETROFIT OF EXISTING BUILDINGS

Despite its technical feasibility, greywater reuse is a relatively uncommon concept in Canadian cities. This is due largely to the public works practice of combining all wastewaters generated within a building into a common waste stream and disposal via sewers or septic systems. Greywater separation and reuse presents a break from tradition, a new paradigm in the design of wastewater handling systems for buildings. Greywater reuse retrofit of existing buildings presents an alternative urban redevelopment strategy having the potential for increasing individual building efficiencies and reducing municipal water costs associated with supply and treatment.

To facilitate informed and effective decision-making regarding the suitability of greywater reuse retrofit for particular buildings, contained in this chapter is the development of a process for relevant data collection for pre-design assessment of feasibility. Relevant issues and necessary considerations related to renovating a building to reuse greywater, as gathered from the review of literature (Chapters 3 and 4), are compiled into a planning tool which identifies protocols for pre-design assessment of greywater reuse retrofit. These protocols, in effect, uncover specific opportunities and constraints to greywater reuse retrofit for particular buildings.

5.1 Protocols For Pre-Design Assessment

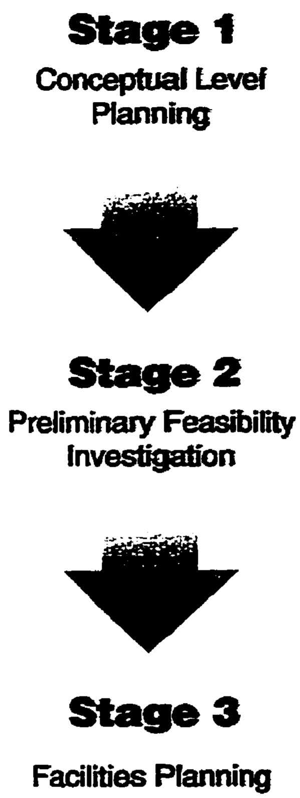
Planning for water reuse (Figure 1) typically evolves through three stages (*Water Reuse Planning and Analysis* , 1990):

1) Conceptual Level Planning
2) Preliminary Feasibility Investigation
3) Facilities Planning

Conceptual level planning involves sketching out a potential project and estimating rough costs. For preliminary feasibility investigation, specific information must first be collected in order to assess existing water supply and wastewater facilities and to develop appropriate water reclamation alternatives. The facilities planning stage involves detailed planning and design.

This study is concerned only with the data collection necessary for the second stage of water reuse planning, i.e., the preliminary feasibility investigation stage. In particular, it is the intent of this study to identify what specific types of data must be gathered to enable a preliminary assessment of feasibility for greywater reuse retrofit of existing buildings.

Figure 1: Planning for Water Reuse



From the review of literature, it would appear that there are three levels of information which should be examined in a preliminary assessment of feasibility:

(i) planning issues related to the institutional or regulatory/policy environment;

(ii) site specific information related to the building environment in question; and

(iii) solution generation related to possible reuse options.

The following subsections examine the above areas, identifying specific issues and items of concern related to each.

5.1.1 Planning Issues: The Institutional Framework

In section 4.1, seven implementation issues related to greywater reuse technology were identified. Five of these (i.e., public health protection, preventing environmental degradation, avoiding public nuisance, meeting user requirements and regulatory compliance) are addressed by specific areas of institutional or regulatory control. In particular, it is proposed that there are six areas of institutional control affecting greywater reuse retrofit:

(i) Public Health

(ii) Environmental

(iii) Building/Plumbing Codes

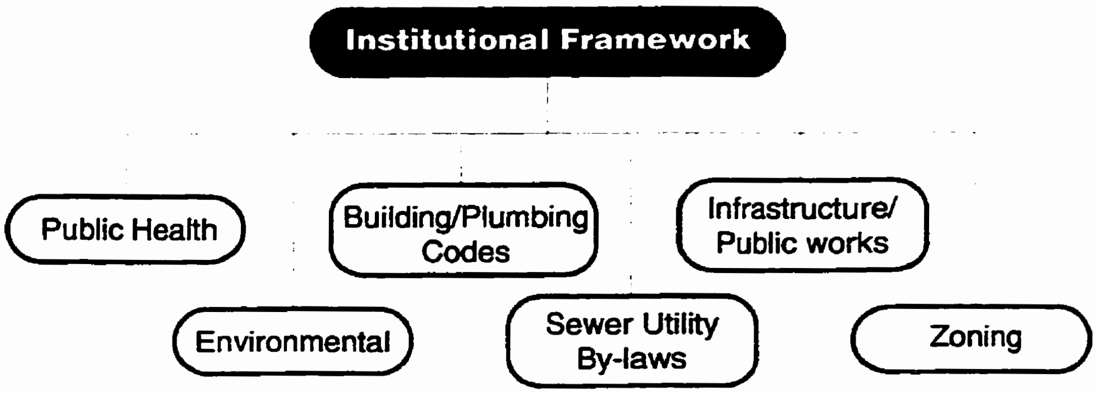
(iv) Sewer Utility By-laws

(v) Infrastructure/Public Works

(vi) Zoning

Together these areas make up an *institutional framework* with respect to greywater reuse (Figure 2).

Figure 2: The Institutional Framework With Respect To Greywater Reuse Retrofit



Public acceptance and cost are both considered important implementation issues (as identified in Chapter 4). However, they differ from the other five implementation issues, as previously identified, in that they are not dealt with by any specific regulatory authority or policy area. Public acceptance of a new technology is typically related to society's opinion of the value of that technology and their willingness to accept change. As discussed in Chapter 4, various measures can be taken to promote public acceptance. Acceptable levels of cost are a factor of the cost effectiveness of the overall system and are determined on a building-by-building basis. Cost will be addressed in the third level of opportunities and constraints which will be discussed later in this chapter.

Through the review of literature and contact with local professionals in each of the five areas of regulatory control, specific items of concern related to each were identified. The following subsections examine the five areas further and identify key items associated with each.

5.1.1.1 Public Health

In any water reuse scheme, public health must be a primary concern. Appropriate steps must be taken to, first, understand the potential health risk posed by the reuse scheme and second, to minimize the potential risk. From the literature review and through contact with local professionals, the most critical items of concern from a public health stand-point include the following:

- Bacteria Content. Of particular concern are concentrations of Salmonella, Shigella and coliforms. Local regulations will vary with respect to specific types of bacteria to be controlled and the concentrations considered acceptable. These should be determined and conformed with.
- Protozoa Content. Typically, concentrations of Entamoeba histolytica, Giardia lamblia and Cryptosporidium are considered significant and must be maintained below the maximum concentrations allowed by the local health authority. Again, these will vary with the jurisdiction.

- Helminth Content. (i.e., parasites) Local health authorities should be contacted for the maximum concentration allowable.
- Viruses. Polio, hepatitis A, Norwalk and rotavirus are of particular concern.
- Chemical Parameters. pH, sodium, chloride, calcium, magnesium, phosphorous, total salts and any others originating from industrial waste streams should be considered.
- Public Exposure. The potential for body contact, inhalation and ingestion should be minimized.

In the data collection stage of a greywater reuse system, the above items must be considered in order to meet the requirements of the applicable public health regulations.

5.1.1.2 Environmental

Another primary concern for a greywater reuse scheme is protection of the environment. From the literature review and through contact with local professionals, the most critical items of concern from an environmental stand-point include the following:

- Nutrient Levels. Local regulations will vary for different jurisdictions.

- Salt Concentration. Again, local regulations must be determined and conformed with.
- Ground/Surface Water Contamination. Appropriate measures must be taken to minimize the risk of contaminating ground and surface water sources.
- Proper Storage and Disposal of Excess Water. Measures must be in place for safely storing and disposing of excess water. Infrastructure for routing greywater to septic or sewer systems should be in place as a back-up disposal option.
- Plant Damage. If the greywater reuse scheme involves irrigation, consideration must be given to the potential for plant damage. Proper control of nutrient and salt levels will minimize the risk of plant damage.

The above items must be considered in the data collection stage of a greywater reuse plan.

5.1.1.3 Building/Plumbing Codes

To gain proper approval and authorization for a greywater reuse scheme, conformance must be made to local building and plumbing codes. These are specific to the jurisdiction in which the building in question is located. Local agencies should be contacted during the data collection stage of a greywater reuse plan to ensure that codes are understood and met by any future design.

5.1.1.4 Sewer Utility By-laws

Sewer utility by-laws must also be conformed with to gain approval for a greywater reuse system. Again, these by-laws are specific to the particular jurisdiction and local agencies should be contacted during the data collection stage.

5.1.1.5 Infrastructure/Public Works

Two types of infrastructure must be considered: on-site infrastructure which is integral to the operation of the greywater reuse system (e.g., pipes, storage facilities, etc.) and infrastructure which is external to the system (e.g., sewer systems). The following are the key items of concern with respect to infrastructure/public works:

- Cross-contamination. Cross-contamination of greywater into potable water pipes must be avoided.
- Adequate Flows. Adequate flows must be maintained through the sewer system.
- Filtering. When greywater is used for toilet flushing, a suitable filtering system must be in place to ensure proper flushing and reduce wear on the flushing mechanism.

- Storage Facilities. Adequate storage facilities must be made available.
- Treatment Measures. Suitable treatment measures must be established and implemented and appropriate measures must be taken for disposal of waste products from treatment.

5.1.1.6 Zoning

If greywater reuse retrofit of a building makes the property conflict with its zoning designation, there are generally two options available: a variance may be applied for in which the conflicting use is allowed to exist for a specified period of time or the land may be rezoned. Spot zoning in which only a small parcel of land is affected by the rezoning may also be an alternative.

The property's zoning designation and specific use restrictions should be determined during the data collection stage of a greywater reuse plan.

5.1.2 Site-specific Considerations

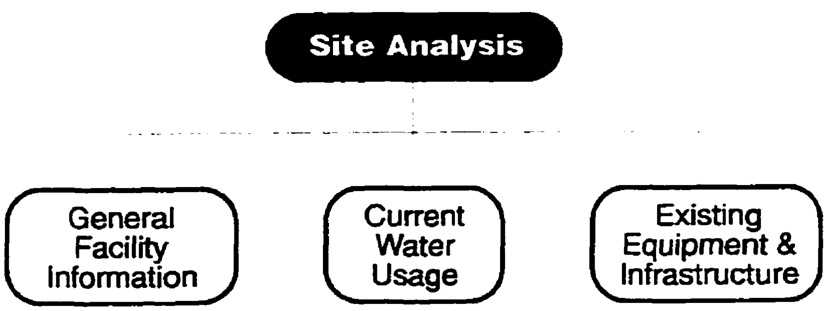
The second level of opportunities and constraints focuses on site specific considerations. In particular, three aspects of the site must be considered (Figure 3):

(i) General Facility Information — to establish characteristics of the building including type, function and future occupancy plans.

(ii) Current Water Usage — to establish types and patterns of water usage for the building and the potential for water conservation.

(iii) Existing Equipment and Infrastructure — to determine the type and condition of water distribution and conveyance infrastructure and water-using equipment and systems within the building environment.

Figure 3: Site-Analysis With Respect To Greywater Reuse Retrofit



5.1.2.1 General Facility Information

From the literature review and through contact with local professionals, the following criteria should be established in the data collection stage of a greywater reuse plan in order to develop an adequate profile of the facility:

- General description of the building including:
- Location
- Number of floors
- Size
- Age of building
- Number of occupants
- Main function(s) of the facility
- Facility systems and architectural drawings
- List of all known dangerous materials used in the facility
- Expected remaining useful life of building
- Future occupancy and use plans
- List of known and deferred maintenance projects or major renovation plans
- Summary of current maintenance practices
- List of contractors currently servicing the facility including type and duration of service contracts

5.1.2.2 Current Water Usage

From the literature review and through contact with local professionals, the following criteria should be established in the data collection stage of a greywater reuse plan to develop an adequate understanding of the type and patterns of water usage occurring within the building:

- Quantity of water used in the building environment. (This can be determined by assessing water bills for the building from the previous 24 months.)
- Peak demand factors.
- Present and projected cost of water usage for the building.
- Types of water uses present within the building environment.
- List of chemicals added to water in the building environment.
- Sources of greywater.
- Quantity of greywater produced from each individual source.
    - How consistent is this quantity? (Weekly or seasonal fluctuations?)
- Quality of greywater from each individual source.
    - How consistent is this quality? (Weekly or seasonal fluctuations?)
    - Are there any industrial-type contributions to the flow? If so, what are they?
- Identify previous measures taken with respect to water conservation.

5.1.2.3 Existing Equipment and Infrastructure

From the review of literature and through contact with local professionals, the following criteria with respect to existing water distribution infrastructure and water-using equipment and systems within the building environment should be established in the data collection stage of a greywater reuse plan:

- Assessment of distribution and conveyance systems, heating and cooling systems which use water, and any other equipment which uses water. Specifically, identify:
    - Type of equipment/infrastructure
    - General condition of equipment/infrastructure
    - Age of equipment/infrastructure
    - Chemicals added to water

5.1.3 Solution Generation Related to Possible Reuse Options

The third level of opportunities and constraints is concerned with solution generation related to possible reuse options. Solution generation must take into consideration the following issues (Figure 4):

(i) Reuse Possibilities — Existing uses of water within the building which may be met with greywater and specific requirements of each.

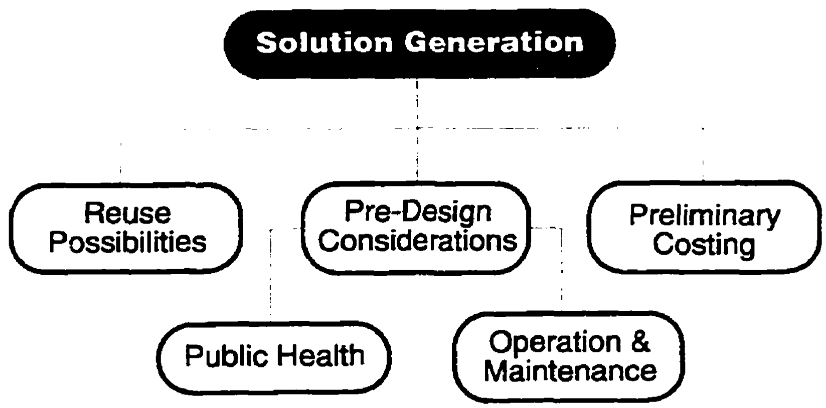
(ii) Pre-design Considerations — Pre-design considerations for each alternative reuse scenario must address both:

(a) Public Health Protection and

(b) Operating and Maintenance Requirements

(iii) Preliminary Costing — Preliminary cost estimates must be made for each alternative and possible funding strategies should be identified.

Figure 4: Solution Generation Related to Possible Reuse Options



5.1.3.1 Reuse Possibilities

From the review of literature and through contact with local professionals, the following criteria must be established in the data collection stage to determine possible uses for greywater in a particular building environment:

- Current uses of potable water within the building which could be replaced with greywater.
- Quantity of water required for each type of use (daily flow and peak demand).
- Quality of water required for each type of use.
- Allowable fluctuation in water quality for each type of use.
- Stability of each potential use of greywater (i.e., whether these uses will continue to be required in the future).
- Stability of the water supply.

5.1.3.2 Pre-design Considerations

The review of literature and contact with local professionals suggests that the design of an appropriate greywater reuse system must focus on the following items: characteristics of the greywater generated; meeting required physical, chemical and microbiological water quality requirements; producing consistent water quality; being responsive to variations in source water quality and quantity and varying use patterns; operability; meeting space and location requirements; and producing a minimum volume of waste products. Generally, these pre-design considerations can be grouped into two specific areas of focus: public health protection and operating and maintenance requirements.

Public Health Protection

With respect to public health protection, the design of a greywater reuse system must take into consideration the following criteria:

- Suitable treatment measures (and appropriate disposal of waste products).
- Adequate control measures for chemical constituents in the greywater.
- Adequate measures for minimization of public exposure to the reclaimed greywater (through contact, inhalation and ingestion).
- Adequate monitoring of greywater sources (including the general health of the contributing population, existence of disease-carriers in the population, etc.).
- Cross-connection prevention. Specifically:
    - Pipe alterations performed by professional plumbers
    - Suitable labeling of all nonpotable components of the system to prevent cross-connections (for example, *Warning — Nonpotable Water — Not Safe For Drinking*)
    - Pipes carrying greywater made of flexible plastic or color-coded rigid plastic (clearly different from water lines)
    - regular visits and inspections by project personnel

Operating and Maintenance Requirements

With respect to operating and maintenance requirements, pre-design must consider the following:

- The required storage facilities including type, volume and location.
- The required conveyance and distribution networks.
- Appropriate instrumentation and control systems for monitoring the treatment process performance and disposal of waste products.
- Appropriate alarms for process malfunctions.
- An appropriate quality assurance program to ensure adequate treatment and sampling protocol (including facilities for sampling).
- Adequate emergency storage to retain reclaimed water of unacceptable quality for retreatment or disposal.
- Alternative disposal facilities (e.g.., sewer or septic system).
- Flexibility of piping and pumping facilities to permit rerouting of flows to alternative disposal facilities under emergency conditions.
- Standby power for essential treatment processes.
- Adequate operator training.
- An effective preventative maintenance program.
- An estimate of the service life of the system.

5.1.3.3 Preliminary Costing

To assess the financial feasibility of the project in the second stage of water reuse planning, certain costing criteria must first be established in the data collection stage. From the review of literature, the following items with respect to preliminary costing should be determined in the data collection stage:

- An estimate of the full cost for the retrofit with the greywater reuse system (including costs of additional facilities for onsite treatment, storage and distribution). Specifically:
    - Capital costs including costs for preliminary analytical work for assessment of feasibility, structures, process equipment, major auxiliary equipment, special foundation requirements, electrical and instrumentation, site work, miscellaneous process and piping, construction contingencies, engineering, project administration and interest.
    - Operating and maintenance costs including costs for labour, electrical power, chemicals, routine equipment maintenance, materials and supplies and disposal of treatment by-products.
- An estimate of projected savings in water costs.
- Savings in treatment and disposal of wastewater.
- Cost effectiveness.

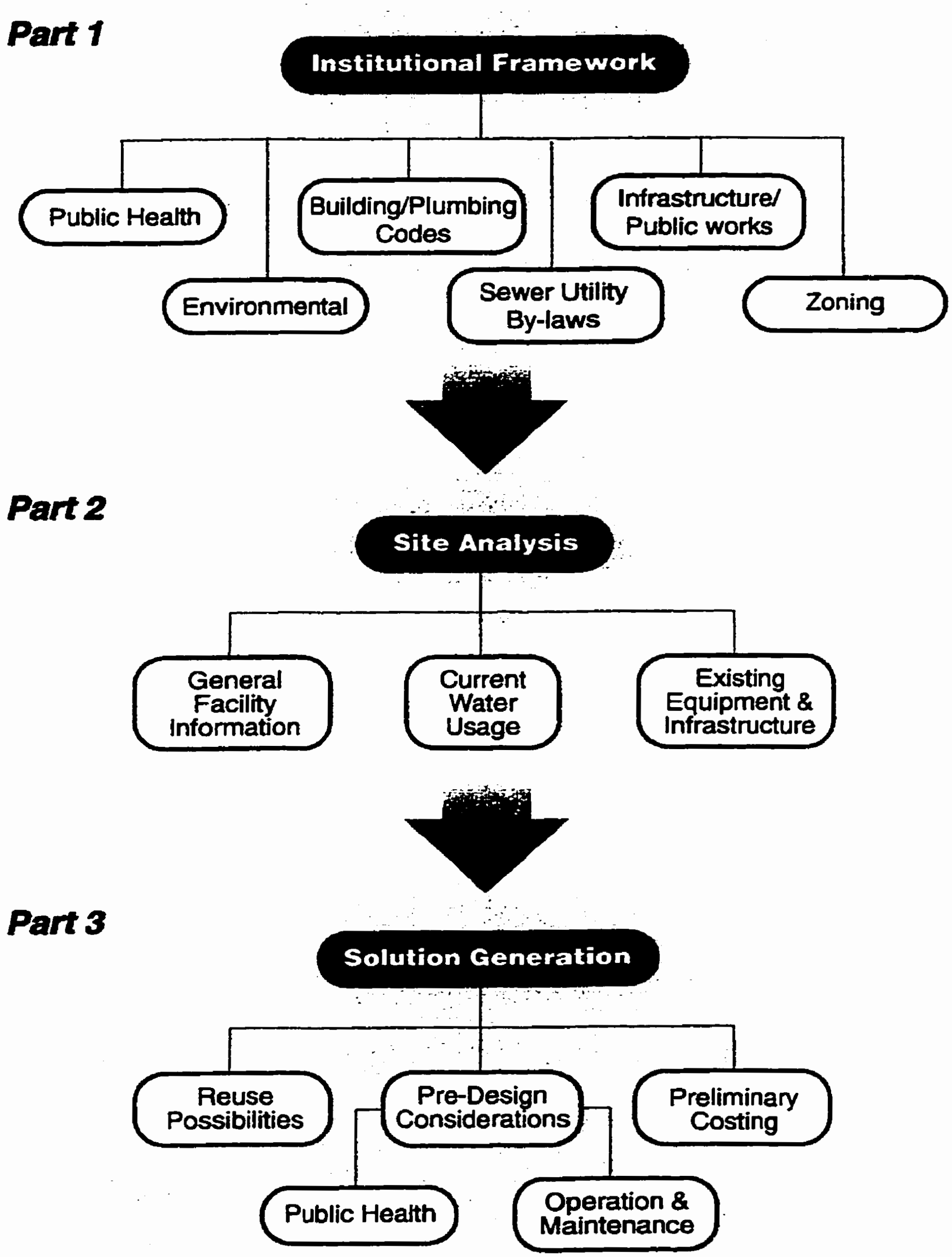
- Cost-benefit and feasibility analyses.
- An acceptable payback period.
- Possible sources of funding (and consideration of any requirements potential funding agencies would impose upon the project).

5.2 An Opportunity/Constraint Analysis Method for Greywater Reuse Retrofit

Three levels of opportunities and constraints and specific issues and items of concern associated with each were identified in the previous subsections. Taken together, these form a three-part opportunity/constraint analysis tool for greywater reuse retrofit of existing buildings (Figure 5).

The opportunity/constraint analysis tool is presented in the form of a checklist (see pages 75 to 78). This format provides a convenient method for identifying and considering relevant issues related to renovating existing buildings with greywater reuse systems. By identifying specific issues and considerations which are essential for a safe and efficient greywater reuse system which complies with all regulations, one is able to assess particular buildings for their appropriateness for greywater reuse retrofit.

Figure 5: An Opportunity/Constraint Analysis Method For Greywater Reuse Retrofit



The tables are set up in three parts, corresponding to the three levels of opportunities and constraints previously developed. Part 1 deals with *planning issues* related to institutional control. Part 2 identifies the relevant considerations to conduct an effective *site analysis* of the building in question. Part 3 identifies criteria associated with appropriate *solution generation* for greywater reuse retrofit. Each part is broken down according to the specific issues identified in the preceding subsections and then further broken down into the major items of concern also previously identified for each. This format allows each item to be isolated and dealt with individually.

Ideally, a planner considering greywater reuse retrofit for a particular building would go through the tables, checking off each item as it is considered and making relevant notes in the comment space provided. After all items are considered, the planner would proceed to the assessment of feasibility stage and finally, if feasibility is established, to the facilities planning and design stage.

By providing planners with a convenient tool for establishing the feasibility of greywater reuse systems for existing buildings, the Opportunity/Constraint Analysis Checklist would facilitate informed and effective decision-making and promote greywater reuse as a retrofit water conservation alternative for urban redevelopment. Ultimately, this is an urban redevelopment strategy which has great potential for increasing the efficiency of the built environment and reducing municipal spending for water supply and treatment.

Opportunity/Constraint Analysis Checklist			
Part I Planning Issues			
Issue	Item	Considered	Comments
Public Health	Bacteria *Salmonella *Shigella *Coliforms (fecal and total)		
	Protozoa *Entamoeba histolytica *Giardia lamblia *Cryptosporidium		
	Helminths (parasites)		
	Viruses *Polio *Hepatitis A *Norwalk *Rotavirus		
	Chemical Parameters *pH *Sodium *Chloride *Calcium *Magnesium *Phosphorus *Total Salts *Chemicals of industrial origin		
	Public Exposure *Body Contact *Inhalation *Ingestion		
Environment	Nutrient Levels		
	Salt Concentration		
	Ground Water Contamination		
	Surface Water Contamination		
	Disposal of Excess Water		
	Plant Damage		
Building and Plumbing Codes	Conformity with local codes and regulations		
Sewer Utility By-laws	Conformity with local by-laws		
Infrastructure/ Public Works	Cross-contamination		
	Flows through sewers		
	Filtering		
	Storage Facilities		
	Treatment Measures		
Zoning	Conformity with local zoning ordinances		

Opportunity/Constraint Analysis Checklist			
Part II: Site Analysis			
Issue	Item	Considered	Comments
General Facility Information	Size		
	Number of Floors		
	Age of Building		
	Number of Occupants		
	Building Function(s)		
	Drawings (Facility Systems & Architectural)		
	Hazardous Materials Used		
	Expected Remaining Useful Life of the Building		
	Current Maintenance Practices		
	Future Occupancy & Use Plans		
	Major Renovation Plans		
	Contractors Serving Facility		
Current Water Usage	Quantity of Water Used		
	Peak Demand Factors		
	Average Demand		
	Present & Projected Water Costs		
	Types of Water Uses		
	Chemicals Added to Water		
	Required Quality for all Uses		
	Sources of Greywater		
	Quantity of Greywater from Each Source (& consistency of these quantities)		
	Quality of Greywater from Each Source (& consistency of these qualities)		
	Previous Water Conservation Measures		
Existing Equipment and Infrastructure	Water Distribution and Conveyance Infrastructure *Type *General Condition *Age		
	Heating/Cooling Systems Which Use Water *Type *General Condition *Age *Chemicals Added		
	Other Water Using Equipment *Type *General Condition *Age *Chemicals Added		

Opportunity/Constraint Analysis Checklist			
Part III: Reuse Options			
Issue	Item	Considered	Comments
Reuse Possibilities	Uses of potable water which could be replaced with greywater		
	Quantity required (peak & averag demand) for each use which could be met with greywater		
	Quality required for each water use which could be met with greywater		
	Stability of each water use which could be met with greywater (likelihood of it remaining a use in future)		
Pre-Design Considerations	Public Health Protection *suitable treatment measures (& appropriate disposal of waste products) *control measures for chemical constituents *monitoring of greywater sources *use of professional plumbers *labeling of all nonpotable & potable components *use of different piping material for potable and nonpotable components *inspection program established		
	Operating & Maintenance Requirements *adequate storage facilities (including emergency storage) *suitable conveyance and distribution network *instrumentation/control systems for monitoring treatment *disposal of waste products *alarms for process malfunctions *quality assurance program *alternative disposal facilities *flexibility of piping & pumping facilities to permit rerouting to alternative disposal		

Opportunity/Constraint Analysis Checklist			
Part III: Reuse Options (con't)			
Issue	Item	Considered	Comments
Pre-Design Considerations (con't)	Operating & Maintenance Requirements (con't) *standby power for essential treatment processes *operator training program *estimate of service life		
Preliminary Costing	Capital Costs *preliminary analytical work *storage facilities *process equipment *special foundation requirements *site work *miscellaneous process and piping *electrical/instrumentation *construction contingencies *engineering *project administration *interest		
	Operating & Maintenance *labour *materials and supplies *chemicals *by-products disposal *routine equipment maintenance *electrical power		
	Estimate of water cost savings		
	Savings in treatment & disposal of wastewater		
	Acceptable payback period		
	Cost effectiveness analysis		
	Possible sources of funding		

6. TOWARDS IMPLEMENTATION OF GREYWATER REUSE RETROFIT: IDEAS FOR FURTHER STUDY

To promote greywater reuse as a viable water management option for buildings and an urban redevelopment strategy leading to a more efficient urban environment both in terms of individual building efficiencies and municipal water costs, much study is still needed.

A number of ideas for further study are presented below. These are identified simply to trigger further study to promote greywater reuse as an alternative water conservation and urban redevelopment strategy.

- The Opportunity/Constraint Analysis Method developed in this report should be applied to an existing building environment to assess the building's feasibility for greywater reuse retrofit.
- A pilot project should be conducted in which an existing building is renovated with a greywater reuse system. Suggestions for possible locations for pilot projects include Winnipeg's Exchange District, the University of Manitoba campus or a core area neighbourhood.
- All regulations that a greywater reuse system would have to comply with for a particular jurisdiction (such as Winnipeg) should be identified and summarized.

- An in-depth study of the City of Winnipeg's building code and sewer utility by-law should be conducted and specific recommendations should be made to the code and by-law requiring all new construction to provide for parallel plumbing to accommodate greywater reuse.
- A study should be made of the implications to the traditional definition of the building as a result of implementing greywater reuse systems (i.e., the introduction of greater efficiencies with respect to resource use, the possible development of a new paradigm in buildings, etc.).
- Opportunities for promoting the public's awareness of how greywater can become an important resource generated within buildings should be identified and developed.
- A technical analysis should be conducted of the impact to sewer flows as a result of reusing greywater for toilet flushing (perhaps for a small community or local sewered area within Winnipeg).
- Opportunities should be identified for reusing greywater in different types of buildings (e.g., single/multi family residential, office complexes, high rise buildings, recreational facilities, industrial applications, etc.).
- A technical analysis should be conducted of different greywater treatment options.

- An economic analysis should be conducted of different greywater treatment options.
- A study should be made of possible cost savings versus implementation costs associated with greywater reuse retrofit of existing buildings.
- A study should be made of possible cost savings versus implementation costs associated with greywater reuse systems in new buildings.
- A study of the implications to settlement patterns (for example for subdivisions) as a result of implementing greywater reuse systems in residential communities should be conducted.
- Opportunities should be identified for incorporating greywater reuse systems into the overall aesthetic quality of buildings (i.e., develop interior design solutions to bring greywater reuse into the overall functioning of buildings).

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Wotton, Dave. Manitoba Environment, Environmental Operations Division, 1995.

APPENDIX A

Quantities of Greywater Typically Produced From Various Sources

The amount of greywater typically produced from washing machines, showers, tubs and bathroom sinks are as follows (Ludwig: 1994):

Washing Machines:	1.5 loads per week per adult 2.5 loads per week per child 30-50 gallons per load for top-loading machines 10 gallons per load for front-loading machines.
Low-flow showerheads:	20 gallons per day per person
High-flow showerheads:	40 gallons per day per person
Bath tubs:	40 gallons per bath
Bathroom sinks:	1-5 gallons per day per person

APPENDIX B

Elements Found In Common Household Products Which Should Be Limited When Irrigating With Greywater

Product	Harmful Elements
Laundry Detergent	Arsenic Mercury
Bleach	Cadmium Nickel
Softener	Chromium Silver
Dishwashing Liquid	Arsenic
Soap	Chromium Nickel
Shampoo	Copper Zinc

(Source:California, State of. Graywater Guide: Using Graywater In Your Home Landscape. Department of Water Resources, Los Angeles, 1994.)

APPENDIX C

Plant Species and Greywater Irrigation

The following is a list of plants that are not suitable for the alkaline conditions associated with greywater irrigation.

Rhododendrons	Gardenias
Bleeding Hearts	Philodendrons
Oxalis (Wood Sorrel)	Camellias
Hydrangeas	Primroses
Azaleas	Crape Myrtle
Violets	Redwoods
Impatiens	Star Jasmine
Begonias	Holly
Ferns	Deodar Cedar
Foxgloves	

The following plant species should respond well to greywater irrigation.

Oleander	Italian Stone Pine
Bougainvillea	Purple Hopseed Bush
Fan and Date Palms	Oaks
Rose	Arizona Cypress
Rosemary	Cottonwood
Agapanthus	Olive
Bermuda Grass	Ice Plant
Honeysuckle	Juniper
Australian Tea Tree	

(Source:California, State of. Graywater Guide: Using Graywater In Your Home Landscape. Department of Water Resources, Los Angeles, 1994.)

APPENDIX D

Recommended Limits For Toilet Flushing

Parameter	Maximum
Turbidity	20 units
Color	30 units
Odor	6 units
Manganese	0.5 mg/l
Copper	1.0 mg/l
Iron	1.0 mg/l
Iron and Manganese	1.0 mg/l

(Source: CMHC, Advancing the Light Grey Option: Making Residential Greywater Reuse Happen, 1993)

APPENDIX E

APPENDIX J

Graywater Systems for Single-family Dwellings

J 1 Graywater Systems (General)

(a) The provisions of this Appendix shall apply to the construction, alteration and repair of graywater systems for subsurface landscape irrigation. Installations shall be allowed only in single-family dwellings. The system shall have no connection to any potable water system and shall not result in any surfacing of the graywater. Except as otherwise provided for in this Appendix, the provisions of the Uniform Plumbing Code (U.P.C.) shall be applicable to graywater installations.

(b) 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 residential building. The system shall discharge into subsurface irrigation fields and may include surge tank(s) and appurtenances, as required by the Administrative Authority.

(c) No graywater system, or part thereof, shall be located on any lot other than the lot which is the site of the building or structure which discharges the graywater; nor shall any graywater system or part thereof be located at any point having less than the minimum distances indicated in Table J-1.

(d) 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. When there is insufficient lot area or inappropriate soil conditions for adequate absorption of the graywater, as determined by the Administrative Authority, no graywater system shall be permitted. The Administrative Authority is a city or county.

(e) No permit shall be issued for a graywater system which would adversely impact a geologically sensitive area, as determined by the Administrative Authority.

(f) Private sewage disposal systems existing or to be constructed on the premises shall comply with Appendix I of this Code or applicable local ordinance. When abandoning underground tanks, Section 1119 of the U.P.C. shall apply. Also, appropriate clearances from graywater systems shall be maintained as provided in Table J-1. The capacity of the private sewage disposal system, including required future areas, shall not be decreased by the existence or proposed installation of a graywater system servicing the premises.

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(g) Installers of graywater systems shall provide an operation and maintenance manual, acceptable to the Administrative Authority, to the owner of each system. Graywater systems require regular or periodic maintenance.

(h) The Administrative Authority shall provide the applicant a copy of this Appendix.

J 2 Definitions

Graywater is untreated household waste water which has not come into contact with toilet waste. Graywater includes used water from bathtubs, showers, bathroom wash basins, and water from clothes washing machines and laundry tubs. It shall not include waste water from kitchen sinks, dishwashers or laundry water from soiled diapers.

Surfacing of graywater means the ponding, running off or other release of graywater from the land surface.

J 3 Permit

It shall be unlawful for any person to construct, install or alter, or cause to be constructed, installed or altered, any graywater system in a building or on a premises without first obtaining a permit to do such work from the Administrative Authority.

J 4 Drawings and Specifications

The Administrative Authority may require any or all of the following information to be included with or in the plot plan before a permit is issued for a graywater system:

(a) Plot plan drawn to scale completely dimensioned, showing lot lines and structures, direction and approximate slope of surface, location of all present or proposed retaining walls, drainage channels, water supply lines, wells, paved areas and structures on the plot, number of bedrooms and plumbing fixtures in each structure, location of private sewage disposal system and 100 percent expansion area or building sewer connecting to public sewer, and location of the proposed graywater system.

(b) Details of construction necessary to ensure compliance with the requirements of this Appendix together with a full description of the complete installation, including installation methods, construction and materials as required by the Administrative Authority.

(c) A log of soil formations and ground water level as determined by test holes dug in close proximity to any proposed irrigation area, together with a statement of water absorption characteristics of the soil at the proposed site as determined by approved percolation tests. In lieu of

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percolation tests, the Administrative Authority may allow the use of Table J-2, an infiltration rate designated by the Administrative Authority, or an infiltration rate determined by a test approved by the Administrative Authority.

J 5 Inspection and Testing

(a) Inspection

(1) All applicable provisions of this Appendix and of Section 318 of the U.P.C. shall be complied with.

(2) System components shall be properly identified as to manufacturer.

(3) Surge tanks shall be installed on dry, level, well-compacted soil if in a drywell, or on a level, 3-inch concrete slab or equivalent, if above ground.

(4) Surge tanks shall be anchored against overturning.

(5) If the irrigation design is predicated on soil tests, the irrigation field shall be installed at the same location and depth as the tested area.

(6) Installation shall conform with the equipment and installation methods identified in the approved plans.

(7) Graywater stub-out plumbing may be allowed for future connection prior to the installation of irrigation lines and landscaping. Stub-out shall be permanently marked GRAYWATER STUB-OUT, DANGER—UNSAFE WATER.

(b) Testing

(1) Surge tanks shall be filled with water to the overflow line prior to and during inspection. All seams and joints shall be left exposed and the tank shall remain watertight.

(2) A flow test shall be performed through the system to the point of graywater irrigation. All lines and components shall be watertight.

J 6 Procedure for Estimating Graywater Discharge

The Administrative Authority may utilize the graywater discharge procedure listed below, water use records, or calculations of local daily per person interior water use:

(a) The number of occupants of each dwelling unit shall be calculated as follows:

First bedroom	2 occupants
Each additional bedroom	1 occupant

(b) The estimated graywater flows for each occupant shall be calculated as follows:

Showers, bathtubs and wash basins	25 GPD/occupant
Laundry	15 GPD/occupant

(c) The total number of occupants shall be multiplied by the applicable estimated graywater discharge as provided above and the type of fixtures connected to the graywater system.

J 7 Required Area of Subsurface Irrigation

Each irrigation zone shall have a minimum effective irrigation area for the type of soil and infiltration rate to distribute all graywater produced daily, pursuant to Section J-6, without surfacing. The required irrigation area shall be based on the estimated graywater discharge, pursuant to Section J-6 of this Appendix, size of surge tank, or a method determined by the Administrative Authority. Each proposed graywater system shall include at least two irrigation zones and each irrigation zone shall be in compliance with the provisions of this Section.

If the mini-leachfield irrigation system is used, the required square footage shall be determined from Table J-2, or equivalent, for the type of soil found in the excavation. The area of the irrigation field shall be equal to the aggregate length of the perforated pipe sections within the irrigation zone times the width of the proposed mini-leachfield trench.

No irrigation point shall be within 5 vertical feet of highest known seasonal groundwater nor where graywater may contaminate the ground water or ocean water. The applicant shall supply evidence of ground water depth to the satisfaction of the Administrative Authority.

J 8 Determination of Irrigation Capacity

(a) In order to determine the absorption quantities of questionable soils other than those listed in Table J-2, the proposed site may be subjected to percolation tests acceptable to the Administrative Authority or determined by the Administrative Authority.

(b) When a percolation test is required, no mini-leachfield system or subsurface drip irrigation system shall be permitted if the test shows the absorption capacity of the soil is less than 60 minutes/inch or more rapid than five minutes/inch, unless otherwise permitted by the Administrative Authority.

(c) The irrigation field size may be computed from Table J-2, or determined by the Administrative Authority or a designee of the Administrative Authority.

J 9 Surge Tank Construction (Figures 1, 2, 3 and 4)

(a) Plans for surge tanks shall be submitted to the Administrative Authority for approval. The plans shall show the data required by the Administrative Authority and may include dimensions, structural calculations, and bracing details.

(b) Surge tanks shall be constructed of solid, durable materials, not subject to excessive corrosion or decay, and shall be watertight.

(c) Surge tanks shall be vented as required by Chapter 5 of this Code and shall have a locking, gasketed access opening, or approved equivalent, to allow for inspection and cleaning.

(d) Surge tanks shall have the rated capacity permanently marked on the unit. In addition, GRAYWATER IRRIGATION SYSTEM, DANGER—UNSAFE WATER shall be permanently marked on the surge tank.

(e) Surge tanks installed above ground shall have a drain and overflow, separate from the line connecting the tank with the irrigation fields. The drain and overflow shall have a permanent connection to a sewer or to a septic tank, and shall be protected against sewer line backflow by a backwater valve. The overflow shall not be equipped with a shutoff valve.

(f) The overflow and drain pipes shall not be less in diameter than the inlet pipe. The vent size shall be based on the total graywater fixture units, as outlined in U.P.C. Table 4-3 or local equivalent. Unions or equally effective fittings shall be provided for all piping connected to the surge tank.

(g) Surge tanks shall be structurally designed to withstand anticipated loads. Surge tank covers shall be capable of supporting an earth load of not less than 300 pounds per square foot when the tank is designed for underground installation.

(h) Surge tanks may be installed below ground in a dry well on compacted soil, or buried if the tank design is approved by the Administrative Authority. The system shall be designed so that the tank overflow will gravity drain to a sanitary sewer line or septic tank. The tank must be protected against sewer line backflow by a backwater valve.

(i) Materials

(1) Surge tanks shall meet nationally recognized standards for nonpotable water and shall be approved by the Administrative Authority.

(2) Steel surge tanks shall be protected from corrosion, both externally and internally, by an approved coating or by other acceptable means.

J 10 Valves and Piping (Figures 1, 2, 3 and 4)

Graywater piping discharging into a surge tank or having a direct connection to a sanitary drain or sewer piping shall be downstream of an approved waterseal-type trap(s). If no such trap(s) exists, an approved vented running trap shall be installed upstream of the connection to protect the building from any possible waste or sewer gases. All graywater piping shall be marked or shall have a continuous tape marked with the words DANGER—UNSAFE WATER. All valves, including the three-way valve, shall be readily accessible and shall be approved by the Administrative Authority. A backwater valve, installed pursuant to this Code, shall be provided on all surge tank drain connections to the sanitary drain or sewer piping.

J 11 Irrigation Field Construction

The Administrative Authority may permit subsurface drip irrigation, mini-leachfield or other equivalent irrigation methods which discharge graywater in a manner which ensures that the graywater does not surface. Design standards for subsurface drip irrigation systems and mini-leachfield irrigation systems follow:

(a) Standards for a subsurface drip irrigation system are:

(1) Minimum 140 mesh (115 micron) 1-inch filter with a capacity of 25 gallons per minute, or equivalent, filtration shall be used. The filter backwash and flush discharge shall be caught, contained and disposed of to the sewer system, septic tank or, with approval of the Administrative Authority, a separate mini-leachfield sized to accept all the backwash and flush discharge water. Filter backwash water and flush water shall not be used for any purpose. Sanitary procedures shall be followed when handling filter backwash and flush discharge or graywater.

(2) Emitters shall have a minimum flow path of 1,200 microns and shall have a coefficient of manufacturing variation (Cv) of no more than 7 percent. Irrigation system design shall be such that emitter flow variation shall not exceed ± 10 percent. Emitters shall be recommended by the manufacturer for subsurface use and graywater use, and shall have demonstrated resistance to root intrusion. For emitter ratings, refer to Irrigation Equipment Performance Report, Drip Emitters and Micro-Sprinklers, Center for Irrigation Technolo-

gy, California State University, 5730 N. Chestnut Avenue, Fresno, California 93740-0018.

(3) Each irrigation zone shall be designed to include no less than the number of emitters specified in Table J-3, or through a procedure designated by the Administrative Authority. Minimum spacing between emitters is 14 inches in any direction.

(4) The system design shall provide user controls, such as valves, switches, timers and other controllers, as appropriate, to rotate the distribution of graywater between irrigation zones.

(5) All drip irrigation supply lines shall be PVC Class 200 pipe or better and Schedule 40 fittings. All joints shall be properly glued, inspected and pressure tested at 40 psi, and shown to be drip tight for five minutes, before burial. All supply lines will be buried at least 8 inches deep. Drip feeder lines can be poly or flexible PVC tubing and shall be covered to a minimum depth of 9 inches.

(6) Where pressure at the discharge side of the pump exceeds 20 psi, a pressure-reducing valve able to maintain downstream pressure no greater than 20 psi shall be installed downstream from the pump and before any emission device.

(7) Each irrigation zone shall include an automatic flush valve/vacuum breaker to prevent back siphonage of water and soil.

(b) Standards for the mini-leachfield system are (Figure 5):

(1) Perforated sections shall be a minimum 3-inch diameter and shall be constructed of perforated high-density polyethylene pipe, perforated ABS pipe, perforated PVC pipe, or other approved materials, provided that sufficient openings are available for distribution of the graywater into the trench area. Material, construction and perforation of the piping shall be in compliance with the appropriate absorption field drainage piping standards and shall be approved by the Administrative Authority.

(2) Clean stone, gravel or similar filter material acceptable to the Administrative Authority, and varying in size between $^3/_4$ inch to $2^1/_2$ inches shall be placed in the trench to the depth and grade required by this Section. Perforated sections shall be laid on the filter material in an approved manner. The perforated sections shall then be covered with filter material to the minimum depth required by this Section. The filter material shall then be covered with landscape filter fabric or similar porous material to prevent closure of voids with earth backfill. No earth backfill shall be placed over the filter material cover until after inspections and acceptance.

(3) Irrigation fields shall be constructed as follows:

	Minimum	Maximum
Number of drain lines per irrigation zone	1	—
Length of each perforated line	—	100 feet
Bottom width of trench	6 inches	18 inches
Total depth of trench	17 inches	18 inches
Spacing of lines, center to center	4 feet	—
Depth of earth cover of lines	9 inches	—
Depth of filter material cover of lines	2 inches	—
Depth of filter material beneath lines	3 inches	—
Grade of perforated lines	level	3 inches/100 feet

J 12 Special Provisions

(a) Other collection and distribution systems may be approved by the Administrative Authority as allowed by Section 201 of the U.P.C.

(b) Nothing contained in this Appendix shall be construed to prevent the Administrative Authority from requiring compliance with stricter requirements than those contained herein, where such stricter requirements are essential in maintaining safe and sanitary conditions or from prohibiting graywater systems.

J 13 Health and Safety

(a) Graywater may contain fecal matter as a result of bathing and/or washing of diapers and undergarments. Water containing fecal matter, if swallowed, can cause illness in a susceptible person.

(b) Graywater shall not include laundry water from soiled diapers.

(c) Graywater shall not be applied above the land surface or allowed to surface and shall not be discharged directly into or reach any storm sewer system or any water of the United States.

(d) Graywater shall be not be contacted by humans, except as required to maintain the graywater treatment and distribution system.

(e) Graywater shall not be used for vegetable gardens.

Table J-1 Location of Graywater System

Minimum Horizontal Distance From	Surge Tank (feet)	Irrigation Field (feet)
Buildings or structures[1]	5[2]	8[3]
Property line adjoining private property	5	5
Water supply wells[4]	50	100
Streams and lakes[4]	50	50
Seepage pits or cesspools	5	5
Disposal field and 100 percent expansion area	5	4[5]
Septic tank	0	5[6]
On-site domestic water service line	5	5[7]
Pressure public water main	10	10[8]
Water ditches	50	50

NOTES: When mini-leach fields are installed in sloping ground, the minimum horizontal distance between any part of the distribution system and ground surface shall be 15 feet.

[1]Including porches and steps, whether covered or uncovered, but does not include car-ports, covered walks, driveways and similar structures.

[2]The distance may be reduced to 0 feet for aboveground tanks if approved by the Administrative Authority

[3]The distance may be reduced to 2 feet, with a water barrier, by the Administrative Authority, upon consideration of the soil expansion index.

[4]Where special hazards are involved, the distance may be increased by the Administrative Authority

[5]Applies to the mini-leachfield type system only. Plus 2 feet for each additional foot of depth in excess of 1 foot below the bottom of the drain line.

[6]Applies to mini-leachfield-type system only.

[7]A 2-foot separation is required for subsurface drip systems.

[8]For parallel construction or for crossings, approval by the Administrative Authority shall be required.

Table J-2 Mini-Leachfield Design Criteria of Six Typical Soils

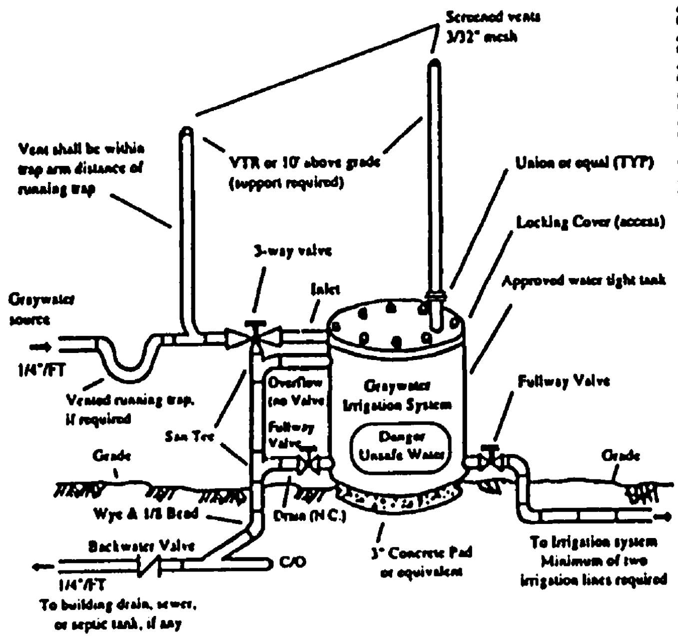
Type of Soil	Minimum sq. ft. of irrigation area per 100 gallons of estimated graywater discharge per day	Maximum absorption capacity, minutes per inch, of irrigation area for a 24-hour period
1. Coarse sand or gravel	20	5
2. Fine sand	25	12
3. Sandy loam	40	18
4. Sandy clay	60	24
5. Clay with considerable sand or gravel	90	48
6. Clay with small amount of sand or gravel	120	60

Table J-3 Subsurface Drip Design Criteria of Six Typical Soils

Type of Soil	Maximum emitter discharge (gal/day)	Minimum number of emitters per gpd of graywater production
1. Sand	1.8	0.6
2. Sandy loam	1.4	0.7
3. Loam	1.2	0.9
4. Clay loam	.0.9	1.1
5. Silty clay	0.6	1.6
6. Clay	0.5	2.0

Use the daily graywater flow calculated in Section J-6 to determine the number of emitters per line.

FIGURE 1

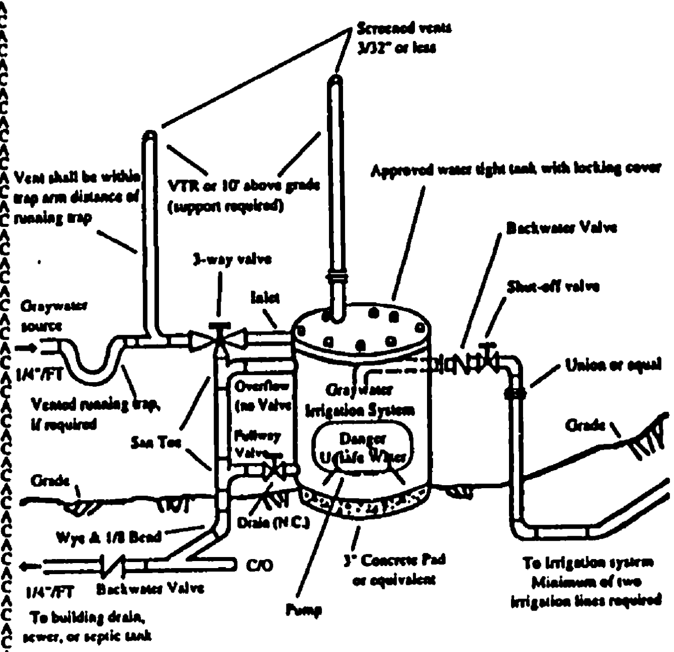


Abbreviations
C/O Cleanout
N.C. Normally Closed
VTR Vent Thru Roof

Figure 1—Graywater System Single Tank—Gravity (conceptual)

FIGURE 2

GRAYWATER SYSTEMS



Abbreviations
C/O Cleanout
N.C. Normally Closed
VTR Vent Thru Roof

Figure 2—Graywater System Single Tank—Pumped (conceptual)

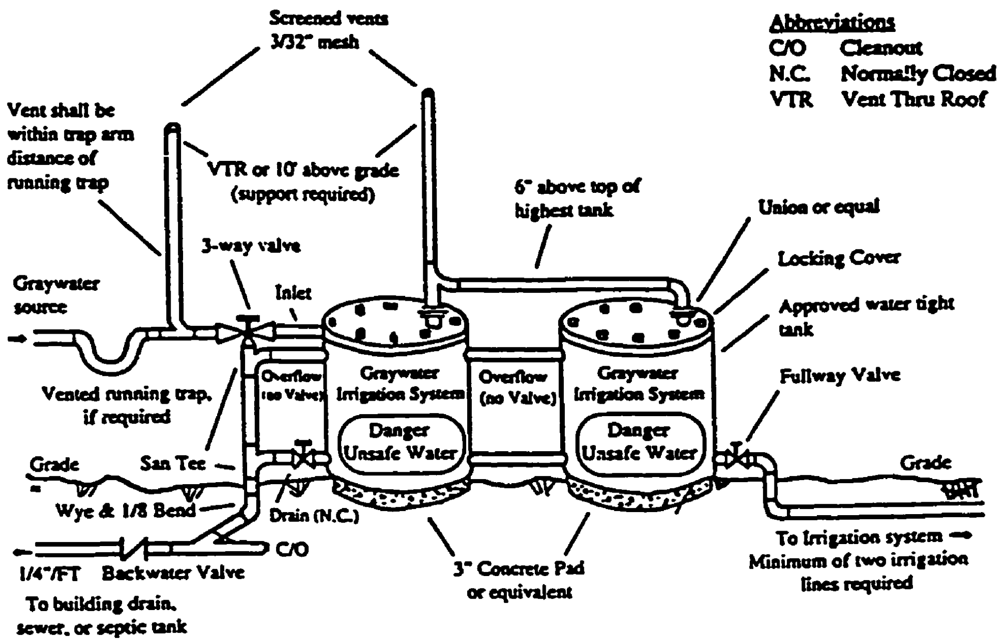


Figure 3—Graywater System Multiple Tank (conceptual)

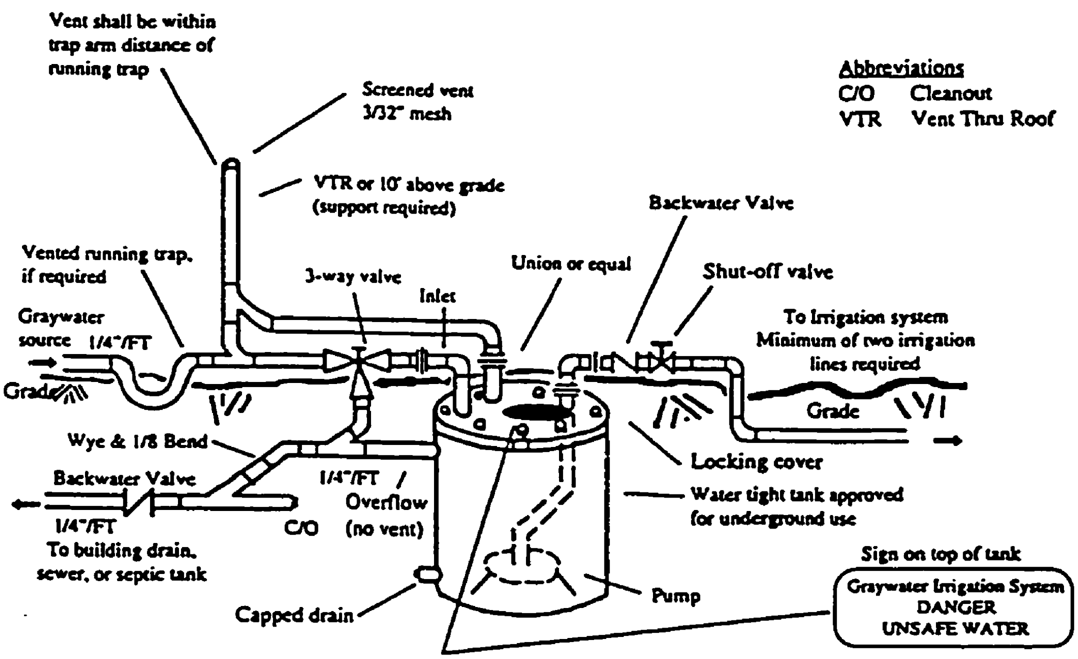


Figure 4—Graywater System Underground Tank (conceptual)

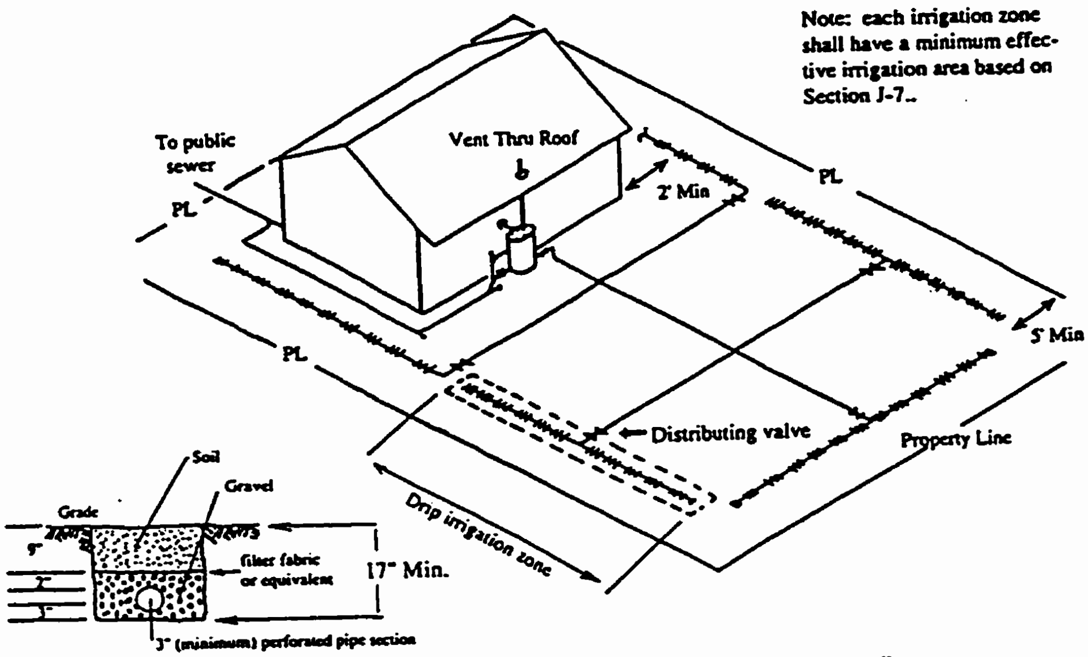


Figure 5—Graywater System Irrigation Layout (conceptual)

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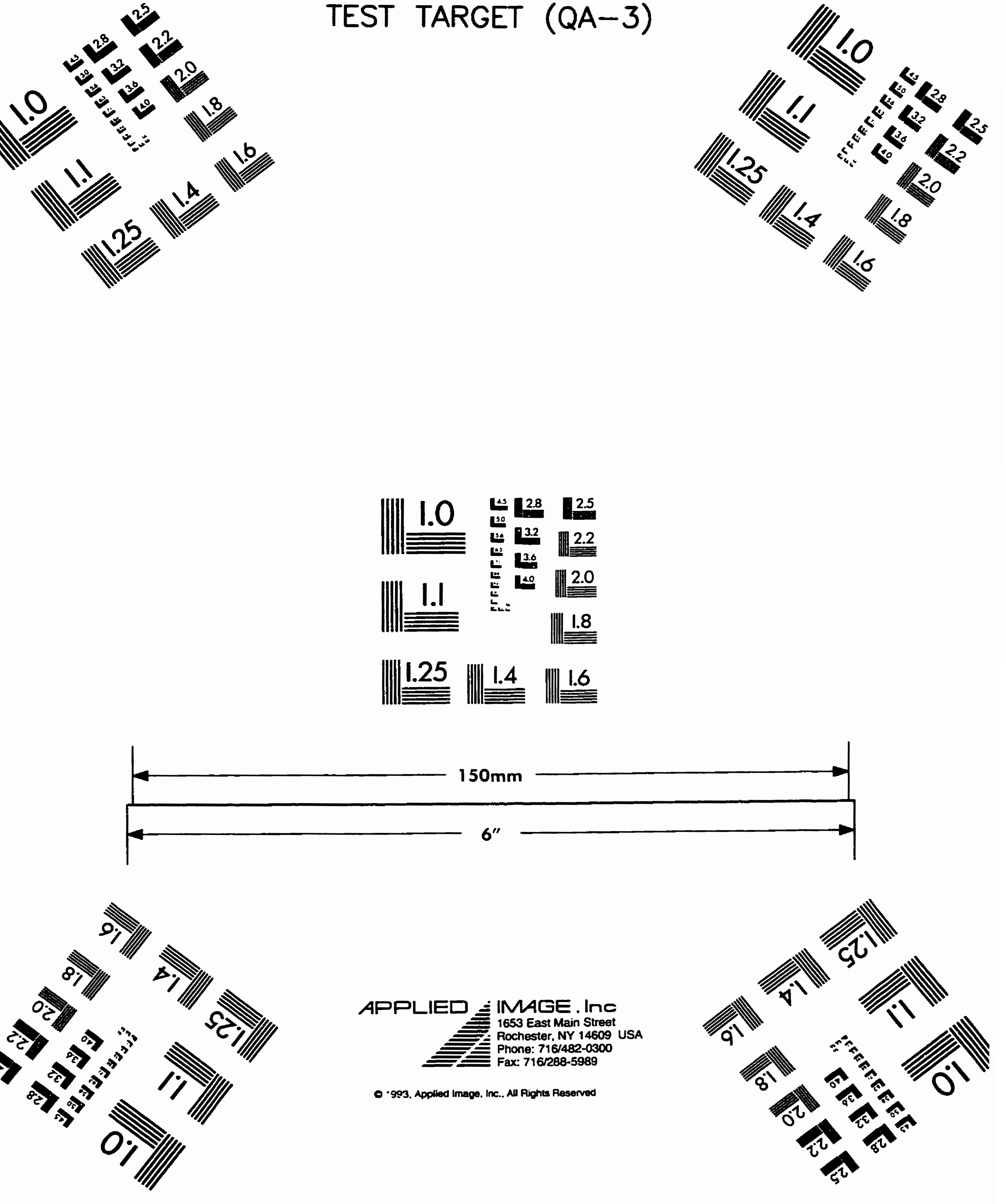
IMAGE EVALUATION TEST TARGET (QA-3)



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